Technical information

ACRYLITE® cast and extruded acrylic

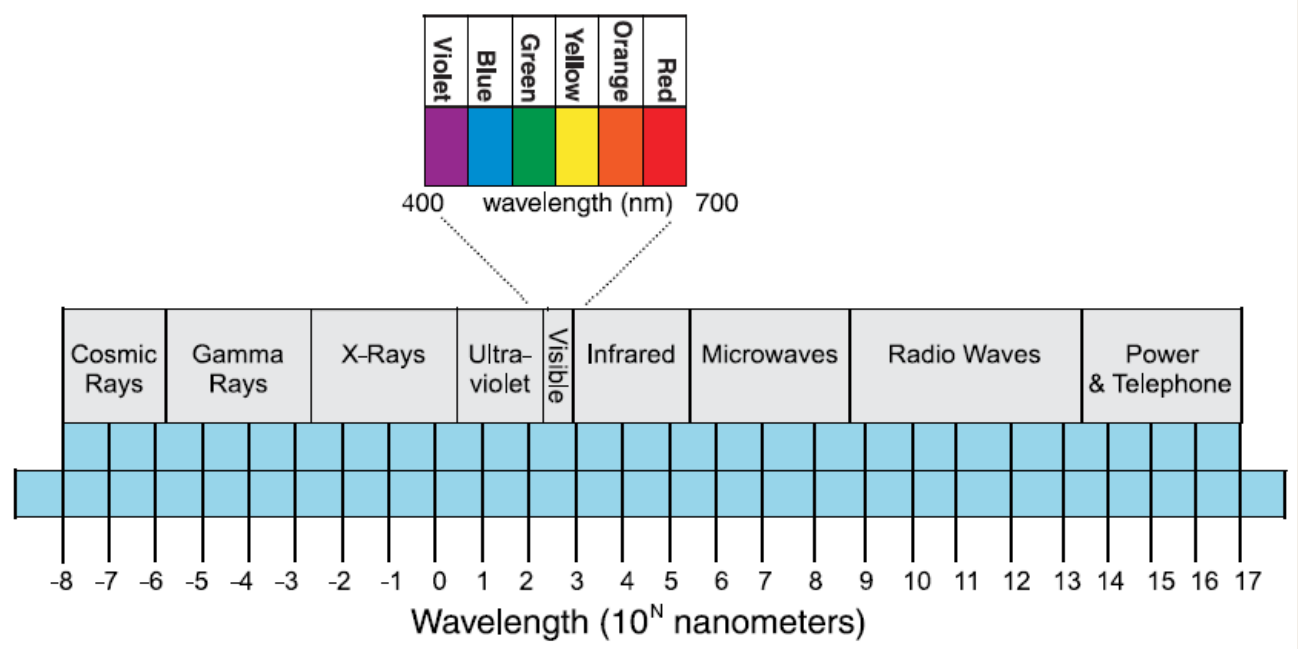
Light Transmission and Reflectance

Light and Radiation

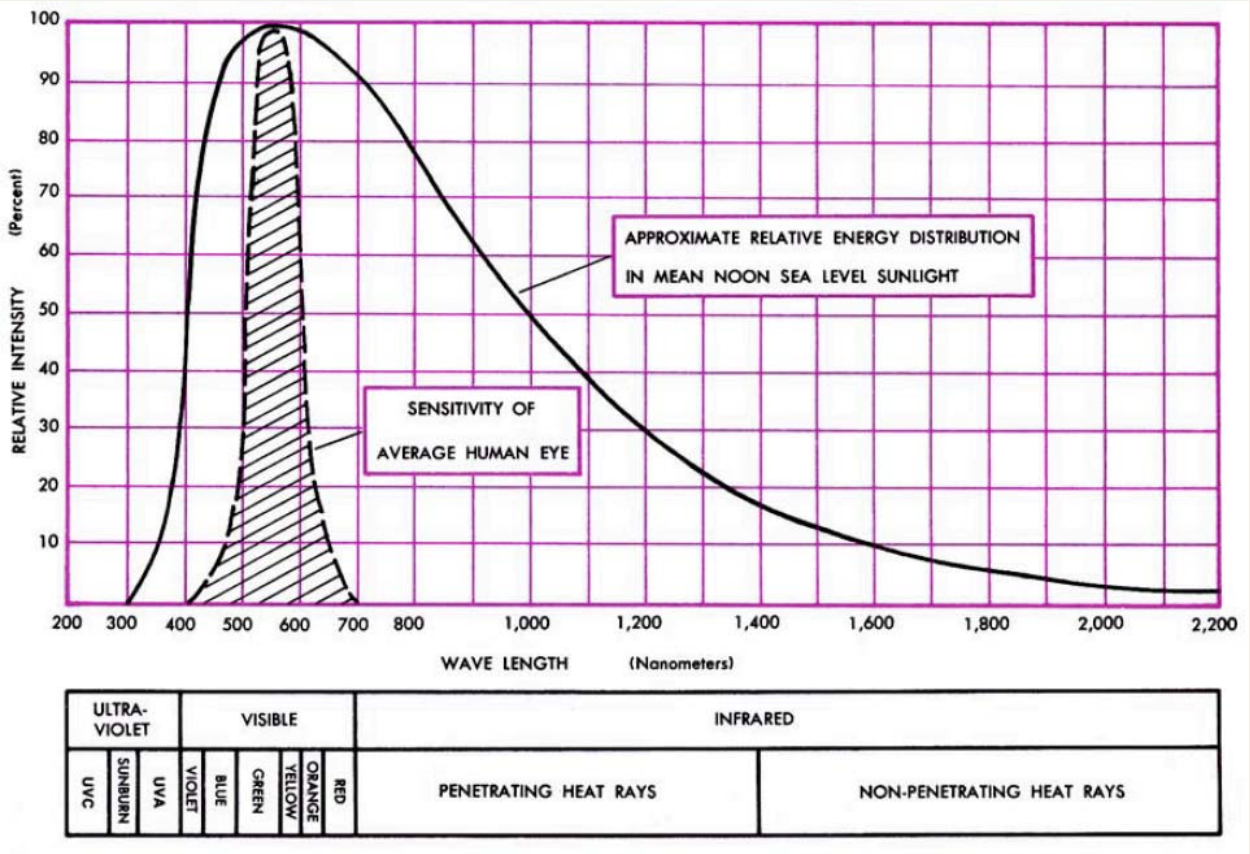
Light or electromagnetic radiation can be divided into several bands or categories each defined by a specific wavelength range. Visible light is the most common type of electromagnetic radiation. Examples of other types of electromagnetic radiation are ultraviolet light, x-rays, radio waves and infrared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

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 (nm). 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: Electromagnetic Spectrum



Graph 2: 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 2. 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 2. Colorless ACRYLITE® cast and extruded does 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

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® cast and extruded sheet have very small amounts of light transmission below 345 nm. In the range from 345 to 395 nm, the light transmission varies with sheet thickness. Between 395 and 1000 nm, all thicknesses transmit 92%. Smooth, colorless ACRYLITE® cast and extruded sheet are warranted for thirty (30) years to not undergo a change in light transmission exceeding 3%.

ACRYLITE® UV filtering (OP2) acrylic sheet is a 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® UV filtering (OP3) 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.

Visible Light

The visible light band ranges from 400 – 700 nm. 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® 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® cast or extruded 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 cast and extruded ACYLITE®

White translucent cast and extruded ACRYLITE® 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 cast or extruded ACRYLITE® 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 3.) 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® cast acrylic

			Thickness		
Evonik Color Number	**Old Cyro Color Number**	**Competitive Color Number**	**3mm (.118)**	**4.5mm (.177)**	**6mm (.236)**
WM32	020-4	2447	51%	41%	32%
WM30	015-2	7328	30%	22%	16%

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

Graph 3: Light Transmission-White Translucent cast and extruded ACRYLITE® sheet

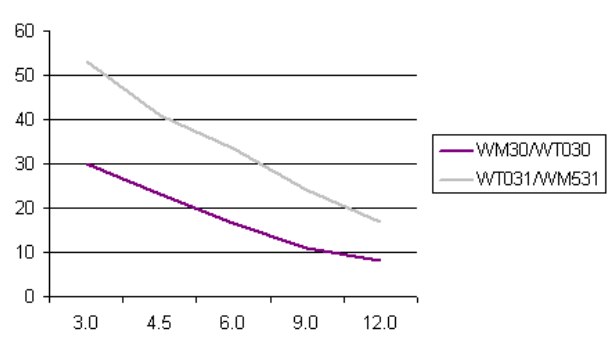


Table B: Light Transmission of White Translucent ACRYLITE® extruded sheet

			Thickness		
Evonik Color Number	**Old Cyro Color Number**	**Competitive Color Number**	**3mm (.118)**	**4.5mm (.177)**	**6mm (.236)**
WT031 GT	020-4	2447	54%	43%	35%
WT030 GT	015-2	7328	31%	23%	18%

Light Reflectance of White cast and extruded ACRYLITE®

Light reflectance is also important in sign applications. Reflectance data is shown in Table C and D. When ACRYLITE® cast or extruded sheet is used for a non-backlit sign panel, a nearly opaque white such ACRYLITE® extruded sheet color WT030 GT having a light reflectance value of 91% will provide good contrast for painted or fabricated letters that may appear on the sign.

Table C: Light Reflectance of White ACRYLITE® cast sheet

Percent Reflected for 3 mm (.118")				
Evonik Color Number	Old Cyro Color Number	Competitive Color Number	BLACK Back-up	WHITE Back-up
WM32	020-4	2447	37%	70%
WM30	015-2	7328	70%	91%

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

Table D: Light Reflectance of White ACRYLITE® extruded sheet

Percent Reflected for 3 mm (.118")				
Evonik Color Number	Old Cyro Color Number	Competitive Color Number	BLACK Back-up	WHITE Back-up
WT031 GT	020-4	2447	33%	68%
WT030 GT	015-2	7328	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® cast or extruded 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 sheets. 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 Evonik Cyro's Technical Center by calling (207) 490-4230.

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 WM32/WT031 may be used. For maximum light reflectance, either color WM30/WT030 may be used.

Because light transmission and light reflectance vary with thickness, don't use a 3 mm thick white sample 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 cast or extruded ACRYLITE® 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 Table E below and Table F on to the right 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® cast or extruded

Evonik Color Number (cast/extruded)	Old Cyro Color Number	Competitive Color Number	Color		Percent Transmitted for 3mm, 4.5mm, 6mm
1H31/1K031	047-2	2146	Ivory	•	34%
-/3K036	202-0	2662	Red		3%
-/3M030	205-0	2157	Red	•	1%
-/3K037	207-0	2115	Red		3%
-/3K038	209-0	2415	Red		9%
3H32/3K032	211-1	2283	Red	•	10%
2H02/2K020	303-0	2119	Orange		6%
-/1K032	406-1	2016	Yellow	•	17%
1H01/1K030	407-2	2037	Yellow		21%
-/6K021	506-0	2030	Green		8%
6H22/6K022	507-0	2108	Green	•	2%
5H30/5RK30	605-0	2114	Blue	•	2%
5H31/5RK31	606-0	2050	Blue	•	1%
/5K036	607-1	2051	Blue		21%

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

• = Available for ACRYLITE® extruded and cast

Colors not marked are for ACRYLITE® cast only

Table F: Light Transmission of Transparent Colored cast or extruded ACRYLITE®

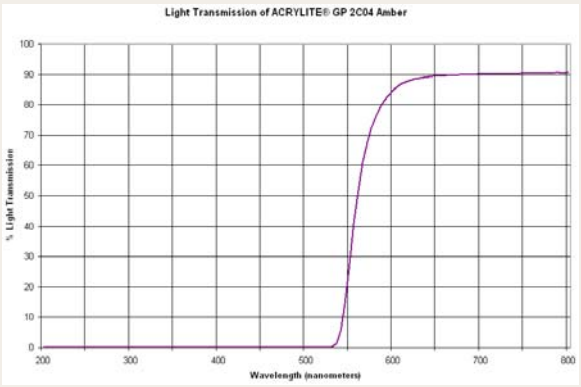
Evonik Color Number cast/extruded	Old Cyro Color Number	Competitive Color Number	Color	Percent Transmitted for 3mm, 4.5mm, 6mm
7C25/7C025	103-2	2064	Gray	27%
7C26/7C026	104-1	2074	Gray	13%
-/7C056	115-0	-	Gray	7%
7C24	126-4	2404	Bronze	44%
7C49	131-2	2412	Bronze	26%
-/3C20	210-0	2444	Red	7%
7C40/8C030	311-1	2370	Bronze	10%
2C04	408-5	2451	Amber	45%
-/1C022	430-7	2208	Yellow	75%
5C026	625-5	2069	Blue	58%
5C028	668-0	2424	Blue	10%

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

ACRYLITE® cast 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. Shown below in Graph 4 is the transmission curve for amber colors having good UV absorption characteristics.

Graph 4: Light Transmission Curves of Amber, UV filtering Colors (Approximate only-Not a specification)



ACRYLITE® LED color changing back lit (black/white P95) 9H04 SC

ACRYLITE® LED color changing back lit 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® cast sheet.

For additional versatility, colored film or sheet can be placed behind ACRYLITE® LED color changing back lit, to alter the color of the sign when backlit.

Infrared Radiation

Infrared radiation is the long wavelength radiation beyond the sensitivity of the eye, ranging from 700 to 1,000,000 nm. 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 nm.

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 nm. 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.

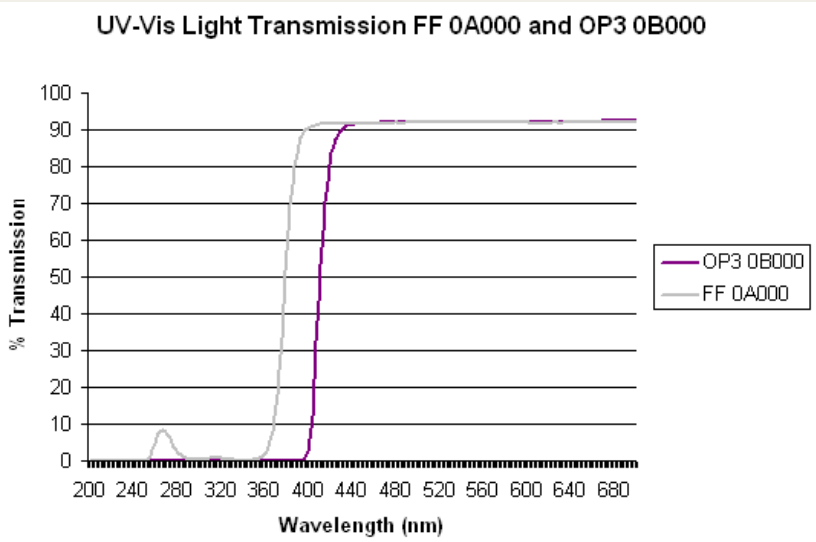
In the penetrating infrared band from 700 to 1400 nm, clear 3 mm ACRYLITE® cast sheet or extruded sheet transmits approximately 90% of infrared radiation – see Graph 5.

The transmission rate decreases slightly with increasing thickness. In the 1400 – 2200 nm range, ACRYLITE® cast and extruded sheet transmit radiation at a gradually decreasing rate; at 2200 nm, transmission approaches zero.

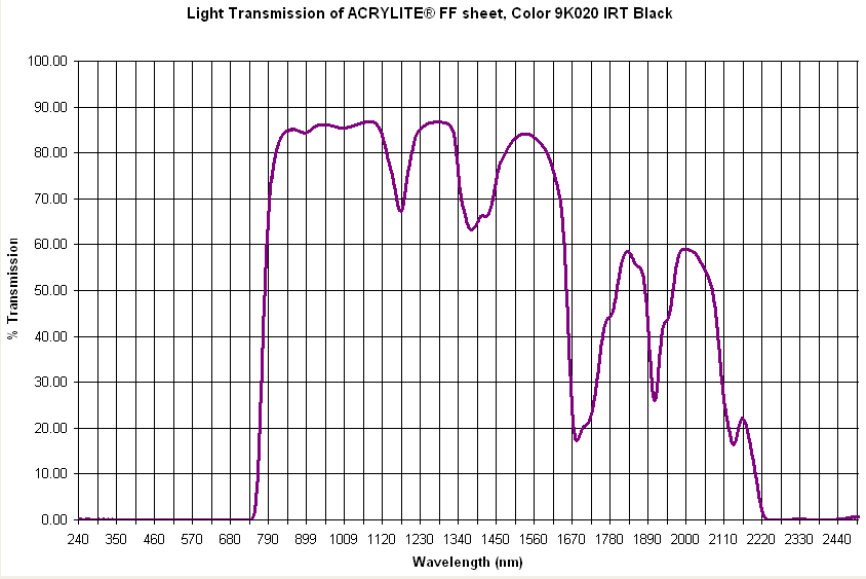
ACRYLITE® cast IRT transmitting black

ACRYLITE® cast color 9C20 and extruded color 9K020 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. Graph 6 shows the light transmission of color IRT transmitting 9C20 and 9K020 compared to standard cast 9H01 and extruded 9M001 black.

Graph 5: Light Transmission of Colorless ACRYLITE® cast and ACRYLITE® UV Filtering (OP3) (Approximation only not a specification)



Graph 6: Transmission of ACRYLITE® extruded 9K020 IRT Black



Greenhouse Glazing

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

ACRYLITE® cast and extruded sheet are opaque to long wave radiation above 2200 nm. Long wave radiation is emitted by the mass, such as soil or concrete, inside a greenhouse. This opacity creates the "greenhouse" or heattrapping, effect.

Light Piping

The very low light absorption characteristic of ACRYLITE® cast and extruded 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, white sheet is 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 ACRYLITE® Satinice is 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 ACRYLITE® Satinice is not specifically designed or optimized for this purpose.

For more efficient back lighting use an edge mounted light source, together with ACRYLITE® LED (EndLighten) acrylic sheet for edge lighting. This sheet contains tiny beads that help diffuse piped light to its surface. By using particles 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 nm to a high level at 700 nm, 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® sheet is a combustible thermoplastic. Precautions should be taken to protect this material from flames and high heat sources. ACRYLITE® sheet usually burns 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 when other common combustible materials are burned. We urge good judgement in the use of this versatile material and recommend that building codes be followed carefully to assure it is used properly.

Compatibility

Like other plastic materials, ACRYLITE® sheet is subject to crazing, cracking or discoloration if brought into contact with incompatible materials. These materials may include cleaners, polishes, adhesives, sealants, gasketing or packaging materials, cutting emulsions, etc. See the Tech Briefs in this series for more information, or contact your ACRYLITE® sheet Distributor for information on a specific product.

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