The Nature of Light

Dual Nature of Light Light shows both wave and particle behavior. It might be described as separate particles, called photons, moving in groups or waves.

Light is one form of energy. It is a tiny part of electromagnetic energy, the transverse waves of which contain electrical and magnetic energies vibrating at 90^0 to each other and to the direction of wave travel. Gamma rays, X-rays, light waves and radio waves are all the same type of energy. They differ in their wavelengths and energy content.

Why We See Things Eighty % of what we know about our environment comes to us as light. We see objects that are luminous (emit light) or illuminated (reflect light). The latter are more common. <u>Transparent</u> matter, e.g., smooth flat glass, transmits light rays undistorted. <u>Translucent</u> matter, e.g., bubbly surface glass, paper, distorts the light rays as they pass through. <u>Opaque</u> matter blocks light. Many surfaces absorb light while others reflect it. (A bit of irony – although the sun blazes with light enough to blind us in an instant, it's gravity makes it sufficiently dense to be opaque. In a transparent material, a light ray travels in a straight path, but because the sun is opaque, a photon of light starting at its core travels in a zig – zag path to the surface where it escapes. The journey takes about 100 000 years!)

Light Speed Light requires no transmitting medium. Its vacuum speed is $3 * 10^8$ m/s, a value suggested by the Danish investigator Roemer in 1676 and refined by the American researcher Michelson in 1926 with his rotating octagonal mirror experiment.

Color The color of a light ray entering our eye depends on three related characteristics: frequency, energy and wavelength. Of the visible portion of the electromagnetic spectrum, red light has the lowest frequency and energy and the longest wavelength. Violet has the highest frequency and energy but the shortest wavelength.

White light is the combination of the rainbow colors - violet, indigo, blue, green, yellow, orange and red. (But, note that it is also the sum of just the three additive primaries, red, blue and indigo.) Each color has a specific frequency and energy to which our retinal chemicals are sensitive. Each color causes a different electrical signal to be sent to the brain where it is interpreted as "light".

Newton was one of the first researchers to systematically study the nature of light. His main instrument was the prism which broke a color into its components. As white light is refracted by passing through a prism, the differences in the colors' wavelengths affects the degree to which their paths bend. Long wave red is refracted the least while short wave violet is refracted the most.

The Solar Spectrum

There are an infinite number of subtle changes in color as we look through the Solar Spectrum. Many closely related colors have not been named and many more are not even distinguishable to our unaided eye. Is there any use to a CRT screen reproducing 16 million colors when we can see only about 300?

Combining Colors Colors combine in either the additive or subtractive processes. The combining of colored lights, e.g., at a rock concert light show, is described by the Additive Color Wheels. The Subtractive Color Wheels describe the mixing of pigments, e.g., paint, looking through filters.

The Additive Color Wheels **The Subtractive Color Wheels**

The colors in the large portions of the circles are called primary colors. Those in between the primaries are the secondary colors. Adjacent primaries mix to form the secondary in between. Colors opposite each other, a primary and a secondary; are complimentary and form the color (the tertiary color) at the center of the wheels, either white or black.. Also, the three primaries will form the tertiary. Note: set designers, set painters and lighting directors avoid confusion by using these terms properly.

Additive Exercises Combining lights: You are a lighting director and a performing group wants to know the results of combining various colored lights. Use the Additive Color Wheels to state the results of: red + green, red + indigo, indigo + yellow, magenta + green.

Applications of Combining Colors Additively *Ooh, How Striking!*

An important aspect of color TV development was the determination of how many colors needed to be seen by the eye in order to recreate all colors. Ideas from Newton indicated that only the three additive primaries were needed, and so, color CRT screens are a pattern of thousands of glowing microscopic trios of red, green and blue circles or bars.

George Land was a researcher at the Polaroid Corporation during the 1950's. He invented the chemistry of "instant photography." His work lead to the development of the self developing photographs taken with the Polaroid camera system. One aspect of his work also was determining the fewest number of colors required to create all other colors. He thought that sometimes only two color combinations would suffice but, as yet, the three standard colors (and sometimes more) are still used in color photography.

Subtractive Exercises Mixing paints: The director of a low budget play wants to save costs by using donated paint for set decorations. He asks you to predict the results of mixing certain paints together. Use the Subtractive Color Wheels to state the results of combining the following pigments: yellow + magenta, cyan + yellow, green + magenta, red + cyan.

Filters and Surfaces: Chemicals in colored glass and plastic selectively absorb some of the incident colors while allowing others to pass. This behavior is called selective transmission. Colored surfaces affect incident colors in a similar fashion by blocking some and reflecting others. The process is called selective reflection.

The following chart can be used to work through selective transmission and selective reflection questions.

Chart for Selective Transmission and Reflection

Incident color(s)	Component(s)	Color of filter or surface	Color(s) that could pass or reflect	Color(s) that do pass or reflect

Incident color(s) - given, (either a pure primary or a secondary with its components)
Component(s) - selected by you from the appropriate sections of the additive color wheels
Filter or surface color - given
Color(s) that could pass or reflect - selected by you; the main color that could pass is the filter's or surface's color name. Note that "leakage" colors located on either side of the main color in the Solar Spectrum can also pass or reflect. Perhaps use Caps for the main colors and lower case for the leakage colors.
Color(s) that do pass or reflect - determined just by matching the colors in the second and forth columns. Any colors found in both columns will pass through the filter or reflect from the colored surface. When matching Caps and lower case for some color, write the lower case in the last column to indicate that just a bit of that color passes or reflects.

Applications of Combining Colors Subtractively *Should We Use Bleach On This?*

Stained glass windows are a striking feature of large older churches. They are intended as an expression of both piety and of artistry. A new generation of craftspeople are rediscovering the impact of stained glass creations.

Dyeing cloth was a well developed art in the Americas when Europe was still young. Colors have always had an emotional appeal and in many early civilizations, certain shades were reserved for religious, social and military leaders. The scarcity of a color was a major factor in its association with status. For example, purple was favored by Roman leaders. A story tells of an emperor walking across a bed of snails on a beach. His weight cracked some of the shells and when fluids leaked out, they stained the bottom of his robe purple. The way of obtaining this new color was thereafter kept a "secret" from the general populous.

Types of Spectra Optical spectra can be divided into two main categories: emission spectra and absorption spectra.

Emission Spectra: there are three examples of this class of spectrum.

a) Continuous spectrum - the complete spectra with adjacent colors blending into each other. It is formed by the dispersion of light from high temperature high density materials.
b) Bright line spectrum - a series of vivid narrow sharply defined color bars set on a jet black background. It is formed by the dispersion of light from room temperature luminous gases. The colors identify which elements' atoms are in the gas.
c) Band spectrum - looks like bright line spectrum in which adjacent color bars are smudged. Vibrating molecules release this type of spectra. (Actually, atoms in the molecules release their bright line spectra but the color bars are so closely spaced that they seem to smudge.)

Absorption Spectrum: there is one example of this type of spectrum and it looks like a continuous spectrum with a few black bars where some colors are missing. It is the opposite of a bright line spectrum. It occurs when a continuous spectrum passes through as cool gas cloud. The elements in the cloud absorb certain colors, hence the missing colors. Note: if the gas cloud were heated, it would release the missing colors as a bright line spectrum. Also, if the pictures of the bright line spectrum and the absorption spectrum were superimposed, a continuous spectrum would result.

Note: to the unaided eye, the light from any optical spectrum is just some single color or blend of colors. To see the structure of the spectrum requires a prism and screen.

Applications of Types of Spectra *Did You Get the Recipe?*

One of the amazing discoveries of astronomy is the incomprehensible scale of things. A basic question posed by sky watchers is the composition of the universe. Hints about its contents come to us in the form of light. When we pass the light through a prism and examine the continuous and bright line spectra, we get a glimpse of the chemicals in the stars and blazing gas clouds producing the light. Analyzing absorption spectra tells us something about the identity of the chemicals in dark dust clouds partially obscuring luminescent bodies.

One romantic point in support of the Big Bang Theory has to do with our fascination with the night sky. The theory suggests that, like everything we see there, we too originated from star dust and so naturally feel connected in some way to heavenly objects.

Shadows Light travels in straight lines, unless bent by a strong gravity tug (rectilinear propagation.) When it is blocked, a shadow is cast behind the barrier. A tiny light source in front of a large barrier casts a jet black sharp edged umbra. A larger light source casts a grey fuzzy edged penumbra which becomes progressively darker toward the center where it becomes until it graduates into an umbra.

Another result of light's rectilinear propagation is the inversion of images in the pinhole camera. Rays from the object's top move in a downward slant through the pin hole to strike the lower inside camera back. Rays from the object's base move in an upward slant through the pin hole to strike the upper inside camera back. The image height is less than the object height. The image is real since it can be captured on a surface.

Eclipses There are two types of eclipses, lunar and solar.

a) Lunar eclipses: A total lunar eclipse occurs when the full moon passes through the shadow cone extending out behind the earth. A partial lunar eclipse occurs when the full moon grazes the Earth's shadow cone

b) Solar eclipses: When the new moon passes between the earth and sun, it casts a circular shadow on the earth. The shadow has two parts, a small, central 269 km wide jet black umbra at the center of a large circular penumbra often several thousands of kilometers wide. Also, the penumbra shows progressive darking as one moves from its edge (daylight) to the zone where the umbra starts (black.) Partial eclipses are seen by people living in areas in the path of the penumbra; a total eclipse is seen by those in the umbra's path. When the moon is most distant from the earth, it is too small to block the sun completely and those in the umbra's path see an annular eclipse – a ring of sun around the black body of the moon.

Diffraction As with water and sound waves, light can bend around corners. The result is that the edges of shadows are fuzzy not sharp. The edge blurring effect is most noticeable with a large weak light and a small barrier, both far from a screen.

Photometry This branch of physics deals with the actual and relative strengths of light sources. A photometer is a device used to compare the illuminations from a pair of light sources. A few calculations and we can compare their luminous intensities. The grease spot photometer is just an unlined index card with a grease spot in its center. It is moved to and fro between the two light sources until the observer thinks it is equally illuminated on both sides, i.e., when the grease spot seems equally bright when viewed from both sides. A paraffin photometer is a sandwich made of two paraffin blocks with a filling of light proof plastic or tin foil. It is used in the same way as the grease spot photometer. Electronic photometers are just pointed at a light source to measure the illumination.

Luminous flux This term refers to the rate at which light energy flows from a source. The unit is the lumen or lm.

Luminous Intensity This is one measure of the amount of light falling on a surface. The unit is the candella or cd. (The strength of a light, the luminous intensity, used to be compared to the light from a carefully made "standard" candle. To be more accurate, a light is now compared to the light from a layer of thorium oxide heated to the white hot melting point of platinum. The candella is now defined as the amount of light coming from a 1/60 cm^2 square of the glowing layer.)

Illuminance This is another measure of the amount of light reaching a surface. Distant bright lights seem dim; nearby dim lights seem bright. Illumination is a relative thing – distant bright lights seem dim, nearby dim lights seem bright. The unit of illuminance is lumens/m^2. (One lumen is the amount of light falling on a 1 m^2 surface 1 m from a 1 cd light source.)

Note: The luminous strength of a light is constant, but its illumination is inversely proportional to the distance between it and the illuminated surface. The luminous intensity and illuminance are related in: $I = E/d^2$, where I is the illuminance (lumens/m^2), E is the luminous intensity (cd), and d is the light-surface distance.

Interference Light waves interfere with each other just as do water and sound waves. Unlike unpredictable seas states or listening conditions, light interference results in changes in brightness and color. If two light rays shining toward a screen are directed through two adjacent narrow slits in a barrier, they become waves, interfere with each other and superimpose; the result will be alternating areas of light and of dark on the screen.

An interesting variation of interference is thin film interference. For example, dip a wire circle in a soap solution and when you remove it, rainbow colors swim over its surface. White light shines on the soap film, some reflects from the front surface of the film while some enters the film and reflects from its back. The difference in reflection path lengths offsets the reflected rays and this is the key to the formation of colors by thin layer interference. The reflected waves leaving any area of the soap film contain all the rainbow colors but the thickness of the soap film in a particular area offsets the "front" and "rear" reflected rays by a certain amount. The resulting complex phase relationships among the two sets of reflected waves allow interference to cancel certain colors while enhancing others. So, we see different colors at different locations across the soap film. The same type of rainbow effects are seen when light reflects from thin layers of oil or gas floating on water. Some modern paints rely on thin film interference for their color. Each color of paint contains millions of tiny crystals of just the correct dimensions to create the required color. These colors are very long lasting.

Polarization

A light ray is like a million long luminous ribbons all with a common axis, all moving in the same direction. If the light is white, each ribbon in a ray is a would be a different color. In a monochromatic ray, each ribbon would be that color.

Polarization is a "filtration" process in which all but one vibration plane is absorbed in some material. Light passing through polarizing plastic or light being reflected are two common ways in which it becomes polarized.

a) Plane Polarization: If we could look at the end of a light ray and see the photons' vibration planes, some would vibrate N-S, others E-W, others NE-SW, and so on. A polarizing filter or polarizer lets through only the photons that are vibrating in the plane parallel to its transmission axis. It acts as though it has numerous parallel slits which let through only one vibration plane. If a second polarizer, an analyser, is held behind the polarizer, light can pass through both as long as their transmission axes are parallel. If the analyser is turned 90^0, it blocks the light.

b) Reflection Polarization: When a ray impinges a highly reflective surface, the reflected ray contains only the vibration plane that is parallel to the surface. Glare is created when light reflects from water or the highway. Polarized sunglasses have a vertical transmission axis and since the vibration plane in the glare is horizontal, it is eliminated.

Polarization Behavior Demonstrations

1. One square of polarizing plastic.
2. Rotating the analyzer above the polarizer.
3. Birefringence with calcite crystal

Applications of Polarized Light *Oh No, It Broke!*

The use of models to predict the behavior of cars is new because they are a modern technological development; modeling buildings has a more ancient history. A problem basic to the whole question of modelling is the scale. How small can the model be and still perform accurately? For example, to a miniature boat, water is a thick gloopy material with unrealistically high friction. On the other hand, large models are expensive and time consuming to build.

Recently, computers have become the common place means of predicting the fate of a particular design. An interesting period of modelling history was the 1960's when some engineers used plastic as a modelling material. It had three advantages: low cost, ease of shaping and the effect of stressed plastic pieces on polarized light.

When a polarized light ribbon passes through relaxed plastic, nothing unusual happens. But, stress the plastic as it would be in use, and then look again. The squished plastic "grabs" the light ribbon and twists it. A plastic model construction element is placed between a polarizer and an analyzer. As the plastic is stressed, the polarized light ribbon is twisted and comes through the analyzer to be seen as a ghostly glow. Wherever the glow is seen within the outline of the plastic piece is an area of the real construction element that will be under stress in the actual construction. This visual data alerts engineers about where the construction elements would benefit from reinforcing.

Light Math

Q. What is the illumination on a surface 1.6 m from a 160 cd source?

Q. Find the luminous intensity of a theatrical luminaire that throws an illumination of 23 450 lux onto a stage surface 21.4 m away.

Q. A photometer at the 60 cm mark on a meter stick is equally illuminated by a 100 cd lamp at the 0 mark and another at the 100 cm mark. What is the luminous intensity of the second lamp?

Q. A 30 cd and a 20 cd lamp are on opposite ends of a meter stick. Where would a photometer be located to receive equal illumination from each lamp?