PART 1
THE INTERACTION OF LIGHT WITH GEOMETRY

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"He will sit as a refiner and purifier of silver."
—MALACHI 3.3

At 10^3 meters—1,000 meters—building outline, color, and shape become apparent. Color at this distance is influenced by surface alterations and by surrounding colors. The reflected accumulation of colors from the various surfaces combine. Shadows darken while reflected sunlight brightens. The view is homogeneous. Edges of the building are distinct, but detail on the surface is less apparent.

At 10^2 meters—100 meters—distinctive color and major aspects of the surface detail become apparent as shadows begin to define edges. From this distance, laps and shadows are nonexistent. The edges and geometric shape are apparent against a contrasting background. The color of the surface is reflected but still heavily influenced by the surrounding colors and light-scattering effects of the surface texture and atmosphere. Slight contrasts can be seen, but they are more ghostlike. Their existence is arbitrary and subjective.

Exterior surfaces viewed at this distance are heavily influenced by how they receive light. White light from an overcast sky "washes out" the color, making it paler. Scattering effects of the clouds can inhibit certain wavelengths, allowing other wavelengths to dominate the reflection off of metal surfaces.

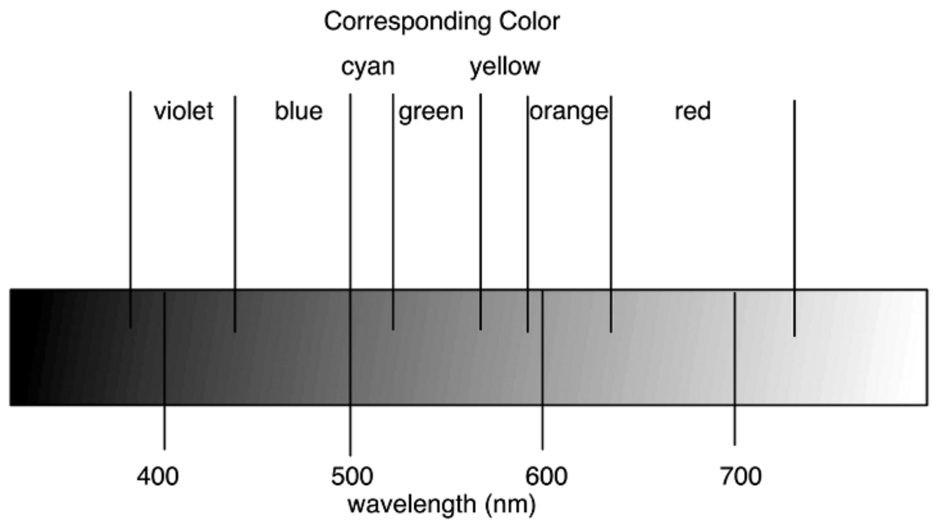

FIGURE I.1. Colors and their corresponding wavelength.

The color can be inherent tones of the metal itself or it can be enhanced by the reflection of the surroundings. The portion of the light wave that makes up the visible spectrum is shown in Figure I.1. The reflective appearance is dependent on several properties all surfaces possess. The reflective nature of the material, the gloss of the surface, will determine the intensity of the reflective image. A surface's texture can be enhanced by the degree of saturation of its color. Consider a lightly wetted surface of coarse stone. The moisture enhances the gloss level of the stone surface. The richness of the color of the stone is increased. Light scattering from the coarse surface is muted by the moisture. The moisture darkens the surface and the color is more saturated. Colors reflecting from a glossy surface are more saturated than those reflecting from matte surfaces. Some thin film interference also may be occurring. For metal surfaces, particularly finely textured surfaces, the condition is similar. Gloss will increase due to the layer of moisture, and the base color of the material will appear.

Approaching a surface from a distance, the eye quickly defines the geometry of buildings wrapped in metal. On bright sunlit days, variations of plane appear as different colors or shades. Light-scattering effects from coarse finishes scatter the light, while specular surfaces reflect the light and image of surrounding structures. Specular reflections are defined as "clear, well-defined images." For metal surfaces, there are degrees of specular reflectivity. Metals can be highly polished to develop mirrorlike reflectivity. Stainless steel and aluminum can be polished to reflect images with little distortion or muting of the reflection. Other surfaces can receive textures with various degrees of specular reflectivity. Satin-finish stainless, glass-bead stainless, and many textured stainless surfaces can reflect intense levels at their angle of

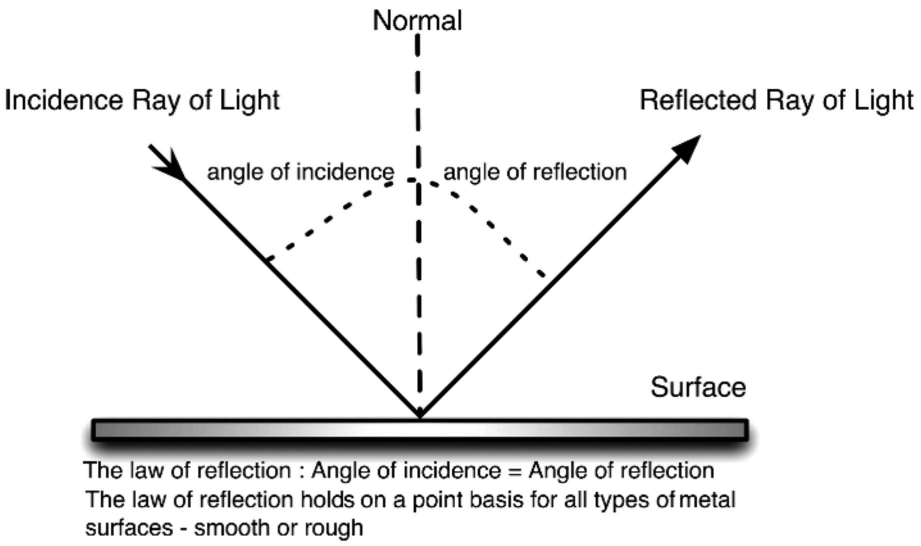

FIGURE I.2. Law of reflection.

reflection. The law of reflection is depicted in Figure I.2. The law holds that a reflection back to the observer is a point-by-point basis. That is why mild dents and imperfections in reflective surfaces can only be seen when the precise angle of view is achieved.

Specular surfaces will reflect colors from surrounding surfaces and light originating from these surfaces, sometimes producing an altered appearance (see Figure I.2). This is important to note: Metal surfaces will reflect the shadows and colors of trees, cloud shadows, and the color of other objects depending on the level of reflectivity of the specular surface.

Surfaces of metals can be made to possess diffused reflectivity as well. Diffused reflectivity is created by a rough or coarse surface. The reflectivity from a diffused surface is low. Essentially, very little, if any, of an image is reflected back to the viewer. For example, if the surface of the pages of this book were specular, it would be difficult to read.

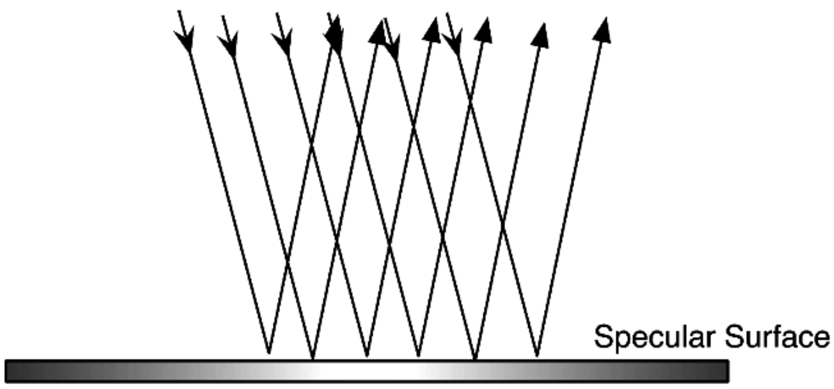

FIGURE I.3. Mirror specular reflectivity.

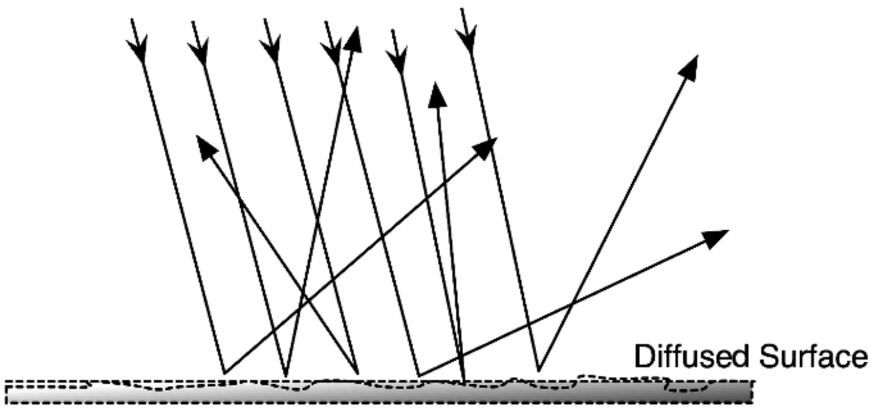

FIGURE I.4. Diffused reflectivity.

Incident light hitting the pages and reflecting off the specular surface would make it difficult to perceive the contrasting text (see Figure I.3).

Diffused surfaces scatter the light in different directions (see Figure I.4). This reduces the intensity and glare from the light source. Metal surfaces can be provided with various textures that achieve this behavior. The roughness of the microscopic surface will determine how diffused the reflection will be. With many metals, leaving them to weather creates a coarse surface as the oxides develop and thicken. Thus, the surface grows more and more diffused with time.

Lights interplay with all surfaces, whether they are stone, glass, or metal, and determine much of our opinion of the object. Metals have a special intimacy with light that changes with conditions throughout the day, and are influenced by shadows and reflections of other objects, as well as the contrast and brightness of the surface itself. The color and tone of the sky, perhaps, is the most influential of all when it comes to exterior surfaces of metals.

The color of the sky and the intensity of light reaching the earth obviously influence all exterior appearances. Trees and grass often appear a deeper green in certain overcast conditions.

The sea will sparkle in the sun as light strikes the tops of waves and reflects back to the viewer. The same sea will appear deep purple and blue when the sky is overcast. Metal will also exhibit similar variations in different lighting conditions.

There are several metals used in architectural and ornamental construction (see Table I.1). The available forms vary depending on the metal type. All of the metals classified as architectural are available in sheet, wire, and cast forms. When considering structural shapes, the available metals are limited.

It is significant to note that the form a metal takes also limits or directs the type of finish that the metal surface can possess. All metal

TABLE P1.1

Architectural Metal and Available Forms

Metal	Available Forms
Aluminum	Sheet, plate, foil, wire, castings, extrusion, pipe, tube, bar, rod, structural shapes, coating on other metals
Copper	Sheet, plate, foil, wire, castings, extrusion, pipe, tube, bar, rod, small structural forms, coating on other metals
Copper alloys	Sheet, plate, foil, wire, castings, extrusion, pipe, tube, bar, rod, small structural forms
Gold	Foil, leaf, bar, coating on other metals
Iron	Sheet, plate, wire, castings, pipe, tube, bar, rod, structural forms
Iron alloys—steels and stainless steels	Sheet, plate, wire, castings, extrusion, pipe, tube, bar, rod, structural forms
Lead	Sheet, plate, wire, castings, extrusion, pipe, tube, bar, rod, coating on other metals
Magnesium	Sheet, wire, casting, extrusion, bar, rod
Nickel	Sheet, plate, wire, casting, pipe, tube, bar, coating on other metals
Tin	Sheet, foil, wire, castings, extrusion, pipe, tube, bar, rod, small structural forms
Titanium	Sheet, plate, foil, wire, casting, coating on other metals
Zinc	Sheet, foil, wire, casting, extrusion, pipe, tube, bar, rod, coating on other metals

forms are created from scrap or ore material at a mill source. The mill source melts down the scrap and ore, then adds various compounds and elements to purify or alloy the metal. The metal typically is poured hot and cast into a large block of material. From here the initial, early form takes shape. For example, foils, sheets, and plates are created from large rectangular cross sections. Extrusions and wire are created from large circular cross sections.

The finish, when produced in the hot form, regardless of the metal, is rough. The surfaces have scale, grain marks, and generally a rough texture. Secondary processes of cleaning the scale and oxides, then passing the surface through more finished rolls or dies, imparts a surface that is smoother and more receptive to postfinishing processes.

Postfinishing processes are typical to what is used in the final product form. These are the finishes that are intended for long-term exposure to the ambient environment. They impart surface quality and behavior to the metal. The postfinishes and textures are what we interface with and formulate our opinions on. There are significantly more metal finishes and textures available to the design community today than at any other time in history.

Metal surfaces do change. Each metal has particular expectations as it undergoes aging. Some are expected to change in a prescribed way, while others are not expected to change for the life of the surface. Weathering of the various metals is dependent on exposure. Exposure to certain elements in the atmosphere will have significant impact on the weathering character of a metal, regardless of expectations. For metal intended to weather, the compounds that develop on the surface change in color and appearance as they gradually develop thick oxide coatings. The interplay with light is altered as the interplay with the environment stabilizes. What was once a shiny surface often changes to a diffused darkening patina.

As we approach the surface from a distance, features that define the character of the metal shell begin to take form. Shadow lines become visible and seams become a mosaic of elements.

CHAPTER 1
EXPECTATIONS OF VARIOUS METAL SURFACE FINISHES

> "*Blue skies*
> *Smiling at me.*
> *Nothing but blue skies*
> *Do I see.*"
>
> —IRVING BERLIN

Light from the surrounding sky reflecting off of a metal surface provides an ever-changing mosaic. Depending on the reflective nature of the metal surface and the light from the atmosphere, the effect will change. Metals have an intimate relationship with light. For example, the No. 2D finish in stainless is a relatively dull surface, but it possesses a gloss level higher than many other metal surfaces. On an overcast day, the metal appears as if it were painted flat white. On a bright sunny day, the surface takes on the color and appearance of still water.

The surface of stainless steel will reflect approximately 49 percent of visible light. The wavelength reflected by stainless steel tends toward the blue scale. Cloudy, overcast skies scatter the sunlight. This phenomenon, known as *molecular scattering*,[1] would suggest that the blue scale of the spectral wavelength is scattered by scattering the blue wavelength; the color blue has less of an impact on the color reflected from the surface of objects. This explains why the sky loses the blue color during overcast and twilight conditions. It also explains why the

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[1] Sunlight contains the full spectrum of visible light. It possesses all colors. As the light from the sun enters our atmosphere, it causes the air molecules to oscillate. The oscillation is caused by the electromagnetic behavior of the light wave. This oscillation causes the electrons and protons in air to produce electromagnetic radiation at the same frequency as the incoming sunlight. This radiation is emitted or scattered in all directions. The blue component of the visible spectrum has shorter wavelengths and higher frequencies than the other colors, particularly red. The electrons and protons oscillate faster from this shorter blue wavelength. This scattered blue light is significantly more prevalent than the red. Violet light is even more scattered than blue, but less violet passes through the atmosphere. Thus, we have a blue sky.

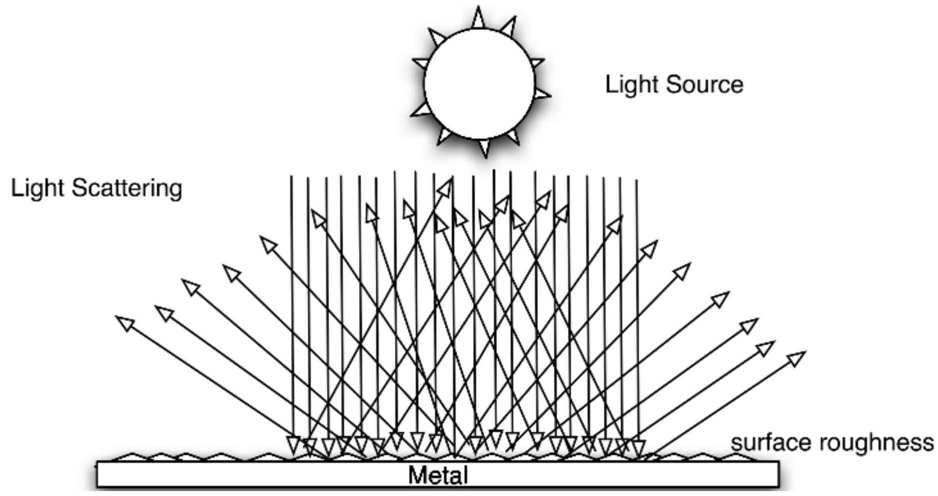

FIGURE 1.1. Light-scattering behavior.

TABLE 1.1

Reflective Metal Surfaces—Higher Reflectivity

Metal	Finish	Degree of Reflectivity—New	Degree of Reflectivity—Aged
Stainless steel	Mirror polish #9, #8, #7	Specular—mirror	Specular—mirror
Stainless steel	#2BA	Specular—mirror	Specular—mirror
Aluminum	Mirror polish	Specular—mirror	Depends on alloy and exposure-dulls down
Monel	Mill- finish	Specular—mirror	Reduced from oxide
Stainless steel	#2B	Specular	Specular
Aluminum	Mill—cold rolled	Specular	Depends on alloy and exposure
Stainless steel	#4	Specular—scattering in one direction	Specular—scattering in one direction
Copper alloys	Mirror polish	Specular—red/yellow	Diffused
Stainless steel	Glass bead	Specular—diffused in all but angle of reflectivity	Specular—diffused in all but angle of reflectivity
Gold	Leaf	Specular—bright yellow	Specular—bright yellow
Stainless steel	Angel hair	Specular—significant scattering	Specular—significant scattering
Copper	Cold rolled	Specular	Diffused
Zinc/zinc coated	Mill—unweathered	Specular	Diffused
Aluminum	Angel hair	Specular	Diffused
Brass—lacquered	Satin finish	Diffused—slight specular	Diffused—slight specular
Titanium	Mill—cold rolled	Diffused—slight specular	Diffused—slight specular

color of stainless takes on the appearance of a white painted surface. The blue color is less prominent, and the other colors wash across the surface. Under direct bright sunlight, sunlight possessing the full spectrum of wavelengths, such as the midday overhead sun, the surface of the metal will look brilliant and consistent (see Figure 1.1). Scattering the full spectrum light of the overhead sun by the rough, diffused surface of the metal will provide the most intense full color.

With metals, it is often desired to have a reflective surface—not necessarily blindingly bright but one that catches the eye (see Table 1.1). Its relative reflectivity is much greater than surrounding surfaces. Human nature, and that of some animals, for that matter, is attracted to gleaming and glittering objects. A gold leaf surface shimmers in the sunlight like a beacon when seen from a distance. As if the light is generated from the metal itself, gold will appear remarkably bright even on overcast days. A zinc surface by contrast, dulled by oxide, reflects a blue-gray tone in bright light and looks the color of pewter in overcast sky.

With all metals you have the ability to adjust the reflective nature of the surface (see Table 1.2). The ability changes with exposure time; and with some metal surfaces, the choices are limited. However, if desired, you can achieve a dull, flat, black appearance, devoid of the slightest visual sheen of any kind. Blackened by oxide, copper, zinc, and aluminum can have grainy, black, mottled surfaces. The mottling has degrees of black, some with a reddish tint, others with a gray tint.

TABLE 1.2

Reflective Metal Surfaces—Lower Reflectivity

Metal	Finish	Degree of Reflectivity—New	Degree of Reflectivity—Aged
Stainless steel	Mirror polish #9, #8, #7	Specular—mirror	Specular—mirror
Stainless steel	#2BA	Specular—mirror	Specular—mirror
Aluminum	Mirror polish	Specular—mirror	Depends on alloy and exposure-dulls down
Monel	Mill- finish	Specular—mirror	Reduced from oxide
Stainless steel	#2B	Specular	Specular
Aluminum	Mill-cold rolled	Specular	Depends on alloy and exposure
Stainless steel	#4	Specular—scattering in one direction	Specular—scattering in one direction
Copper alloys	Mirror polish	Specular—red/yellow	Diffused
Stainless steel	Glass bead	Specular—diffused in all but angle of reflectivity	Specular—diffused in all but angle of reflectivity
Gold	Leaf	Specular—bright yellow	Specular—bright yellow
Stainless steel	Angel hair	Specular—significant scattering	Specular—significant scattering
Copper	Cold rolled	Specular	Diffused
Zinc/zinc coated	Mill—unweathered	Specular	Diffused
Aluminum	Angel hair	Specular	Diffused
Brass—lacquered	Satin finish	Diffused—slight specular	Diffused—slight specular
Titanium	Mill—cold rolled	Diffused—slight specular	Diffused—slight specular

Other metal surfaces can have a low reflectivity generated by layering a light-scattering texture over a dull coarse grain. These finishes, such as glass-bead titanium or shadow stainless steel, have a metallic feel but a diffused reflectivity. Anodized aluminum has a coarse grain created by the hexagonal cell growth of its oxide. This reduces the reflectivity sufficiently, yet the surface still possesses a metallic quality.

Weathering steel develops a very coarse surface, as does blackened aluminum. The darkened surface of weathering steel does not reflect light well and appears dark reddish-brown. Blackened aluminum appears mottled flat black with streaks of occasional whitish deposits.

THE COLORS OF METALS

Theory and Behavior

Solar radiation that reaches the earth's surface occupies a small portion of the complete electromagnetic band. Radiation is caused by vibrations and is characterized by wavelengths rather than mass. This portion includes some ultraviolet, all visible light wavelengths, and approximately half of the infrared (see Figure 1.2). Light is an electromagnetic wave.

All metals are sensitive to particular light waves and emit electrons when these electromagnetic waves interact with the surface. The electromagnetic wave

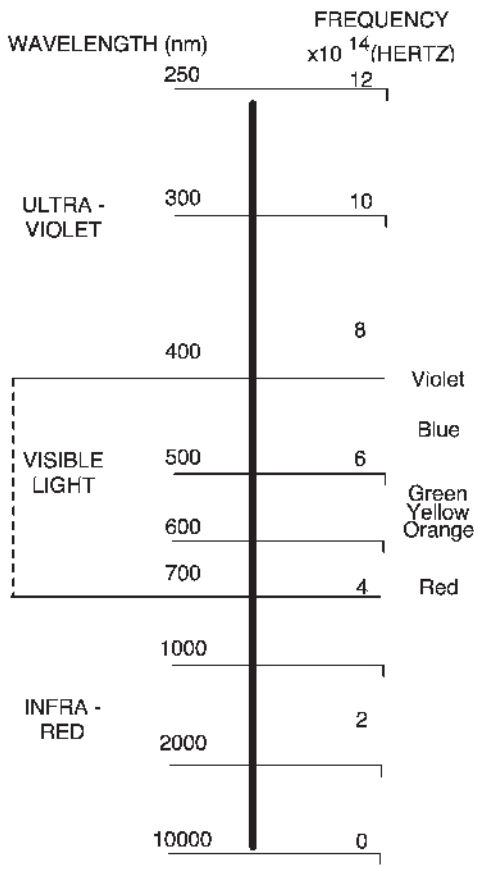

FIGURE 1.2. Solar radiation portion of the electromagnetic band.

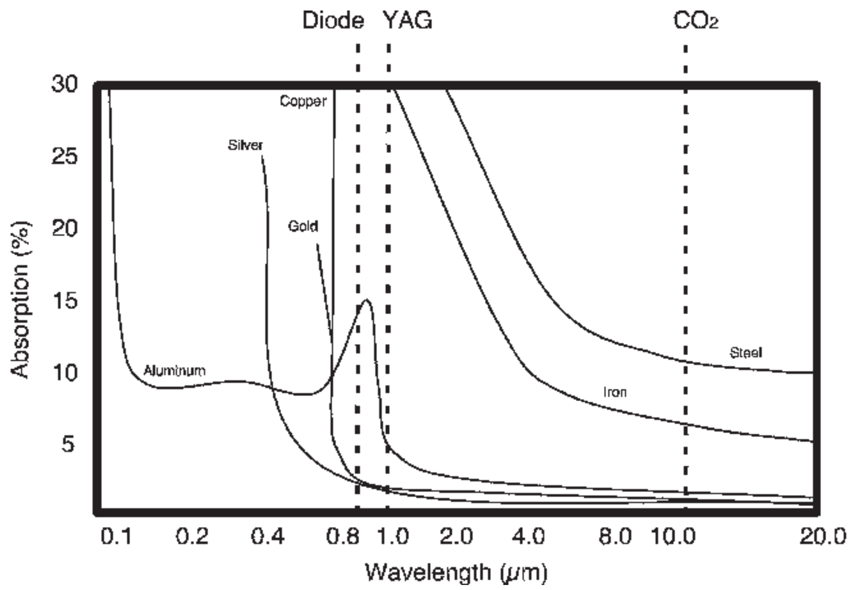

FIGURE 1.3. Wavelength and the corresponding absorption percentage of various metals.

excites the electrons in one energy level and moves it to higher energy level. Due to the atomic makeup of metal atoms, one would expect that light falling on a metal surface would be fully absorbed. Metals readily and strongly absorb electromagnetic radiation from light. But the light wave is absorbed only to a level a few molecules thick. Because of this very strong absorption characteristic at the surface, further absorption is inhibited. This behavior is also why certain metals can be efficiently cut with a laser while others cannot. Lasers produce high energy light at various wavelengths, depending on the energy source.

Figure 1.3 shows a CO_2 laser emitting a high-energy beam at a wavelength of 10.6 μm. Steel and iron absorb light at this wavelength, steel at about 12 percent, and iron more around 6 percent. The light energy is quickly absorbed and the molecules of steel are energized to the point at which the molecular bonds break down and allow the laser beam to cut through the metal. However, using the same beam with the same energy level that just cut through 3 mm steel on copper, the result has no effect. Copper absorbs a different wavelength while reflecting the others.

With most other materials, the reflectivity of the surface is defined by how much of the light is transmitted through it and how much is reflected from it. Defined as a percent reflectivity, R, for a beam of light hitting or reflecting off a surface at an angle perpendicular to the surface, known as normal incidence, is defined by the equation:

$$R = 100 \times (n - 1)^2 / (n + 1)^2$$

where n is the refractive index[2] of the material (see Table 1.3).

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[2] The refractive index is a constant used to describe the relationship of the speed of light through two materials. The value n is defined as the ratio of:

$$\frac{\text{Speed of light in material 1}}{\text{Speed of light in material 2}}$$

The incident light is in material 1 and the refracted light is in material 2.

TABLE 1.3

Refractive Index of Various Materials When Compared to a Vacuum

Material	Refractive Index
Vacuum	1
Air	1.0005
Water	1.33
Glass	1.5
Diamond	2.417

For instance, glass with a refractive index of 1.5 gives an R of 4 percent. This would mean that 96 percent of the visible light is transmitted into the glass. However, for metals, the equation changes. A more rigorous algorithm goes further by replacing the refractive index with what is known as the *complex refractive index*. $N = n + ik$, where k is the coefficient of absorption and i is given the value of $\sqrt{-1}$. Thus, for metals:

$$R = 100 \times (n - 1)^2 + k^2 / (n + 1)^2 + k^2$$

With metal, light is intensely absorbed only to a depth of a portion of the light wavelength—a few hundred atoms thick. The light causes slight electrical currents on the surface of the metal, exciting more electrons, which emit light out from the surface. This creates a very strong reflection. The very intense absorption on a polished metal surface free of oxides and foreign substances will cause an equally intense reflection. From the surface, this enhanced reflective characteristic creates the bright intense tones know as *metallic luster*.

The metals are selective in what they reflect in visible light (see Table 1.4). Likewise, they are selective in what other wavelengths they will transmit or absorb. This is because of the ariations in their coefficient of absorption values, k.

TABLE 1.4

Light Reflected from Metal

Metal	Visible Light Reflected from a Polished Surface
Silver	95%
Aluminum	90%
Tin	70%
Gold	61%
Chromium	61%
Iron	58%
Nickel	50%
Stainless steel	49%

Lead, for example, will block short wavelengths such as X-rays and gamma rays; it also blocks low-frequency sound waves. Zinc, on the other hand, is very sensitive to very short wavelengths and will emit electrons when these waves interact with the surface. Aluminum hampers radio waves. Gold has the capability to reflect radiation above 500 nm, which is the region of infrared. Thus, gold is often used as a thin coating on glass and protective gear used by firefighters.

The phenomenon of metals appearing different shades or tones in different lighting conditions is directly related to the wavelength absorbed and reflected (see Figure 1.4).

Additionally, light-scattering behavior of the finish can influence the surface color of various panels. For example, satin-finish stainless steels with small, tight finish grit lines or tiny lapping indentations are excellent light-scattering surfaces. On bright sunny days, the metal has a bluish cast because of the reflection of the blue wavelength of the sky. Hot spots of reflectivity are diffused, softening the intensity. If circular polishing with overlapping grits creates the satin finish, the reflected light is more polarized (similarly with the glass bead finish), so much so that on overcast days, or when the sun is low in the sky, distinct differences are apparent. These differences are the result of the stainless-steel surface not reflecting consistently in the 500 nm and below wavelength. In bright sunlight, all parts of the stainless-steel surface reflect well in the 500 to 600 nm range. The overcast sky and the twilight sky scatter the blue wavelength so that the surface of the stainless steel, which reflects this wavelength well, appears flatter, washed out in color. Variations appear that are not apparent in bright light. Sometimes even an opposite characteristic occurs where dark contrasting spots appear in the sunlit surface but appear light in the twilight, blue wave-

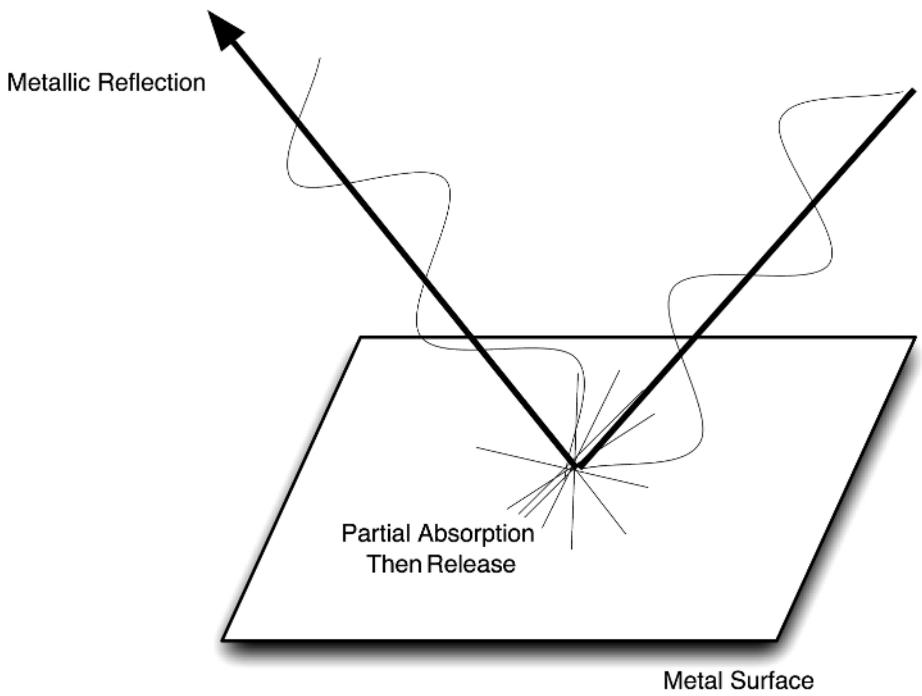

FIGURE 1.4 Light reflected off of a metal surface is partially absorbed, then reemitted, creating the intense metallic reflection.

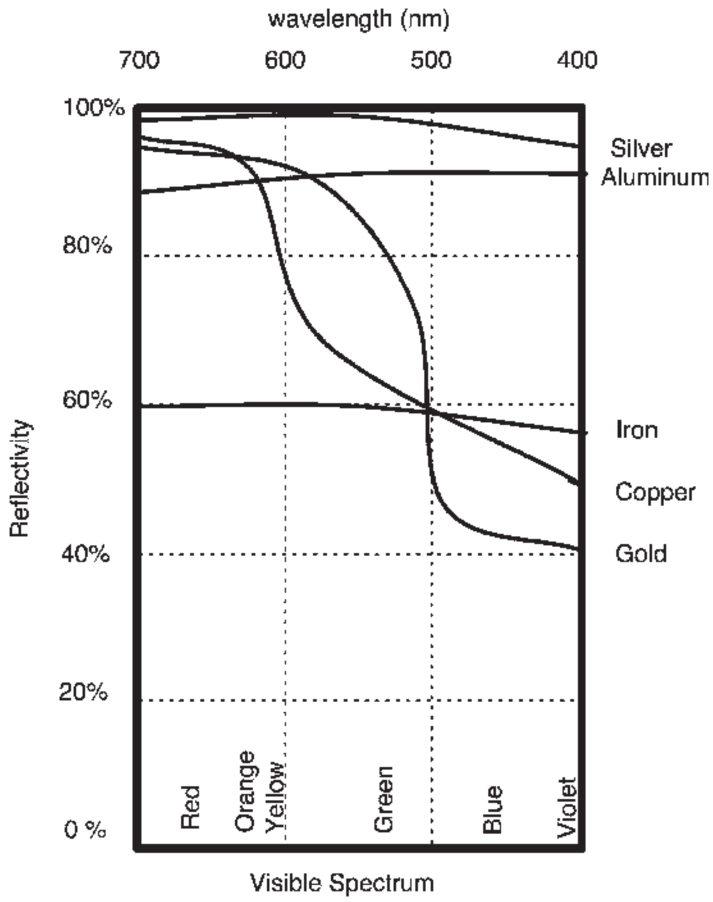

FIGURE 1.5. Color and wavelength reflected by various metals.

length-deficient glow. Figure 1.5 shows a variety of metals and the percent reflectivity of various wavelengths of the light spectrum.

Other metals have similar characteristics. Aluminum reflects a whitish-gray tone. The more intense the sun, the fuller the spectrum and the greater the white intensity will be. Overcast or twilight, and the metal is more silver gray. Anodized aluminum surfaces are composed of aluminum oxide. Clear anodized is aluminum oxide with a seal applied within the pores of the metal, the seal being deionized water or nickel. Colored anodized aluminum utilizes metal dyes impregnated into the pores or chemical reactions of the impurities in the alloy. The aluminum oxide is a crystalline surface, glasslike in nature. It has extremely poor formability and fractures when impacted, heated excessively, or formed. Light reflecting off of the surface is scattered by the many tiny pores on the surface and the microscopic roughened surface created by the etching prior to the oxide growth. There is an added depth in thick oxide coatings, which is created by light passing through the surface and reflecting back off of the base metal. Sometimes a slight rainbow effect can be seen created by light interference.

New copper can look as if it is on fire in low twilight, when the red wavelength of light is more prevalent. The surface of new copper is specular, moderately polished from the cold rolling process, imparting a burnishing effect on the copper. This polished surface will show minor distortions in and out of plane. In the light of the low sun, the surface comes alive with variable distortions across the surface. The copper looks as if it's a flaming vertical pool of water as the strong red tones are reflected. Eventually, the surface oxidizes and reflectivity gives way to earthy tones of a dull, darker, surface. Oil-canning distortions on the surface are no longer apparent because there is such a drop-off of reflectivity.

COLORS OF METAL SURFACES

The color of a metal surface as one approaches from a distance is influenced by several factors: the reflective nature of the metal surface, the context of the color, the position of the sun in the sky, overcast or haze conditions, and shadow effects created by surface alterations such as fenestration, relief and intaglio (see Table 1.5).

Brightness and Context

The perceived color in any surface is dependent on *brightness* and *context*. Brightness is considered the overall intensity of the reflection and is quantified as such: 100 percent brightness would be brilliant white; 0 percent brightness would be dark black. Context is considered to be the color hue and saturation, where hue is defined as the dominant wavelength that best matches the perceived color. For example, you might describe a color as more red than blue or more green than yellow. The red or green in this example would be the hue.

Saturation is the purity of the color. It is defined as the intensity nearest the dominant wavelength. Saturation is further distinguished as *chroma*, *tint*, and *shade*. Chroma is the color intensity, tint is the color modified toward white, and shade is the color modified toward black. Saturation can also be described as vividness, dull or sharp. Using these criteria, you could arrive at the values indicated in Table 1.6 for the various metals used in architecture.

Various colors can be imparted to surfaces, colors other than the typical gray-silver tones or the soft reddish tones of copper. The colors are imparted to metal surfaces by means other than pigmented coatings. Light interference or alloying attributes can introduce various color tones into metal surfaces with remarkable results. Metallic salts can be impregnated into the pores of anodized

TABLE 1.5

Color Influences

Color Influence	General Effect	Specific Influence
Surface texture	Brightness/dullness	Reflective nature of the surface
Surface color	Context	Hue and saturation
Sun position	Light wavelength	Full or partial spectrum reaching the surface depending on position of the sun in the sky
Overcast/haze	Light wavelength	Scattering of wavelength—partial spectrum reaching the surface
Fenestration, relief and intaglio	Shadow contrasts	Darkens surface or creates banding
Angularity of reflection	Color contrast	Light and dark tones

TABLE 1.6

Colors of Metal

Metal	Lighting Condition	Brightness	Hue	Saturation: Dull or Sharp
Aluminum—natural	Noon sun	90 to 100	White	Sharp
Aluminum—clear anodized	Noon sun	70 to 80	White	Sharp
Aluminum—clear anodized	Overcast	40 to 60	White	Dull
Aluminum—blackened	Noon sun	0	Black	Sharp
#2D stainless	Noon sun	80 to 90	Blue	Sharp
Titanium	Noon sun	50 to 60	Yellow	Sharp
Zinc—preweathered	Noon sun	40 to 50	Blue	Sharp
Copper	Overcast	20 to 40	Red	Dull
Lead	Overcast	10 to 20	Blue	Dull
Gold leaf	Noon sun	80 to 90	Yellow	Sharp

aluminum to produce an amazing array of colors that still maintain the metallic sheen of the base metals (see Table 1.7).

The colors listed in Table 1.6 all have a degree of metallic luster. With the exception of the patinas and weathering steel, the colors are glossy or specular in their reflective levels. Matching specific colors—that is, matching, say, a specific green tone—is not practical. These metals achieve their color from the interplay of light off their surface and the character of the oxide growth on their surface. If you want specific colors, then consider pigments and dyes.

REFLECTIONS OF SKY: SUN POSITION AND LIGHT SCATTERING

Very few materials reflect the natural beauty of the sky the way metal surfaces will. As described earlier, metals absorb particular wavelengths of light and then reemit them with a heightened energy level, producing the metallic luster we associate with metal. This is a property unique to metals (and semiconductors).

The smoother the surface, the more this effect will be apparent. The surface texture of the metal will affect the appearance significantly when viewed from a distance. Similarly, the atmospheric conditions—cloudy, sunny, smog-covered, and sun position in the sky—all affect the light the metal receives. The position of the sun in the sky will determine the intensity of various wavelengths of light that are delivered to the metal surface. Scattering effects of cloud cover will alter the wavelength reflected off of the metal.

Angle of view is another condition that can create alterations in the surface appearance of metals. Depending on the nature of the finish, light-scattering effects will be different when viewed from different angles. The physics involved are not unlike light reflecting off of a rippled surface of water.

TABLE 1.7

Colors of Metals

Color	Metal Type
Violet	Anodized aluminum with metallic salt Titanium with interference coloring Stainless steel with interference color Titanium-coated stainless steel—interference Copper—initial oxide interference
Blue	Anodized aluminum with metallic salt Titanium with interference coloring Stainless steel with interference color Titanium-coated stainless steel—interference Zinc—slight bluish tint Steel—oxide tinting
Green	Anodized aluminum with metallic salt Titanium with interference coloring Stainless steel with interference color Titanium-coated stainless steel—interference Gold alloy—greenish yellow tint Copper patina Copper alloy patinas
Yellow	Gold Copper alloys—brass Anodized aluminum with metallic salt Titanium with interference coloring Stainless steel with interference color Titanium-coated stainless steel—interference Nickel silver—silver-gold color Zinc patina—custom yellow-white oxide
Orange	Weathering steel Copper alloys—high copper content Copper patinas Anodized aluminum with metallic salt
Red	Anodized aluminum with metallic salt Titanium-coated stainless steel—interference Copper alloys—high copper content

Finishes that are made of small scratches on the metal surface or of microscopic indentations will scatter light. The angle of view, as well as the angle of reflection, will influence the appearance of the surface. Scattered light is partially polarized. When the light beam reflects off the surface, the wavelength is shifted. Under polarized light, hues of relative light and darkness appear. The reflected light seen by the viewer is coming not from a single point on the surface of the metal, but from several points arriving at different angles.

Light-scattering effects occur on cloud-covered days as well. Under light scattering, the longer wavelengths, the blues, tend to be muted. For metals that absorb and reflect more on the blue wavelength, you would expect them to appear darker. Stainless steel is one of the metals that reflect more on the blue scale. Copper and gold absorb most strongly on the red region of the light spectrum, hence reflect more intensely on the red scale. Thus, cloudy days have only a minor effect on the reflected light from gold and copper surfaces.

Blue light is a higher energy level and tends to scatter more readily off of small particles or small surface scratches. The atmosphere is full of small, microscopic particles, as are the fluids in the eye. Light scattering in the atmosphere not only gives the sky its blue color but also can create haze or glare in the case of the fluids within the eye. This is why pilots and hunters use amber-colored lens. The amber color filters out the blue wavelength and provides greater sharpness to the image reaching the eye.

Full sunlight during the middle of the day contributes nearly the full intensity of the light spectrum. Metals look most brilliant in such light, even if they are not in direct reflection such as north-facing surfaces or sunlit interiors. When the sun is near the horizon, again the shift of the wavelength is to the red side. The sky is darker, less blue, and has more red or purple tones. Metals respond to this change according to the wavelength they absorb and reemit.

Different metals absorb and reflect different wavelengths of light, and light conditions change constantly throughout the day, as diagrammed in Figure 1.6. Therefore, in conditions where light-scattering effects and polarization occur, you should expect variations in surface appearances at different times of the day and under different cloud covers. This is precisely what occurs.

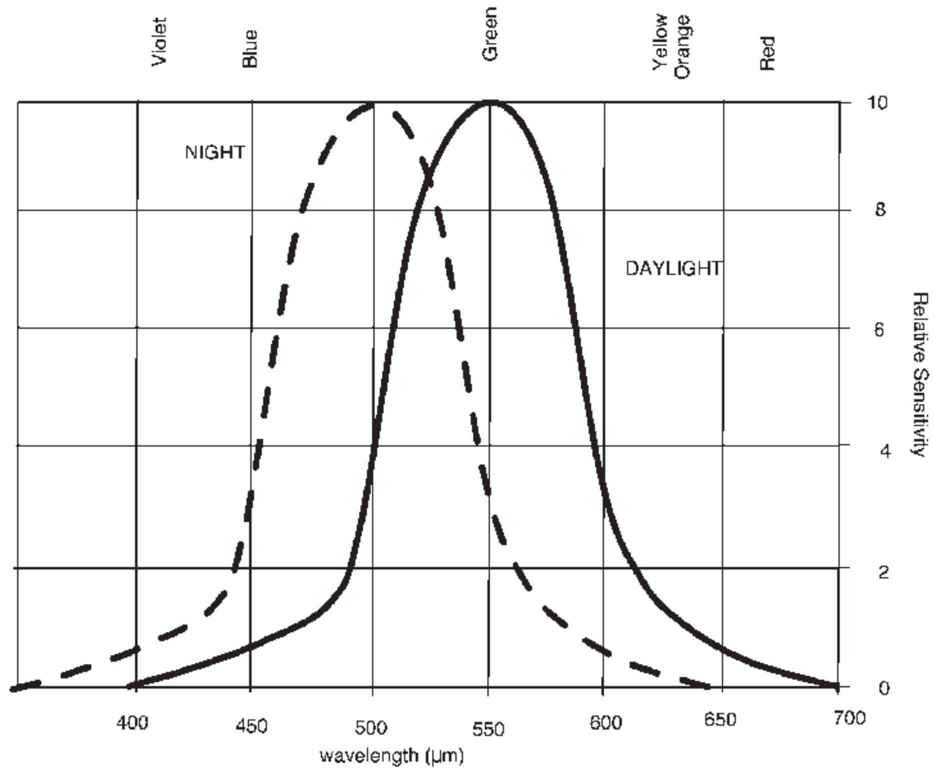

FIGURE 1.6. Shift in wavelength intensity with time of day.

A metal surface with the sun directly behind the viewer creates a relative bright spot. Shadows are diminished or eliminated, and the bright spot moves as the viewer moves around the surface. This effect is known as the *opposition effect*. The bright spot is white in color because of the intensity of the sun's reflection. All other colors are washed out by the intense whiteness. "Angel hair" finishes and satin finishes show this opposition effect. A bright, white circle of light moves across the surface, tracking with the viewer as he or she moves.

The brightness of all exterior surfaces is compared to the brightness of the sky. When discussing contrast in brightness, David Lynch and William Livingston, in their book *Color and Light in Nature*, Cambridge University Press, 2001 state: "The only difference between black, gray and white is their brightness for which the surrounding background provides the standard of comparison."

This is true in particular for low reflective surfaces. A dull stainless-steel surface in overcast light can appear as if it is flat white paint next to the brightness of the sky. By altering the reflectivity of the surface by glass-bead blasting, the diffused nature of the finish as it reflects the diffused light from the overcast turns the appearance to pewter gray. Apply an angel hair finish, and the surface takes on a brown-gray cast. Seams and reveals appear muted. Sensory relationships of dimension are reduced.

REFLECTIONS AND WATER

Light from water arrives via three regions: (1) the surface of the water, refracted through the top section of the water and scattered from the water volume and suspended particles; (2) refracted through the water as light is reflected from the bottom of the pool surface; then (3) refracted a second time from the water to air interface.

The reflected light is polarized from the scattering nature of the waves and from the effects of the refractions through the water from the bottom and intermediate regions. This reflected light plays off of the waves at different times of the day. The effect, known as *glitter*, produces shimmering reflections on metal surfaces, creating a fabriclike flow of contrasting color.

At high sun (Figure 1.7), the waves roll under the light beam and scatter at an angle approximately four times that of the wave angle. When the sun is low in

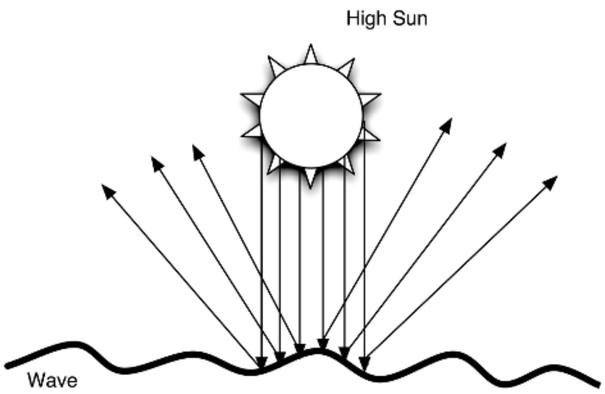

FIGURE 1.7. Reflection off the surface of water at high noon.

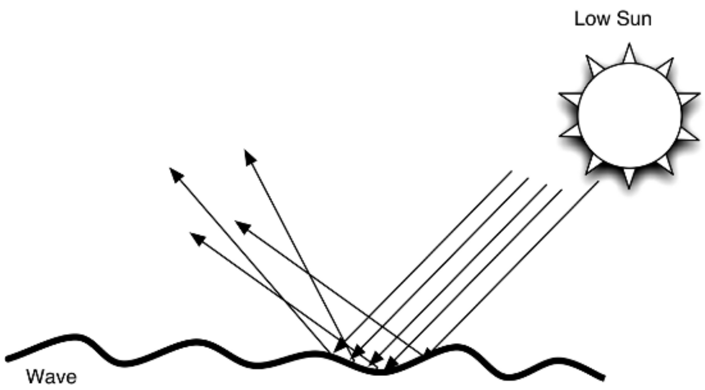

FIGURE 1.8. Reflection off the surface of water at sunset or sunrise.

FIGURE 1.9. Glitter from the overhead sun.

FIGURE 1.10. Dark zones from overcast sky.

the sky, the effects are markedly different. As the sun moves lower in the sky (Figure 1.8), the angle of incidence changes with each wave pulse.

On overcast days, the opposite of glitter occurs. Each wave top, instead of being a bright light is now dark. Blue color is toned down and water takes on a purplish color.

Metal and water in their relationship with light have similar behaviors. Just as the wavelength of light reaching the surface changes in intensity, like the waves rolling over a beach, the appearance of a metal surface changes as it interacts and reflects these varying intensities created by changing light and angle of incidence (see Figures 1.9 and 1.10).

The deciding factor of whether to use metal or not for a particular surface is dependent on the way light interplays off the surface and back to the viewer. The light coming from the surrounding environment changes, as does the metal surface itself. The interplay is far more dynamic and interesting. Metal is unique among surfacing materials in this regard. Each metal has its own peculiar way of interacting with the light striking it. Look the other way for a moment and something new may appear.