



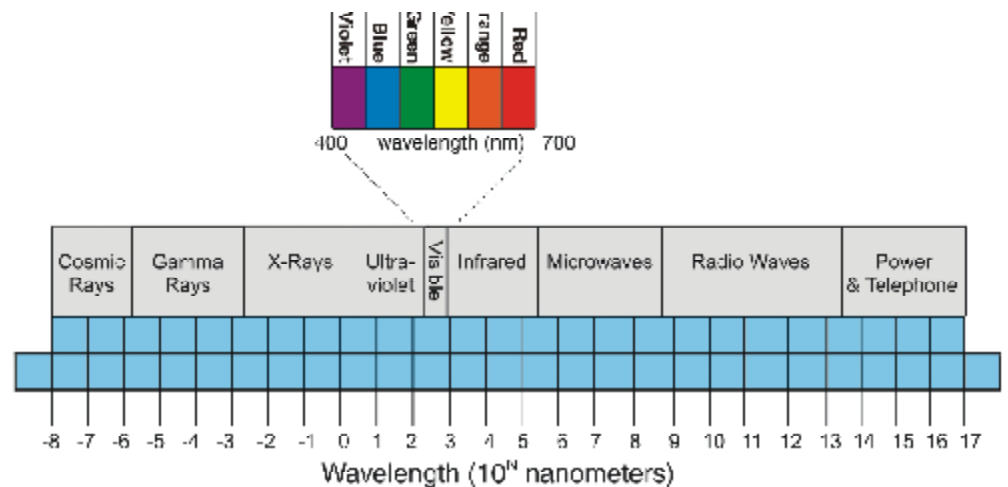
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Light Transmission and Reflectance

Light and Radiation

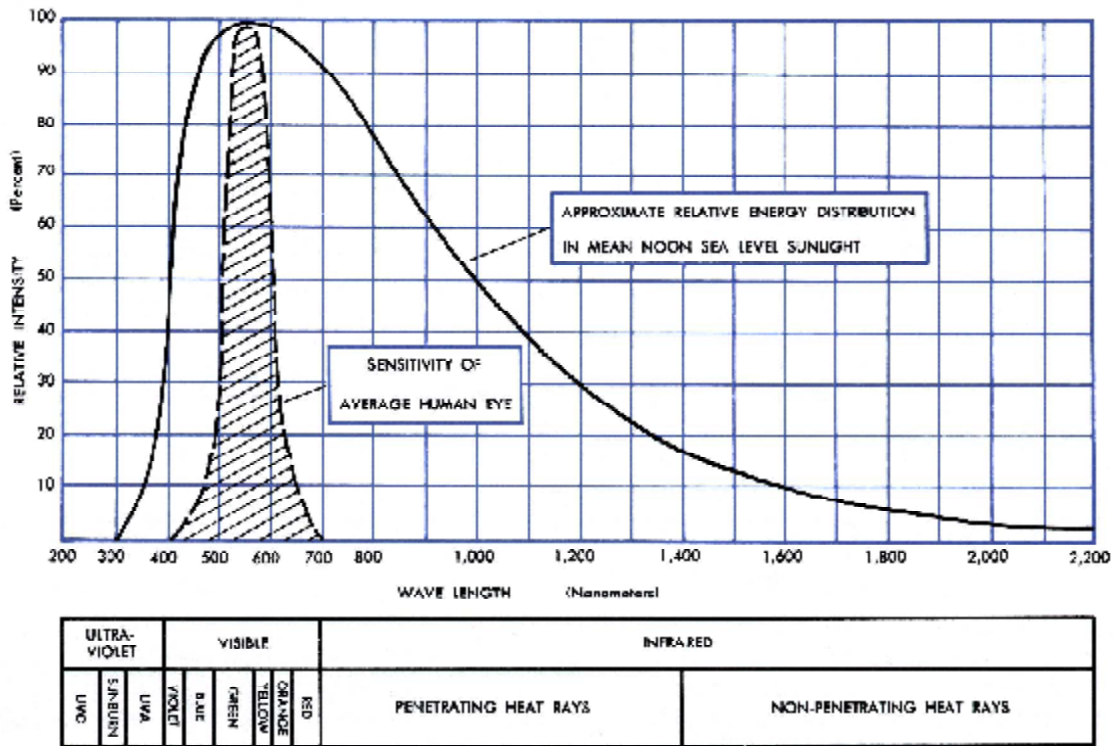
Light or electromagnetic radiation can be divided into several bands or categories each defined by a specific wavelength range. Visible light is the most common type of electromagnetic radiation. Examples of other types of electromagnetic radiation are ultraviolet light, x-rays, radio waves and infrared light (Figure 1).

Figure 1: Electromagnetic Spectrum



Solar radiation is the naturally occurring radiation that reaches the earth's surface. It includes visible light as well as ultraviolet and infrared light (Graph 1). The visible band of the electromagnetic spectrum, which is the only range that can be detected by the human eye, falls between 400 and 700 nanometers. Energy in the visible band is sensed as "light" due to the sensitivity of the human retina, which acts as a detector for energy at this wavelength. On either side of the visible light band are ranges of similar electromagnetic radiation undetectable by the human eye.

Graph 1: Relative Distribution of Solar Energy



The primary wavelengths of interest are those that fall between 200 and 2200 nanometers (nm). This section of the electromagnetic spectrum can be divided into three components:

1. **Ultraviolet (UV) band, 200 – 400 nm**
2. **Visible Spectrum, 400 – 700 nm**
3. **Near Infrared Band, 700 – 2200 nm**

Nanometers (nm) are commonly used for measuring wavelengths in the three bands listed above. One nanometer equals one billionth (1 X 10⁻⁹) of a meter.

The intensity of the solar radiation that penetrates the atmosphere and reaches the earth varies considerably, depending on the altitude, ozone levels, concentration of water vapor, carbon monoxide, dust and other types of

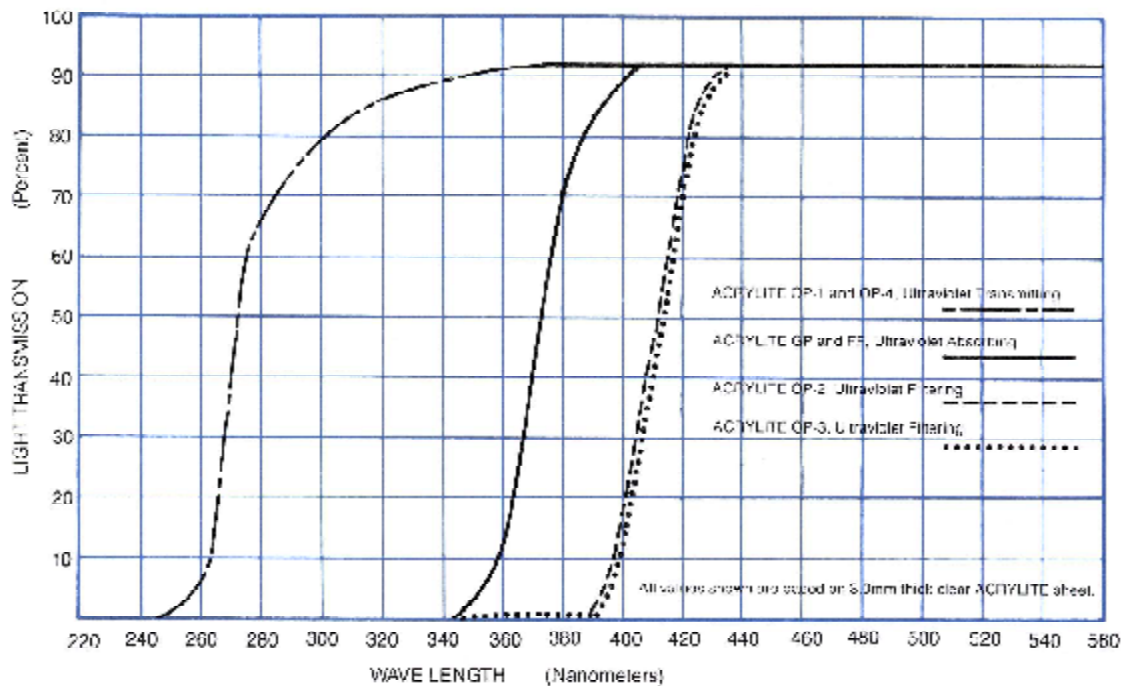
contamination. The approximate relative distribution of solar energy (mean noon sea level sunlight) from 200 to 2200 nm is represented in Graph 1. The ultraviolet band accounts for approximately 3% of the total solar energy, whereas the visible band accounts for 45% and the infrared band accounts for 52%.

X-ray Transmission

X-rays and gamma rays are characterized by wavelengths shorter than those in the ultraviolet spectrum, thus they are not included in Graph 1. Colorless ACRYLITE® GP and ACRYLITE® FF acrylic sheet do not shield x-rays or gamma rays very effectively. They shield approximately 1/100 to 1/400 as much as lead of the same thickness. The transmission characteristics are like those of flesh; therefore these materials can be used in medical as well as industrial applications where x-ray transmission is required.

Ultraviolet Radiation

Graph 2: UV Light Transmission of Colorless ACRYLITE GP, ACRYLITE FF, ACRYLITE OP-1, ACRYLITE OP-2, ACRYLITE OP-3 and ACRYLITE OP-4 sheet (Approximation only – not a specification).



Although ultraviolet (UV) radiation amounts to only 3% of the total radiation that reaches the earth, it is energetic enough to cause chemical reactions, weathering of polymers, fading of certain dyes and even eye damage.

The UV spectrum is commonly divided into three ranges:

1. **UV-C, 200 – 290 nm**
2. **UV-B, 290 – 315 nm**
3. **UV-A, 315 – 400 nm**

Wavelengths in the UV-A range are responsible for tanning and pigmentation of the human skin. Wavelengths in the UV-B range cause the most photochemical degradation in plastics as well as sunburn. UV-C radiation is absorbed in the ozone layer and never reaches the earth's surface.

Colorless ACRYLITE GP (cell cast) and ACRYLITE FF (continuously manufactured) sheet have very small amounts of light transmission below 345 nanometers. In the range from 345 to 395 nanometers, the light transmission varies with sheet thickness. Between 395 and 1000 nanometers, all thicknesses transmit 92%. Smooth, colorless ACRYLITE GP and ACRYLITE FF sheet are warranted for ten (10) years to not undergo a change in light transmission exceeding 3%.

ACRYLITE® OP-1 (ultraviolet transmitting) acrylic sheet transmits much of the radiation in the range from 260 - 370 nanometers. Above 370 nanometers, it has light transmission properties similar to colorless ACRYLITE GP and ACRYLITE

FF sheet. ACRYLITE OP-1 sheet is typically used in scientific and instrument applications where maximum UV light transmission is required. Because this product contains no stabilizers, it will degrade under intense and prolonged UV light exposure. Therefore, it is not suitable for use in sun tanning beds.

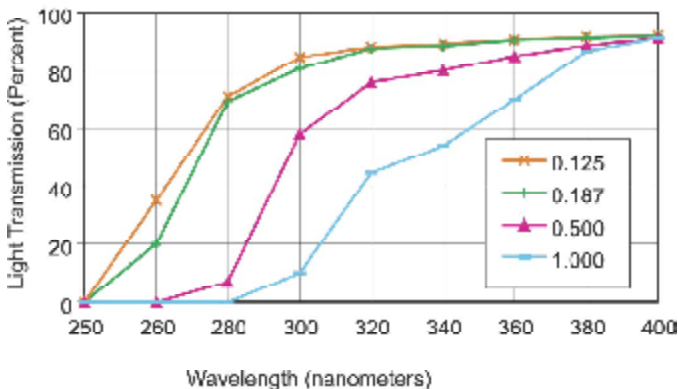
ACRYLITE® OP-2 (ultraviolet filtering) acrylic sheet is a cell cast sheet product that absorbs approximately 98% of the incident UV light. It is used in museums to protect historical documents and artifacts from the harmful effects of ultraviolet rays.

ACRYLITE® OP-3 (ultraviolet filtering) acrylic sheet is a continuously manufactured sheet product that absorbs approximately 98% of the incident UV light. It is used in picture frames and shadow boxes to protect photos, posters and other valuables from damaging ultraviolet rays.

ACRYLITE® OP-4 (ultraviolet transmitting) acrylic sheet is a cell cast sheet designed for use in sun tanning beds. It transmits much of the radiation in the range from 260 – 370 nanometers. Above 370 nanometers, it has light transmission properties similar to colorless ACRYLITE GP and ACRYLITE FF sheet. It is specifically formulated to resist the degradation caused by continuous exposure to the high-intensity ultraviolet radiation from tanning bed bulbs.

The light transmission of ACRYLITE OP-1 and ACRYLITE OP-4 sheet will vary with thickness in the range from 260 – 370 nanometers. This is shown on the following page in Graph 3.

Graph 3: Light Transmission vs. Thickness of ACRYLITE OP-1 and ACRYLITE OP-4 Sheet (Approximation only – not a specification).



Visible Light

The visible light band ranges from 400 – 700 nanometers. Within this band, colors occur in the sequence observed in the rainbow, ranging from violet, to blue, green, yellow, orange and red. Each wavelength in the visible light band causes a particular sensation of color. As shown in Graph 1, solar radiation is most intense in the visible light band. This band is also the area where the human eye is most sensitive to radiation. However, the eye is not equally sensitive to light emitted at all wavelengths; it is most sensitive to the light in the yellow and green areas of the spectrum. When a light beam strikes material, some light is transmitted, some reflected and the rest is absorbed. Light transmission depends on the reflectance at both surfaces of the material and the absorption of light into the material. Colorless ACRYLITE® acrylic sheet typically absorbs less than 0.5% of visible light per inch of thickness. However, some light is reflected at both surfaces. A beam of light striking a smooth ACRYLITE sheet perpendicular to the surface (at 0° angle of incidence) will lose approximately 4% of its light at each surface due to reflection, resulting in a total loss of 8%. Therefore, the overall light transmission will be approximately 92%. If light rays strike the sheet at angles greater than 30° from the vertical, the surface reflectance will be greater than 4% and the overall transmission will be smaller. For example, when light falls on colorless ACRYLITE GP or ACRYLITE FF sheet from all angles, as from a sky of uniform brightness, the transmission factor will be approximately 85%.

Colors

Acrylic sheet can be formulated in thousands of different colors and shades. This is because colorless acrylic sheet transmits visible light uniformly throughout the entire visible light spectrum. Therefore, its transmission characteristics can be predictably modified using dyes and pigments to create a variety of colored sheet. The addition of fillers and the application of surface textures or patterns are also used to

vary the light transmission and reflection properties of the sheet. Ultimately, the color of the sheet results from the combination of transmitted and reflected light that the human eye receives from the sheet. Since the ratio of transmitted to reflected light and the nature of the light source can vary based on application parameters, the perceived color of a sheet can also vary with these parameters. Therefore, it is very important to evaluate colors under the intended end use conditions. To assist in color selection, light transmission and reflectance measurements can be used but actual evaluation in the end use is always recommended to ensure the expected results.

Light Transmission of White Translucent ACRYLITE GP and ACRYLITE FF Sheet

White translucent ACRYLITE GP and ACRYLITE FF sheet are available in different densities to provide a variety of options for light transmission, diffusion, lamp hiding power and surface brightness. For lighting applications, a formulation offering maximum diffusion combined with high light transmission is usually desirable.

The color transmission of each white ACRYLITE GP or ACRYLITE FF sheet will vary with the type and concentration of the pigment in the sheet. In addition, the light transmission of almost every translucent white color will decrease with an increase in thickness. (See Tables A and B and Graph 4.) This is due to the fact that the pigment concentration for most of the translucent white colors is not changed for different thicknesses. Although the pigment concentration remains constant, the amount of pigment absorbing the light that passes through the sheet will increase with the sheet thickness. For instance, when light passes through a 1/4" thick sheet it will pass through twice as much pigment as when it passes through an 1/8" thick sheet. Therefore, the 1/4" thick sheet transmits less light than the 1/8" inch thick sheet.

Table A: Light Transmission of White Translucent ACRYLITE GP Sheet

Color Number	Thickness		
	3 mm (.118)	4.5 mm (.177)	6 mm (2.36)
051-6	67%	54%	44%
020-4	51%	41%	32%
054-3	41%	32%	25%
049-3 *	40%	40%	40%
015-2	30%	22%	16%
048-2	21%	15%	11%

Above values are based on ASTM Test E-308, using CIE Illuminant C.

* The transmission of 049-3 is the same for all thicknesses.

Graph 4: Light Transmission - White Translucent ACRYLITE GP and ACRYLITE FF Sheet

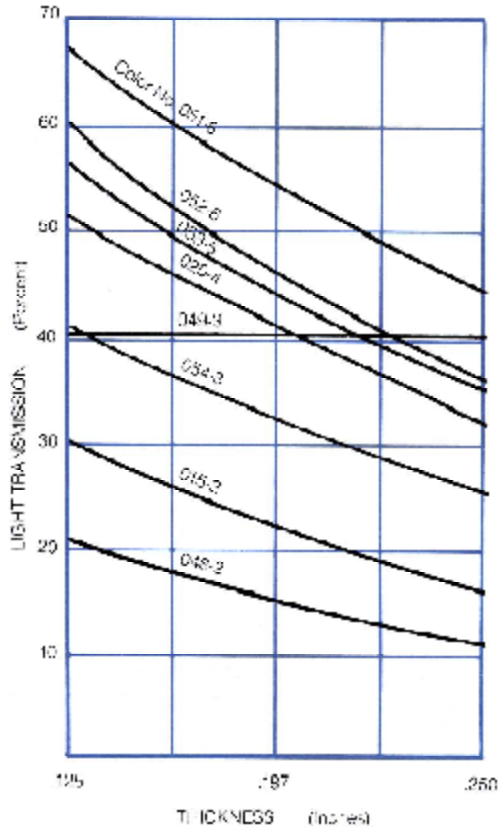


Table B: Light Transmission of White Translucent ACRYLITE FF Sheet

Color Number	Thickness		
	3 mm (.118)	4.5 mm (.177)	6 mm (2.36)
020-4	54%	43%	35%
015-2	31%	23%	18%

Above values are based on ASTM Test E-308, using CIE illuminant C.

Light Reflectance of White ACRYLITE GP and ACRYLITE FF Sheet

Light reflectance is also important in sign applications. Reflectance data is shown in Table C and D. When ACRYLITE GP or ACRYLITE FF sheet is used for a non-backlit sign panel, a nearly opaque white such as ACRYLITE GP sheet color 048-2 or ACRYLITE FF sheet color 015-2 having a reflectance value of 93% or 91% respectively, will provide good contrast for painted or fabricated letters that may appear on the sign.

Table C: Light Reflectance of White ACRYLITE GP Sheet

Color Number	Percent Reflected for 3 mm (.118")	
	BLACK Back-up	WHITE Back-up
051-6	18%	60%
020-4	37%	70%
054-3	55%	84%
049-3	56%	86%
015-2	70%	91%
048-2	79%	93%

Above values are based on ASTM Test E-308, using CIE illuminant C.

Table D: Light Reflectance of White ACRYLITE FF Sheet

Color Number	Percent Reflected for 3 mm (.118")	
	BLACK Back-up	WHITE Back-up
020-4	33%	68%
015-2	67%	89%

Above values are based on ASTM Test E-308, using CIE illuminant C.

When a backlit sign must be as effective during the day as at night, a compromise is in order. Select a white color that not only transmits a high percentage of light, but also reflects a sufficient amount of daylight. Otherwise, the sign will look gray during the day when it isn't illuminated from behind.

Because all white ACRYLITE GP or ACRYLITE FF sheet is translucent, the surface brightness (reflectance) will be influenced by the color of the material behind the sheet or behind the sample when measured.

This tech brief lists two kinds of reflectance values that have been obtained using two different test methods. The values shown in the left column in Tables C and D were obtained by measuring samples supported on black background material. In the right column of Tables C and D, the values were obtained by measuring the same sample supported on a standard white background. The right column of data simulates the performance of white sheet when used in a sign box painted white on the inside.

The percentages listed apply to 3 mm thick sheet. Other thicknesses will reflect different percentages of incident light. It is not practical to give a factor for all these sheet thicknesses, but any necessary information can be obtained from CYRO's Technical Center in Orange, CT by calling (203) 795-6081.

As you can see from the comparison of the transmission and reflectance values of various 3 mm white colors as listed in Tables A, B, C and D, light reflectance increases as light transmission decreases. For applications requiring high light transmission, color 020-4 (GP/FF) or 051-6 (GP only) may be used. For maximum light reflectance, either color 015-2 (GP/FF) or 048-2 (GP only) may be used.

Because light transmission and light reflectance vary with thickness, don't use a 3 mm thick sample of a white for selecting other thicknesses of the same color. Always evaluate the translucent white colors using samples that are the same thickness as the sheet that will be used in the final application.

Light Transmission of Translucent and Transparent Colors

Each white ACRYLITE GP or ACRYLITE FF sheet color's light transmission decreases with an increase in thickness. The percentage of light transmission for all thicknesses of a given translucent or transparent color other than white is the same. This is accomplished by adjusting the colorant concentration according to sheet thickness. See Tables E and F on page 6 for a sampling of standard colors. When any of these colors are selected for a sign application, samples should be checked under reflected light as well as with transmitted light. Some colors are quite similar in appearance under reflected light but transmit light at different rates.

Table E: Light Transmission of Translucent Colored ACRYLITE GP or ACRYLITE FF Sheet

Color Number	Color	Percent Transmitted for 3 mm, 4.5 mm, 6 mm
047-2	Ivory	34%
202-0	Red	3%
205-0	Red	1%
207-0	Red	3%
209-0	Red	9%
211-1	Red	10%
303-0	Orange	6%
406-1	Yellow	17%
407-2	Yellow	21%
506-0	Green	8%
507-0	Green	2%
605-0	Blue	2%
606-0	Blue	1%
607-1	Blue	21%

Above values are based on ASTM Test E-308, using CIE illuminant C.

• - Available for ACRYLITE FF and ACRYLITE GP sheet.

Colors not marked are for ACRYLITE GP sheet only.

Table F: Light Transmission of Transparent Colored ACRYLITE GP or ACRYLITE FF Sheet

Color Number	Color	Percent Transmitted for 3 mm, 4.5 mm, 6 mm
103-2	Gray	27%
104-1	Gray	13%
115-0	Gray	7%
126-4	Bronze	44%
131-2	Bronze	26%
210-0	Red	7%
311-1	Bronze	10%
408-5	Amber	45%
430-7	Yellow	75%
508-7	Green	76%
625-5	Blue	58%
668-0	Blue	10%

Above values are based on ASTM Test E-308, using CIE illuminant C.

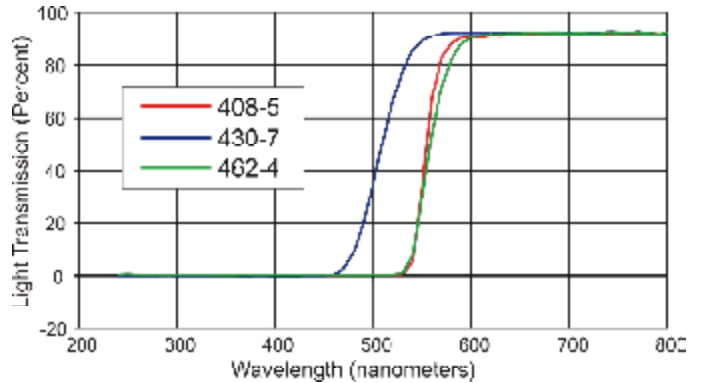
• - Available for ACRYLITE FF and ACRYLITE GP sheet.

Colors not marked are for ACRYLITE GP sheet only.

ACRYLITE GP Sheet: Amber, UV Filtering Colors

Amber colored sheet is frequently used to filter UV light in welding, laser cutting and UV curing operations. Proper choice of the appropriate amber color will depend on the exact parameters of the application. It is important to note that not all amber colors have effective UV filtering properties. Shown above in Graph 5 are the transmission curves for several amber colors having good UV absorption characteristics.

Graph 5: Light Transmission Curves of Amber, UV Filtering Colors (Approximate only– Not a specification)



ACRYLITE GP Black/White Sheet: Color 1124-1, P-95 Texture

ACRYLITE GP Black/White sheet (also referred to as day/night sheet) is intended for applications in sign channel letters and faces. This product offers sign manufacturers and designers an appearance which is black in daylight (with no backlighting) and translucent white at night, when backlit. A special combination of color and texture provides this versatility without any change to the physical, chemical and thermal properties, which are characteristic of ACRYLITE GP sheet.

For additional versatility, colored film or sheet can be placed behind ACRYLITE GP Black/White sheet, to alter the color of the sign when backlit.

ACRYLITE GP and ACRYLITE FF Sheet Color Coding System

The ACRYLITE GP and ACRYLITE FF sheet color coding system uses 4 or 5-digit numbers for all colors, including white and black.

The first digit identifies the color group as follows:

0 white and ivory	3 orange and brown	6 blue
1 gray and black	4 yellow and amber	7 violet
2 red	5 green	8-9 not assigned

The second, third and sometimes fourth digits are assigned to specific colors. These digits have no special significance and are not related in any way to the code used for the first digit. They are used only to label and identify different shades within each color group. The last digit indicates the approximate percentage range of light transmission. For example, -3 indicates a range from 30% to 39%.

Infrared Radiation

Infrared radiation is the long wavelength radiation beyond the sensitivity of the eye, ranging from 700 to 1,000,000 nanometers. Its source may be the sun, infrared heating elements or any hot object. Each type of infrared radiation is characterized by a specific range of wavelengths. We are primarily interested in the near infrared range (NIR) from 700 to approximately 10,000 nanometers.

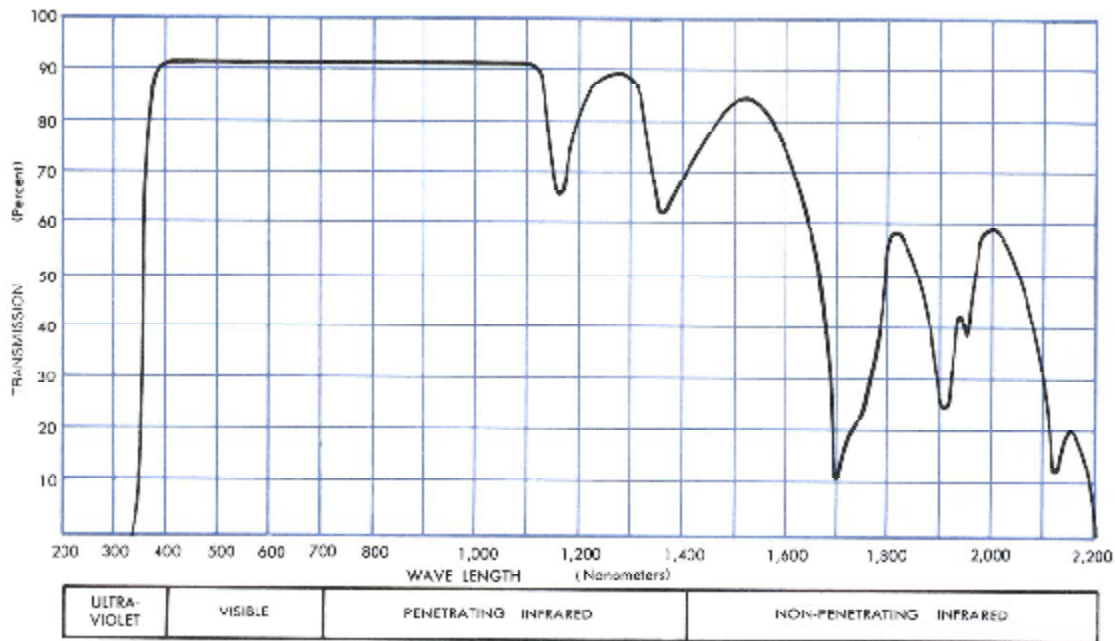
Incandescent lamps and infrared heat lamps emit radiation in both the visible and infrared spectra. A major portion of energy,

especially in the case of infrared heat lamps, is radiated at wavelengths above 700 nanometers. As the temperature of the energy source decreases, radiation is emitted at longer wavelengths. All solar radiation as well as artificially created radiant energy will be converted into heat when absorbed and reradiated by any material.

In the penetrating infrared band from 700 to 1400 nanometers,

clear 3 mm ACRYLITE GP sheet or 3 mm ACRYLITE FF sheet transmits approximately 90% of infrared radiation – see Graph 6. The transmission rate decreases slightly with increasing thickness. In the 1400 – 2200 nanometers range, ACRYLITE GP and ACRYLITE FF sheet transmit radiation at a gradually decreasing rate; at 2200 nanometers, transmission approaches zero.

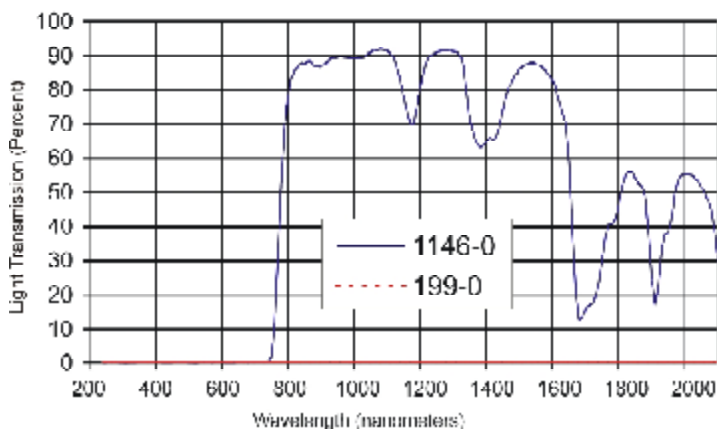
Graph 6: Light Transmission of Colorless ACRYLITE GP and FF Sheet (Approximation only not a specification)



ACRYLITE GP Black 1146-0 IR Transmitting Sheet

ACRYLITE GP sheet color 1146-0 is designed to transmit infrared light but to absorb visible light. This color is ideal for use in applications where it is desirable to conceal infrared security cameras or infrared transmitters and receivers. Below, Graph 7 shows the light transmission of color 1146-0 ACRYLITE GP sheet compared to color 199-0 black, ACRYLITE GP sheet.

Graph 7: Transmission of ACRYLITE GP Sheet, Colors 1146-0 (IRT) and 199-0



Greenhouse Glazing

Transmission characteristics of colorless ACRYLITE GP and ACRYLITE FF sheet are equal or superior to those of ordinary window glass. Colorless ACRYLITE GP and ACRYLITE FF sheet can be used for greenhouse glazing since plants will grow as well under these materials as they would under glass.

ACRYLITE GP and ACRYLITE FF sheet are opaque to long wave radiation above 2200 nanometers. Long wave radiation is emitted by the mass, such as soil or concrete, inside a greenhouse. This opacity creates the “greenhouse” or heat-trapping, effect.

Light Piping

The very low light absorption characteristic of ACRYLITE GP and ACRYLITE FF sheet makes it perfect for light piping applications, such as engraved signs, inspection lights, instrument dials and other similar items. To prevent excessive light loss at curves, the radius of curvature should not be less than three times the sheet’s thickness. It’s important that the sheet’s surfaces be highly polished and free of scratches to assure optimum reflection and prevent light scattering.

The amount of light that enters a sheet from the edge depends on the sheet’s thickness and the edge transparency. *Edges should be highly polished to maximize light transmission.* Edges through which light will not enter should be polished and covered or coated with a highly reflective material to increase internal reflection. Large sheets may need to be illuminated from two or all four edges.

Back-Lighting

For back-lighting applications such as signs or light boxes, textured finished sheets or white sheets are often used between the light source and the sign face to improve light diffusion. This helps to eliminate bright spots caused by the light source.

Sometimes textured sheets are used in combination with edge lighting. The textured surface provides a means of re-directing some of the piped light to the face of the sheet. Generally, this is not a very efficient method of back-lighting because textured sheet is not specifically designed or optimized for this purpose.

For more efficient back lighting using an edge mounted light source, a special type of sheet has been developed, ACRYLITE® GS 1001 light diffusing acrylic sheet. This sheet contains tiny beads that help diffuse piped light to its surface. By using beads of a specific refractive index and size, and by selecting the right concentration of beads, the efficiency of this back-lighting sheet has been optimized for edge lighting applications.

Alternately, back lighting using an edge mounted light source can also be accomplished by employing a sheet printed or painted with a white light diffusing pattern on one surface. The pattern density can be varied across the sheet surface as the distance from the light source changes to adjust the amount of light being reflected to the sheet surface.

Artificial Light

Ultraviolet, visible and infrared light can also be produced by artificial sources. Artificial light sources produce radiation with characteristics varying from source to source. Fluorescent lamps, mercury vapor lamps, germicidal lamps and welding arcs produce significant ultraviolet radiation. The typical emission curve for an incandescent bulb shows that its output increases from a low level at 400 nanometers to a high level at 700 nanometers, and then rises steeply into the infrared range. As a result, heat as well as light is emitted. Also, colors appear warmer or redder than in daylight.

In the case of fluorescent tubes, the wavelengths of light emitted by the tube depends on the type of phosphor coating used on the inside. Fluorescent lamps are available in a number of different types. Manufacturers publish the spectrophotometric distribution curves of each type.

Fire Precautions

ACRYLITE GP and FF acrylic sheet are combustible thermoplastics. Precautions should be taken to protect these materials from flames and high heat sources. ACRYLITE GP and ACRYLITE FF acrylic sheet usually burn rapidly to completion if not extinguished. The products of combustion, if sufficient air is present, are carbon dioxide and water. However, in many fires sufficient air will not be available and toxic carbon monoxide will be formed, as it will from other common combustible materials. We urge good judgment in the use of these versatile materials and recommend that building codes be followed carefully to assure they are used properly.

Important Notice

The information and statements herein are believed to be reliable but are not to be construed as a warranty or representation for which we assume legal responsibility. Users should undertake sufficient verification and testing to determine the suitability for their own particular purpose of any information or products referred to herein. **NO WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE IS MADE.** Nothing herein is to be taken as permission, inducement or recommendation to practice any patented invention without a license.

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