Michigan Agricultural Energy Council

Electrical Tech Note — 341D

Biosystems & Agricultural Engineering Department
Michigan State University

Lamps & Lighting Design

Introduction: Light is electromagnetic radiation that travels in the form of waves. It is visible radiant energy that travels through air or a vacuum at a speed of approximately 186,000 miles per second or 3×10^8 meters per second. It will only travel through certain materials and it's velocity will be different through different materials. Light is a narrow band of wavelengths of electromagnetic waves that can stimulate two types of specialized receptors in the eye. The unit of measure of the wavelength of visible radiant energy is the nanometer (nm). One nanometer is one thousand-millionth of a meter (1×10^{-9} m). Electromagnetic energy that is considered visible light to humans is in the wavelength range of 380 nm to 760 nm. Wavelengths shorter or longer than this range do not stimulate receptors in the human eye to see the light.

Color Vision: White light to the typical human eye is a distribution of wavelengths across the visible radiant energy spectrum. Directing a beam of white light containing every wavelength of electromagnetic radiation between 380 nm and 760 nm at an angle to one surface of a glass triangular prism and the light beam will be subdivided so that each wavelength will be projected onto a different point on a white target beyond the prism as shown in *Figure 341.1.* The beam of light will bend as it passes from the air into the glass. The shortest wavelengths (violet) will bend the most. Long wavelengths (longer than 630 nm) will appear red. Short wavelengths (shorter than 490 nm will appear blue or violet). Wavelengths in the range of 490 nm to 560 nm will appear green. If the distribution of wavelengths of a light source is uneven the eye will interpret this uneven distribution of wavelengths as a color.

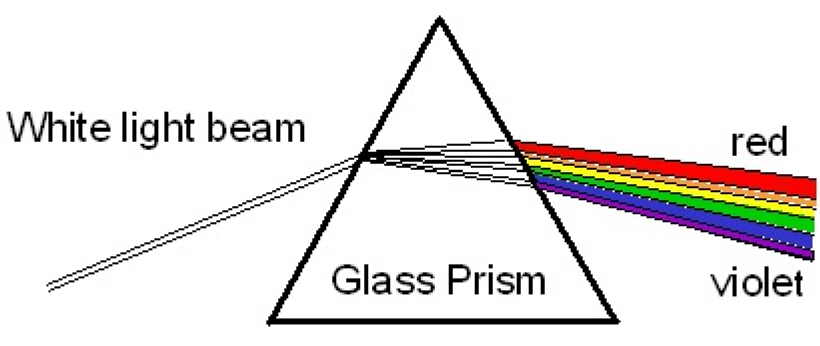

Figure 341.1 *Light travels at different speeds through different materials such as air and glass. If light passes from one material to another at an angle, the light beam will bend with short wavelengths bending more than long wavelengths. The light will be subdivided into individual colors. The distance each color travels through a prism is different so the various colors cannot recombine to form white light again when they emerge from the prism. The result is the projection of a spectrum of colors that are in the light beam striking the prism.*

If an object is illuminated by a light source that has an even distribution of all wavelengths that object will appear white if it evenly reflects all wavelengths of light striking the surface. If some of the wavelengths of light striking an object are absorbed by the object and not reflected the object will have a color depending upon how the eye interprets the wavelengths reflected. *An object will appear the color of light reflected.* If an object transmits light it will appear a color if some of the wavelengths are absorbed by the object. In this case the object appears the color of light transmitted. This is how color filters work. The filter absorbs all wavelengths except the color transmitted.

The eye receives all of the wavelength of light reflected or transmitted by an object and interprets the wavelengths and their intensity as a single color. If the eye sees an even distribution of all wavelengths it will see the object as white. If the object reflects mostly red light such as for a tomato shown in *Figure 341.2* the eye will see the tomato as red. Examination of a color picture in a newspaper using a 10X magnifier will reveal that each color is made up of color dots not necessarily the color the eye sees.

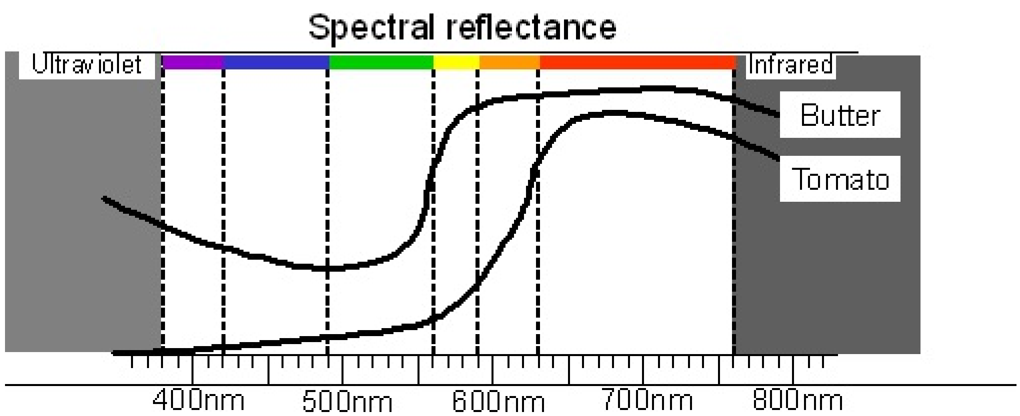

Figure 341.2 *The light received from an object by the eye is usually a wide range of wavelengths of different intensities. The eye will interpret these wavelengths as a single color hue such as yellow for butter and red for a tomato.*

How the Eye Works: Light entering the eye is projected by the lense onto the retina. The retina is a thin layer of material attached to the back of the eye and contains specialized nerves that are excited by electromagnetic radiation in the visible range of wavelengths. The radiant energy is converted to electrochemical impulses that are transmitted to the brain by means of the optical nerve. The brain interprets these electrochemical impulses as an image.

There are two types of light sensitive nerves in the retina. One type can distinguish different radiant energy wavelengths and are responsible for seeing color. These nerve endings are called **cones** because of their shape. The central portion of the retina is made up mostly of cones. Cones are quite scarce on the outer edges of the retina. A different type of nerve is very sensitive to light levels but cannot distinguish color. These nerve endings are called **rods** because they are long and slender. Rods are especially useful at night when light levels are low. Rods can only see black and white but they are very sensitive so they can distinguish slight changes in light level often because an object moves. The outer portion of the retina is made up mostly of rods and there are very few in the center. A person looking at a faint object through a telescope often looks to the side of the object to direct the image onto the sensitive rod nerve endings of the retina.

The eyes of animals and other creatures cannot be assumed to be the same as humans. The eyes of various creatures will be specially adapted to perform necessary functions for survival. Some but not all insects have eyes sensitive in the ultraviolet portion of the electromagnetic spectrum. These insect are attracted to ultraviolet bug zappers. These insects are generally blind to the long wavelengths of the visible spectrum such as yellow, orange, and red. The eye of a chicken tends to be most sensitive to longer wavelengths such as red and are nearly blind to blue and violet light. Instruments designed to measure light levels for humans are probably of little value when measuring light levels for other creatures.

Color: All color hues can be created by projecting varying intensities of three primary colors onto a white background. If all three colors are projected onto the same spot with the same intensity white is produced. Color television works by illuminating three primary colors in varying intensities. These **primary additive colors** are **red**, **green**, and **blue**. These same colors are used for lighting on a theatrical stage. In order for objects to look their natural color the light source illuminating them must have an even distribution of these primary colors. This is why the same object will appear a different hue when lit with different sources. Special attention must be given to the type of light source used for color television and photographic studios.

Red, green, and blue are called *primary additive colors* because they can be added together to form another set of primary colors called the *subtractive primaries*. Shining red and green on the same spot will create yellow. The eye still sees red and green but it averages the wavelengths and the brain interprets the result as yellow. Shining red and blue on the same spot creates the color *magenta*. Green and blue shining on the same spot creates the color *cyan*. **Yellow, magenta, and cyan** are called the *primary subtractive colors*. The primary colors are illustrated in *Figure 341.3.* When mixing paint or for color printing these three subtractive primary colors can be used to create all other color hues.

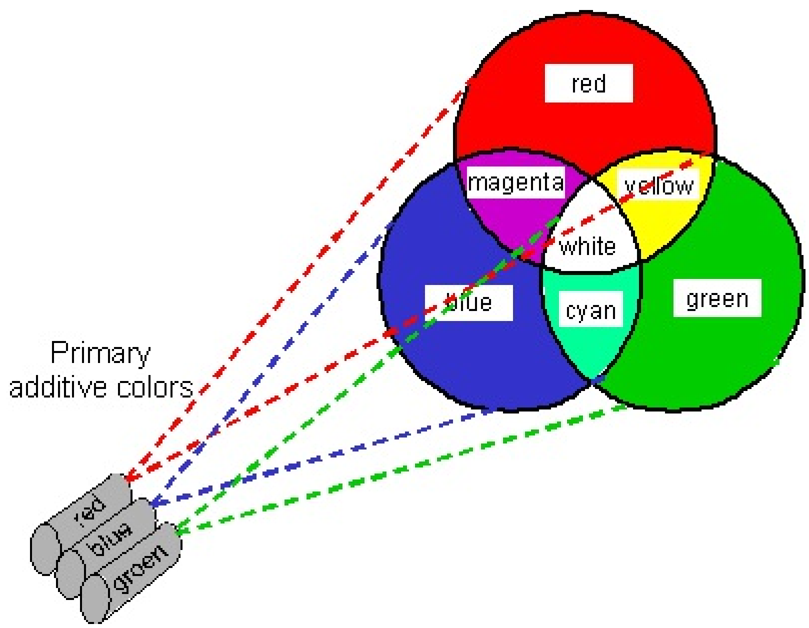

Figure 341.3 *Any color hue can be created by projecting the three primary additive colors in varying intensities onto a white screen. The primary additive colors are red, green, and blue.*

To study the primary subtractive colors imagine a white light shining through a yellow filter. All colors are present in the white light beam but the *yellow filter will absorb all colors except red and green* which are permitted to pass through the filter. Placing a cyan filter in front of a white light beam leaving the yellow filter as shown in *Figure 341.4.* The *cyan filter will allow green* *only the light* to pass through. Since the light beam leaving the yellow filter only contains red and green light, there will only be green available to pass through the cyan filter. An observer looking at the white light through a *cyan* and *yellow* filter will see the primary additive color green. Looking at a white light through a *magenta and yellow filter* the observer will see the primary additive color *red*. Looking at the same white light through a *cyan and magenta* filter the observer will see the primary additive color *blue*. Theoretically mixing the three primary subtractive colors in equal quantity should result in *black* since all colors are absorbed. In real life this turns out to be a dirty brown so in painting or color printing black must be used to get true black. Color printing then involved printing four times, once with each of the three primary subtractive colors and black.

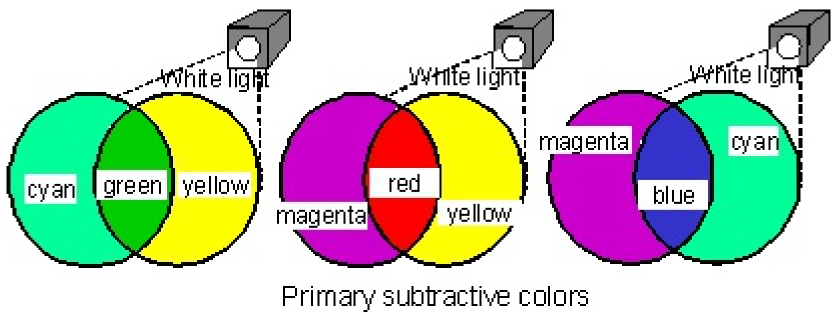

Figure 341.4 *The primary subtractive colors are yellow, magenta, and cyan. Passing white light through primary subtractive filters the three primary additive colors can be recreated.*

Color Temperature: All objects will produce light if heated to a sufficiently high temperature and the color will change as the temperature changes. A special type of object called a blackbody radiator will emit a specific color range with a peak at a specific color. Color temperature of electric lamps can range from a soft yellowish color (2,700°K) to bright white light. *Figure 341.5* shows a color temperature rating output curve for 3,000°K and 3,400°K of color output curves of incandescent lamps where a tungsten metal filament is heated to give off visible light. Notice that a large portion of incandescent lamp output is in the infrared (heat) portion of the spectrum. A large portion of incandescent lamp output is heat not visible light. Present day lighting such as LED (light emitting diode) lamps produce a range of light such as warm yellowish colors to bright blueish white colors. These lamps produce light with a long operating life and minimum heat compared to an incandescent lamp. *Figure 351.5* shows the light produced by typical incandescent lamps. Notice the amount of heat energy produced by incandescent lamps. A light source with high color temperature (4,000 °K) is best for blue and violet colors. For orange and red colors best lamp color temperatures are below (3,000 °K).

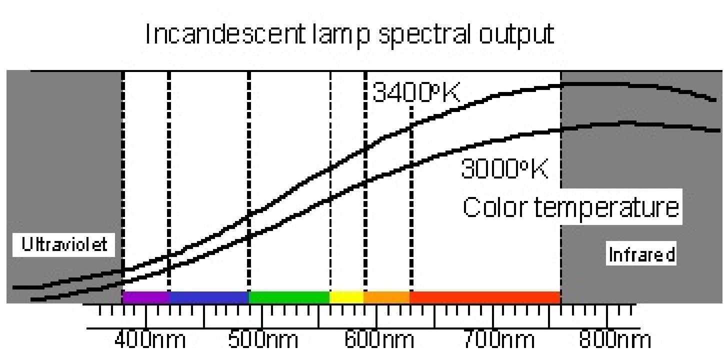

Figure 341.5 *The radiant energy output of an incandescent lamp contains an even distribution of light as the operating temperature of the filament increases but with most energy as heat.*

Light Sources: Light is produced in different ways and the different sources do not generally contain an even distribution of wavelengths across the visible electromagnetic spectrum. Absence of certain wavelengths in the light from a source will affect the color of an object. A tomato will not appear red if the light source does not contain wavelengths longer than 630 nm. When color is important it is necessary to know the wavelengths produced by the lamp. For practical illumination there are several basic types of light sources used. These are incandescent, fluorescent, high intensity discharge, and light emitting diode (LED).

Incandescent lamps: Incandescent lamps have a high resistance tungsten filament that is heated to the point where the output includes all wavelengths of the visible spectrum. Typical examples are shown in *Figure 341.5.* The filament is contained within a protective transparent envelope such as a glass bulb or a quartz tube. The space within the envelope is either a vacuum or sometimes it is filled with an inert gas. Even though the filament is operating well below the melting point it does tend to evaporate at such a high temperature that the inert gas puts pressure on the filament and tends to retard evaporation. Another way to deal with filament evaporation is to introduce iodine vapor into the envelope. The envelope will be quartz rather than glass. The iodine combines with the tungsten when it evaporates to form a substance that will not stick to the quartz envelope. The tungsten actually is redeposited back onto the filament. These lamps are called *tungsten-halogen* or *quartz-halogen* lamps. They can be operated at a high filament temperature and can give better color output. An ordinary incandescent lamp has a life of about 1,000 hours. A quartz-halogen lamp typically has a life of about 2,000 hours.

Fluorescent lamps: Fluorescent lamps use a completely different concept in producing light than an incandescent lamp. An electrode is placed at each end of a tubular glass envelope filled with argon gas and a small amount of mercury. A current flows through the glass envelope from one end to the other and energizes the mercury atoms to produce ultraviolet radiation. The inside of the glass envelope is coated with crystals of phosphor which produce visible light when energized by the ultraviolet radiation. *Figure 341.6* is a representation of a rapid start fluorescent lamp circuit.

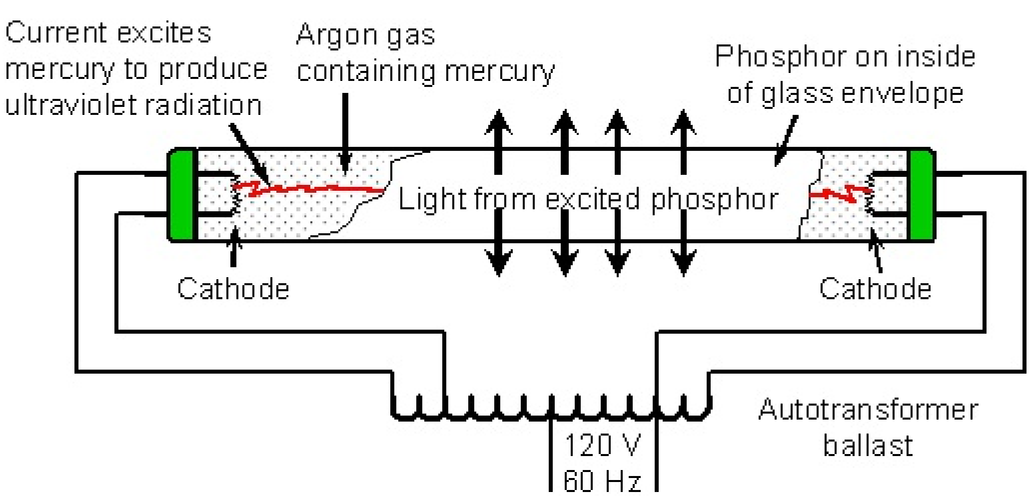

Figure 341.6 *An autotransformer in this rapid-start fluorescent circuit heats the cathodes at each end of the lamp and an arc will strike through the argon gas and mercury vapor. The current flow is limited by the ballast to about 400 mA. The ultraviolet radiation stimulates the phosphor coating on the inside of the glass envelope and produces visible light.*

Fluorescent lamps have the ability to convert electricity into visible light. Fluorescent lamps produce nearly full illumination immediately when turned on except in cold environments. This process works efficiently when the ambient temperature is above 10°C (50°F). Fluorescent lamps are not well suited for cold environments. A simple rapid start fluorescent lamp circuit is shown in *Figure 341.6.* An arc will strike between the lamp cathodes if there is sufficient voltage. A device called a ballast is used in a fluorescent lamp circuit to limit the current through the lamp. The inductive reactance of the ballast coil serves as a choke to limit current flow. Most ballasts also operate as a transformer to increase the applied voltage to the lamp electrodes. The ballast in *Figure 341.6* is an auto-transformer type.

The phosphor coating on the inside of the glass envelope of a fluorescent lamp produces light mainly at specific wavelengths in the visible portion of the spectrum . Cool white fluorescent is a common color designation for fluorescent lamps and its spectral energy distribution across the visible part of the spectrum is shown in *Figure 341.7.* A cool white lamp (color temperature 4,100°K) does not emit as much red light as the warm white fluorescent lamp that produces a large quantity of red light (3,000°K). Red objects and other warm colored objects will look best when illuminated with a warm white fluorescent lamp.

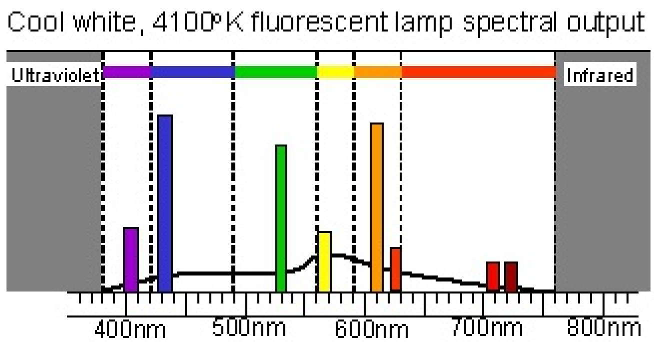

Figure 341.7 *Spectral distribution curve for a cool white fluorescent lamp showing light emitted at specific wavelengths which is a characteristic of electric discharge lamps. In addition to a complete color spectrum there will be a violet, blue, green, yellow, and orange bright lines and some red.*

Light Emitting Diode: The LED lamps (*Figure 341.8*) are a solid state device consisting of a PN junction made of semiconducting silicon materials. When current passes across the PN junction visible light is produced. Improvements in the LED lamps in recent years have resulted in the ability to use LED lamps as an efficient and useful form of illumination for most applications.

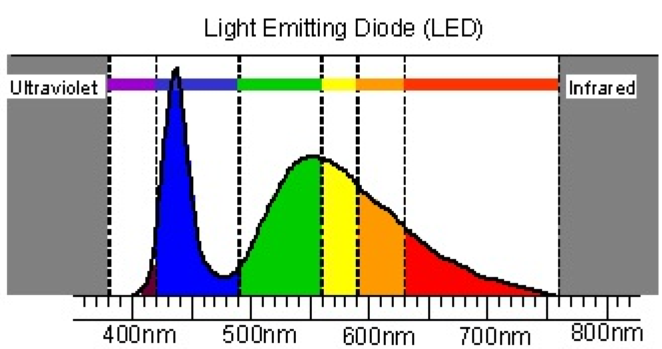

Figure 341.8: *LEDs produce light in a narrow wavelength band and are often provided with a phosphor coating that produces light at other wavelengths. The peak to the left is produced by the LED while the emissions to the right are colors produced by the phosphor coating.*

A device called a ***driver*** is used to convert the circuit 60 Hz alternating current to direct current (dc) which is required for LED lamps. *Efficacy* is very high and length of life is estimated at more than 20,000 hours. LED lighting is highly efficient with low power requirements. Tube lighting that used to be fluorescent now contain LEDs inside the non-glass envelope. The fluorescent luminaires are easily converted for LED lamps. The ballast used for a fluorescent lamp is disconnected and replaced with a small electronic **driver**. A light output diagram for a typical LED luminaire is shown in *Figure 341.8.* LED luminaires are used for sports stadiums and arenas. They have good color, long life and illuminate instantly when turned on.

High Intensity Discharge (HID): An HID lamp passes current through a quartz arc tube containing metallic vapors within a glass outer envelope. This process is similar to that of the fluorescent lamp except the vapor is contained in a small arc tube that requires a warm-up time of several minutes before emitting visible light. These lamps have long life and high efficiency at converting electricity to light. There are several types of HID lighting. The first HID lamps were the mercury vapor type that were very popular for years as outdoor lighting. HID lamps operate well in cold environments. The color output of the mercury vapor lamps was lacking in the red end of the visible spectrum. Mercury vapor lamps had a very long life but they had low efficiency at converting electricity to visible light. Mercury vapor lamps are no longer manufactured in the U.S.

Metal Halide HID Lamps: The metal halide high intensity discharge lamp uses several types of metal iodide vapors in the arc tube to obtain a more even distribution of color across the visible spectrum. Objects tend to look normal colors when illuminated with metal halide lamps. These lamps were popular at illuminating sports fields and sports arenas. A spectral output distribution chart for a typical metal halide lamp shown in *Figure 341.9.*

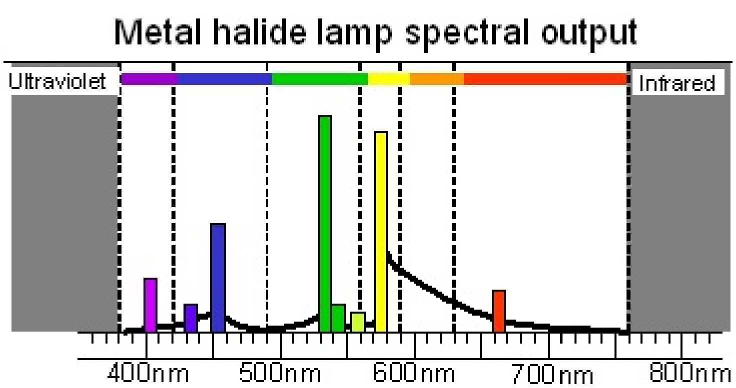

Figure 341.9 *Spectral distribution curve for a metal halide lamp produces light at specific wavelengths in the violet, blue, green, and yellow portion of the spectrum with extra light produced in a range of wavelengths in the red portion of the spectrum to give good color balance.*

A negative aspect of the metal halide lamps is that light output tended to decrease with lamp life more rapidly than other types of electric discharge lamps. Usually these lamps are replaced due to drop in light output rather than failure of the lamp. The light output for power used is very high for metal halide lamps. Light output for these lamps is not affected by cold conditions. One negative issue is that these lamps do not produce light immediately when energized. It takes sometimes up to 10 minutes before the lamps would be up to full brightness. Another issue is that metal halide lamps required emergency back-up lighting in case of an temporary power interruption. If turned off metal halide lamps do not immediately produce light. LED luminaires now replace metal halide lamps for sports lighting applications. Metal halide luminaires in the past were used for sports stadium lighting.

High Pressure Sodium Lamps: High pressure sodium lamps produce the major portion of light in the orange, yellow, and green portion of the spectrum with some light emitted in all portions of the spectrum. The color output of the high pressure sodium lamp is well enough distributed across the visible spectrum that they are suitable for a wide variety of general illumination applications. The major advantage of the high pressure sodium lamp is an extremely high light output for the power used. These lamps also do not provide light immediately when energized but are faster at re-strike than other HID lamps. These lamps are very efficient with long life but with a large quantity of yellow light. The spectral distribution for a high pressure sodium lamp is shown in *Figure 341.10.* LED lighting has taken over for most applications.

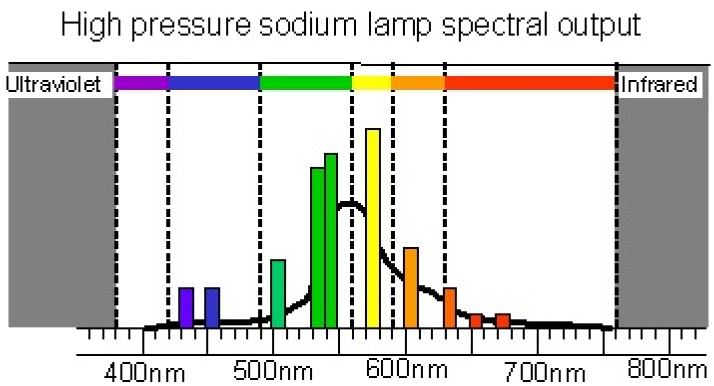

Figure 341.10: *The high pressure sodium lamp has high efficiency and long life. The disadvantage is the minimum one minute to begin illumination and several more minutes to achieve full brightness. Color distribution is good except there was too much yellow, orange and green illumination.*

Lamp Color Quality: *Color rendition index* (CRI) gives an indication of how well a light source will represent colors. For example, if the light source has a high color rendition index it should be possible to distinguish the difference between two surfaces of nearly the same color hue. If the CRI is low the colors may actually be different but they will look like the same color. Even though incandescent lamps do not produce the different colors of light at the same intensity they do produce every color across the spectrum and are generally considered to have a CRI of 100. The CRI scale ranges from zero to 100. A CRI of 60 to 75 is considered good and above 75 is considered excellent. As discussed earlier in the *Tech Note* other lighting sources tend to produce light in narrow bands of wavelengths and sometimes little or no light at some wavelengths. It is difficult to distinguish between color hues when illuminated by some light sources. When proper color rendition is important it is necessary to choose a light source with a high CRI.

When selecting a light source that will properly represent colors it is important to look both at the **correlated color temperature** (CCT) and the *color rendition index* (CRI). Sunlight at sunrise has a color temperature of about 2,000°K while sunlight at noon has a color temperature of about 4,500°K. A bright overcast sky is at about 7,000°K color temperature. A light source with a color temperature in the 4,000°K range is best for illuminating cool colors such as green, blue, and violet. A color temperature in the range of 3,000°K to 3,500°K works better for warm colors such as red, orange, and yellow. Generally fluorescent lamps use the terms “warm” and “cool” rather than giving a specific color temperature. After selecting the color temperature of the lamp then select a source with the highest *color rendition index* possible at that color temperature. This will ensure that different color hues are less likely to blend together and one color hue can be distinguished from a sightly different color hue.

Terminology: The intensity of a light source in a particular direction is called **candlepower** and the unit of measure is the **candela**. An approximation of one candela is the intensity of an ordinary candle viewed from close range. Intensity decreases in proportion to the square of the distance from the source. Candlepower is not necessarily a measure of the amount of light produced by a lamp. It simply gives an indication of the *intensity of light* output from a lamp or luminaire in a particular direction. *Figure 341.11* is a candlepower distribution curve for a one candela source. At a distance of one foot from the one candela source the quantity of light on a one square foot surface is *one lumen*. If the distance is two feet from the one candela source the lumen value is reduced by a factor of four.

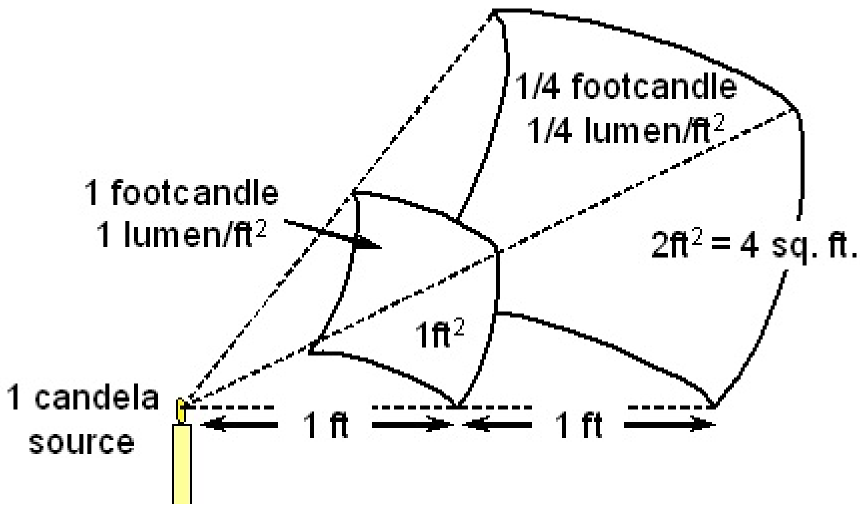

Figure 341.11 *The luminous flux within the solid angle formed by a one square foot area located one foot from the one candela source is equal to one lumen.*

The amount of light or **luminous flux** is the time rate of flow of luminous energy or light. The unit of measure is the **lumen**. Since the *lumen* is a unit of time *rate of flow* of luminous energy *it is a unit of power* where over the range of visible wavelengths *one lumen* is approximately equal to 1.464 mW. *NASA* has used the power of light to help steer space crafts.

Assume a light source is one candela and radiates light uniformly in all directions. One lumen is the amount of light flowing away from the source in a unit solid angle from the source. For example assume a surface of one square foot is positioned such that all points on the surface are one foot from the one candela source the amount of light flowing within that solid angle is one lumen and one lumen will be reaching the one square foot area. By moving out two feet from the source the lumen will be projected onto a surface that is four square feet. If the surface is positioned one meter from the source the lumen will be evenly distributed over a one square meter surface.

Illumination is the result of a luminous flux falling upon a surface. Lamps are installed to achieve a certain level of illumination. The conventional unit of illumination in the U.S. is the *footcandle*. A *footcandle* of illumination is achieved when *one lumen* is *distributed over* a one *square foot surface* (lumen / ft^2). The metric unit of illumination is the *lux* which is one lumen per square meter (lumen / m^2). To convert a footcandle to lux multiply the footcandle by **10.76**.

Luminance: Luminance is *light leaving an area*. The *light may be transmitted through a material or it may be reflected from a surface*. An illumination meter can be used to measure the light being received at a surface such as a wall. Aim the meter at the wall and measure the light leaving the surface. The meter is measuring the luminance of the wall. The unit of measure of luminance in the conventional measurement system is the *footlambert.* A *footlambert* is defined as *one lumen leaving a one square foot surface*. The metric unit of luminance is the *nit* which is one lumen leaving a one meter square surface. A *nit* is a much smaller level of luminance than the *footlambert* by a factor of 0.0929. (1 / 0.0929 = 10.76)

Measuring Light: An illumination meter is needed when designing a lighting system for human or other applications. A light meter is placed at a location where a specific level of illumination is desired. In order to make a meaningful measurement the light meter must be calibrated to have a wavelength response similar to the human eye. *Figure 341.12* shows the sensitivity of the normal human eye to wavelengths of electromagnetic radiation across the visible spectrum. The normal human eye is most sensitive to light in the green and yellow portion of the spectrum. A selenium type photo cell has a sensitivity somewhat like the human eye although it is more sensitive to violet, blue, and red than is the human eye as shown in *Figure 341.12.* If this selenium photo cell is used for making light measurements it will tend to indicate higher levels of illumination than can be seen by the human eye. A filter can be added to the selenium photo cell so it will have a sensitivity nearly the same as the human eye. This is called a *visual corrected photo cell*. An illumination meter is calibrated to indicate the total light received in footcandles or lux. They are sometimes referred to as a footcandle or a lux meter.

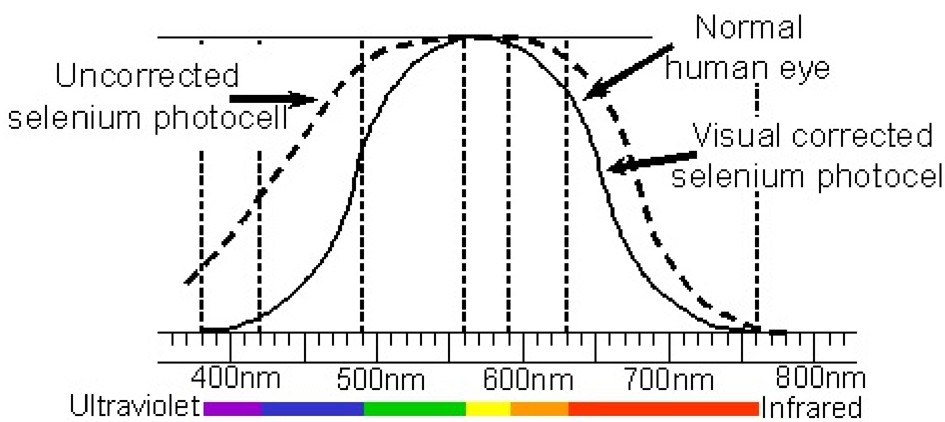

Figure 341.12 *Spectral sensitivity curve for the normal human eye and for an uncorrected selenium type photo cell. A filter is added to the meter to better approximate the human eye.*

Light reaches a surface from all angels. Light may enter windows or be reflected from light colored walls. Light reaching a surface from a wall or window is often being received from a low angle. The photo cell is mounted down inside a case for protection and light coming at a low angle may be blocked from reaching the photo cell by the edge of the case. This problem can cause a significant error in the reading in some cases. A special *cosine corrected* meter can be used to avoid this problem. A *cosine corrected* meter will catch light being received at a work surface from a low angle such as from windows.

Research has been conducted over the years to determine the optimum illumination level for different tasks. Building codes will specify a minimum illumination level for areas such as stairs. These are minimum levels found to be necessary for safety. An illumination meter is placed at the desired location such as at a desk surface and the person making the measurement must back away so as not to affect the reading. A significant loss factor is reflectance from walls, ceiling and floor surfaces. Light colors such as white on walls and ceilings will reflect rather than absorb light. A light meter can be used to make an estimate of the reflectance of a wall or ceiling surface.

Reflectance of a wall or ceiling can be estimated in percent by measuring the light being received and the light being reflected. It is best to use a visual corrected illumination meter that is *not cosine corrected.* Hold the illumination meter near the surface and measure the light being received. Next aim the photo cell at the surface and then slowly pull it away until the meter reading reaches a maximum. Be careful not to block light from the measurement surface. To determine the percentage reflectance divide the light reflected by the light received using *Equation 341.1.*

$$\text{Reflectance} = \frac{\text{Light reflected from surface}}{\text{Light received at surface}} \times 100 \qquad \textbf{Eq. 341.1}$$

Transmittance of a surface can be measured in a similar manner as measuring reflectance by first measuring the level of illumination received at the top surface and then the level of illumination just below the surface. Divide the level of light transmitted by the level of illumination falling on the top surface.

Efficacy: When discussing efficacy there is a tendency to concentrate only on the light source and not the entire installation. It is important to choose a luminaire with the highest efficacy that will satisfy the design criteria of the application. ***Efficacy** for lamps is given in lumens per watt* with typical values in *Figure 341.13.* Efficacy varies widely for some types of lighting sources. Generally the higher the wattage the higher the efficacy. *Lamp life* is defined as hours of operation when 50% of a group of lamps have failed when operated under specified conditions. Lumen output of a lamp is a unit of power since it is the rate at which luminous energy is being produced by the source. *Efficacy* is really efficiency except the units are lumen's divided by power draw in watts. An approximate conversion is 1.464 mW per lumen.

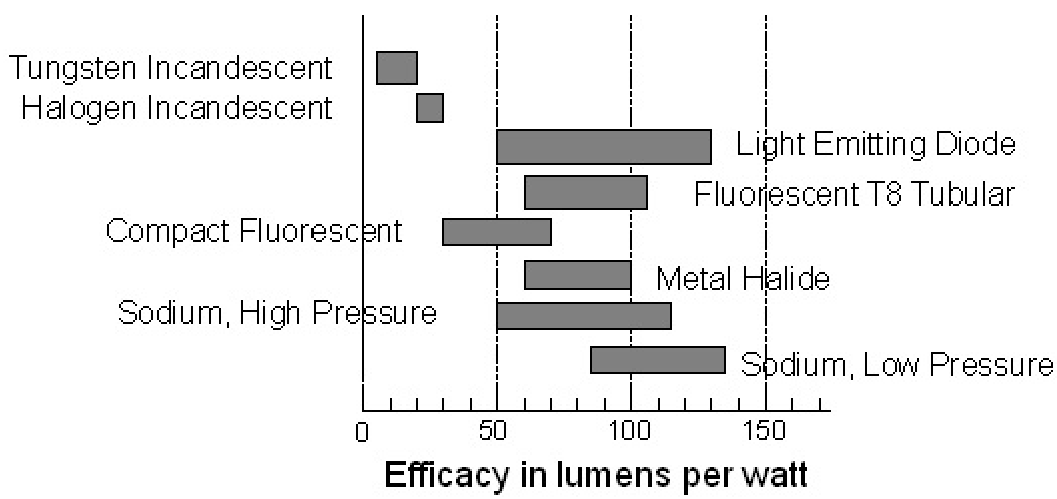

Figure 341.13 *Lamp efficacy is given in lumens per watt. Incandescent lamps have the lowest efficacy while fluorescent, LED and high intensity discharge lamps have high efficacy. LED source used for illumination purposes usually have the highest efficacy.*

Controlling Light: It is desirable to get as much of the light as possible from the lamp to the work area to be illuminated without creating negative effects. Light can be controlled and directed to the desired location using reflection and refraction. With refraction light passes through a transparent material with an irregular shaped pattern on one side to bend the light and send light in the desired direction. A refractor can have several patterns in order to obtain the desired light pattern in the work area. A disadvantage of a refraction material is that light is absorbed. Sometimes the absorption increases as the material ages.

Light can be controlled with reflection. Reflectors can be placed around a lamp that are designed to create a particular pattern in the work area. Rather than using a refractor a reflector can be placed in front of a lamp to create the desired pattern. This technique is frequently used to reduce glare in rooms where people are working on computers. Indirect lighting uses reflection where the lamps are directed towards a wall or ceiling surface that is painted white. This is a good way to create a diffuse pattern with minimal glare.

Whatever method is used to control light it is important to keep light absorption in mind. Getting the maximum amount of light from the lamp to the work area is a combination of the luminaire used and the room in which it is installed. Luminaires that prevent the entrance of dust is important in dirty industrial areas. If wall and ceiling surfaces cannot be used effectively as reflectors then it is important to use luminaires that will direct the light to the work area.

Lamp Life: Typical values for lamp life are given in *Figure 341.14.* The electrodes in electric discharge lamps sustains some damage every time the lamp is started. Electric discharge lamp life is determined where the lamp is on for 10 hour periods, turned off, allowed to cool, then turned on for another 10 hours.

LEDs produce light by passing electrical current through a small solid state device. Heat produced due to the current flow must be conducted away from the solid state device. LED sources must be installed according to manufacturer recommendations or the source can fail prematurely due to lack of proper ventilation or dust accumulation.

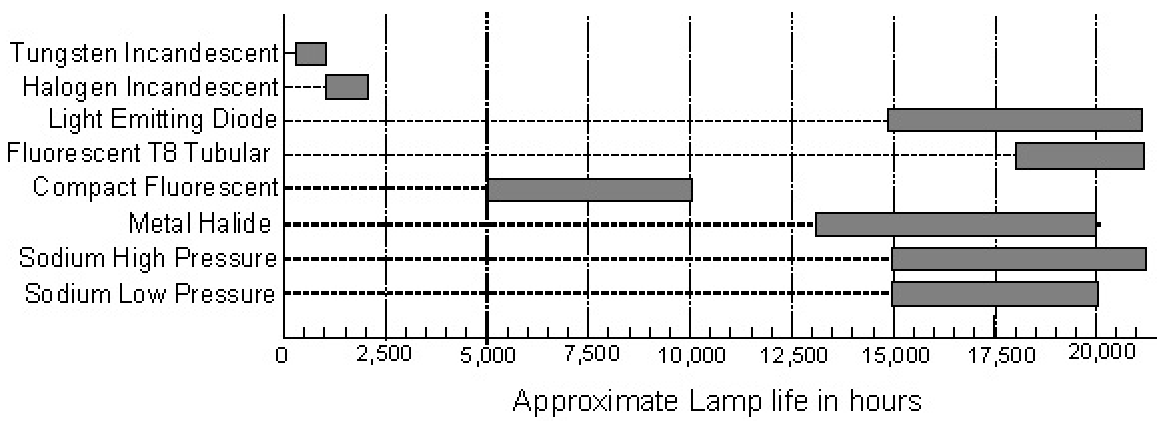

Figure 341.14 *Lamp life is the average time until 50% of a test group of lamps fail under prescribed conditions . Incandescent lamps have the shortest lamp life. Electric discharge lamp life is reduced if the lamps are turned on and off frequently. LED lamps tend to have the longest life.*

Quality of Light: Eye fatigue is frequently the result of poor quality light. Two important quality factors are contrast and glare. Contrast is the brightness of the object to be seen in comparison to the surrounding area within the field of vision. An example of poor contrast is looking at a dark object with a bright background such as a window. Because of the bright background, the iris of the eye closes to limit the amount of light entering the eye. The result is too little light to properly see the object. Eye strain can be caused by high contrast within the field of vision. For example the top of a desk should have some light and not darkness rather than dark so there will be little contrast difference between the desk and papers laying on the desk. If there is considerable contrast on a work surface within the field of view the iris of the eye will be constantly changing position due to slight head movements. This will cause eye fatigue.

Glare is a bright reflection of light in the field of view or a bright light shining in the eye within the field of view. A computer for example should be located such that light from windows, luminaires, and bright walls does not reflect from the screen into the eyes. Parabolic reflectors in ceiling luminaires will direct the light downwards rather than spreading it out across the room. This can help prevent reflection on computer screens. Luminaires with bright lamps in low ceilings can create a glare problem when a person is working at a desk. Reducing glare in the work place can help prevent eye fatigue. Dark lettering on a dark background is a common cause of contrast that result in fatigue, failure to read words, or recognize illustrations.

Lamp Ratings: In addition to lamp wattage there are a number of other lamp ratings that are important for a design or installation. For most applications it is a good idea to accomplish the illumination level with the minimum wattage. The total wattage of the lamps in the area will be converted to heat. One watt is equal to one Joule per second or 3.14 Btu per hour. Electric discharge lamps have a ballast and the total wattage is 10% to 15% higher than the lamp wattage. Wattage will also give an indication of the number of luminaires that can be installed on a circuit. Typical circuits are rated 20 amperes and the electrical code allows the circuit to be loaded to 80% which is a maximum of 16 amperes. Electric discharge, LED, compact fluorescent bulbs (CFLs) and induction luminaires will have the operating voltage and current marked on the ballast or driver. In the case of incandescent lamps and CFLs the current draw must be calculated. Divide the total wattage of the lamp or luminaire by the circuit voltage to get the incandescent load current.

Essential for lighting design is to know the light output of the luminaire or lamps in lumens. Incandescent lamps are required to list on the package wattage, lumen output, and average life in hours. The light output listed is generally the initial lumens. The lamp lumen depreciation is generally not a problem. Some lamps do have a significant lamp lumen depreciation.

Luminaire Ratings: Manufacturers will provide a considerable amount of design information about the luminaires they produce. A radiant distribution curve will give an idea of the pattern of light output from the luminaire. Another number provided for the luminaire is the *coefficient of utilization*. When providing luminaires for general illumination a common method of designing the lighting is the *zonal cavity method*. The *coefficient of utilization* is the *percentage of the light from the lamp* that will *reach the work surface* for the particular type of luminaire used plus specific room factors such as wall and ceiling reflectance and luminaire mounting height.

Spacing to mounting height ratio is important when installing luminaires for general illumination. In some areas the luminaires will be required to be mounted in a specific location. In this case if the ceiling height is low and the distance between rows is great choose a luminaire with as high a *spacing to mounting height ratio* as possible to avoid dark areas between the rows of luminaires. Assume a room is to be illuminated with luminaires that have a *1.2 spacing to mounting height ratio*. If the distance from work surface to the bottom of the luminaire is 10 ft. the maximum luminaire spacing center-to-center to avoid dark areas is 12 ft.

Lighting Design: Many factors as discussed earlier must be considered in a lighting design. Assuming a type of lamp and luminaire have been selected for an installation this section deals with the determination of the number of luminaires required to provide the desired illumination. This method assumes a relatively clean room with highly reflective ceiling, floors and walls. Under these conditions only about *one-third* of the lamp lumen output will reach the work surface. The minimum number of luminaires required can be determined using *Equation 341.2.*

$$\text{Luminaires} = \frac{\text{Room Area} \times \text{Illumination Level}}{\text{Lamp Lumens} \times \text{Lamps per Luminaire} \times \text{Light Loss Factor}} \qquad \textit{Eq. 341.2}$$

Room Area . . . . ft^2
Illumination Level . . . . footcandles
Lumens per Lamp . . . . lumens
Light Loss Factor . . . . decimal number less than one

Example: An office area has a white ceiling and light colored walls, floors and will be illuminated to a level of 40 footcandles. The room is 30 feet by 40 feet. The luminaires to be will be 3 lamp LED lay-in troffers in a suspended ceiling. The luminaires are 2 ft. by 4 ft. Each lamp has an output of 2,200 lumens. The ceiling height from the work surface to the bottom of the luminaires is 10 ft. Assume the light loss factor to be 0.33 in this case. Determine the minimum number of luminaires required for this room.

$$\text{Number of Luminaires} = \frac{30 \text{ ft.} \times 40 \text{ ft.} \times 40 \text{ fc}}{2{,}200 \text{ lumen} \times 3 \text{ lamps} \times 0.33} = 22 \text{ luminaires}$$

It will take 22 luminaires to achieve the desired level of illumination. Assume there will be three rows of 7 luminaires run the long way of the room. If the room is 30 ft. in width the spacing between the rows center line to center line will be approximately 10 feet.

Table 341.1: *Comparison of several light source capabilities used in determining the light source for different applications.*

	Incandescent	Fluorescent	Metal Halide	H.P Sodium	LED
Life	Low	High	High	High	High
Efficiency	Low	High	High	High	High
Color Rendition	Good	Good	Good	Fare	Good
Cold Environment	Good	Poor	Good	Good	Good
Immediate illumination	Yes	Yes	No	No	Yes
Instant Re-strike	Yes	Yes	No	No	Yes