Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1987 Volume VI: Science, Technology, and Society

LET THERE BE LIGHT

Curriculum Unit 87.06.08
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The technologies of light production have changed the world profoundly. The twenty-four hour day has shaped a twenty-four hour economy and the lives of the industrial and post-industrial societies have been forever transformed. The relative merits of this transformation may be argued, but the suggestion that we return to the limitations of a daylight controlled existence would, at best, raise eyebrows in concern for the sanity of the suggester.

Light is the ultimate facilitator of sighted, visually educated beings. In order to better understand light, I have proposed several areas of investigation to be used in eighth grade earth science and ninth grade physical science classes. Each area will involve some instruments that relate to light and vision or some mathematics directly or indirectly associated with light technologies.

The *objectives* of this unit will be to:

1. To demonstrate the role that lighting plays in the lives of the students.
2. To demonstrate what can be learned about light by the use of prisms and lenses.
3. To demonstrate the nature of wave motion.
4. To introduce the dual nature of light.
5. To demonstrate the construction and functioning of the eye.
6. To demonstrate the principles of light manipulating devices such as eyeglasses, the telescope and the microscope, and how they extend the range of what man can see.
7. To present the background of today's light technology.
8. To investigate new light technologies and their promise and possible effects on the future of the students' lives.

When one teacher presents her strategies for the development of any unit it is with the understanding that each of her colleagues will have those gifts by which he/she will make the unit peculiarly his or her own. The strategies that I choose to employ for “light” are:

1. The chief strategy, throughout the unit will be to provide as many hands-on activities and experiences with light as possible.
2. To emphasize the importance of keeping records of experiments and investigations, each student will be required to keep a small notebook of his/her activities throughout the unit. He/she will be encouraged to expand on classroom activities through readings, short reports, and perusal of current publications, articles and news releases.
3. Throughout the unit information about scientists and philosophers who contributed to our present understanding of light will be presented to instill appreciation for that special curiosity and approach to finding answers to their questions that marks the inventive mind.
4. To use models and diagrams to represent aspects of light behavior for comparison and interpretation. Students will be required to also do some drawings of apparatus or patterns of light behavior.
5. Demonstrations will be given by the teacher for certain “labs” where it is appropriate.
6. We will use community resources whenever possible, perhaps an optician, or a speaker from the Yale Speakers’ Bureau.
7. Notes will be given periodically to give body to the unit.

Much of the optical material mentioned in this unit will be collected in a kit designated for this light study and which will be on file at the office of the Yale New Haven Teachers’ Institute Office at 43 Wall Street in New Haven. Others may be purchased through the Edmund Scientific Company, Barrington, New Jersey. A copy of their catalog is also in the kit box.

NATURE OF LIGHT

Our natural source of light is, of course, the sun. Sunlight may be examined from many approaches, but one of the most delightful experiences with light is with that of the rainbow created as the rays of white light pass through the droplets of a summer sun shower. Everyone can recall some of the colors, but perhaps not all of them, or in their correct order of appearance. To unify this experience prisms may be used to look into the light (never directly into the sun). The colors observed will finally be described as red, orange, yellow, green, blue, indigo, and violet, or ROY B. GIV. A scientist will refer to this rainbow as the spectrum of white light, so white light is actually the addition of many colors (those named). The triangular glass prism bends, or refracts the many colors, or their wave lengths, at different angles and spreads them out. Refraction is defined as the

bending of light between two media, in this case, the air and the glass of the prism. Actually, the lightwaves are bent both when they enter the glass and when they exit it. Other media will also bend the wave lengths according to the media's index of refraction. A common experience with this is the enlargement we see when an object is immersed in water in a clear glass container.

ACTIVITY: The use of prisms to determine what one is looking at as compared to what one sees. Students can estimate the angle between the two planes. A table of indices of refraction will be examined to try predicting the outcome if those media were used.

Prisms are employed in the study of light within our atmosphere, on the light from celestial bodies (our sun and other stars), and in light produced by heating elements to incandescence for analysis. One instrument used for these purposes is the spectroscope. It is comprised of a small telescope and a prism. Light is allowed to enter a tiny slit at one end, pass through a lens which arranges it into parallel rays which then pass through the prism and emerge as a band of color (spectrum). Sometimes the spectrum is projected onto a photographic plate making the spectroscope into a spectrograph.

(figure available in print form)

The longest waves (red) are about 1/30,000 of an inch long.

The shortest waves (violet) are about 1/70,000 of an inch long.

PRINCIPLE OF THE SPECTROSCOPE

Two prisms may be arranged to first break down white light into the various colors and then to unify the rays back into white light. Newton first did this in the early l8th century (1704). We will attempt it in a dark room with a different light source.

ACTIVITY : Diagram in notebook.

Other forms of light may also be examined with our prisms. We may inspect the differences in the spectrum of fluorescent lighting, or in flames produced by the burning of copper sulphate, boric acid, sodium chloride, or magnesium, for instance. Certain elements give typical color flames when burned, for instance copper, sodium, lithium, potassium and strontium. By seeing this, students may be able to project why it is possible to recognize the spectra of elements that are heated to incandescence in far-off celestial bodies.

ACTIVITY : Demonstration of flame tests and burning of some compounding solution by teacher. Chemicals should be available from chemistry teacher.

Diffraction is the bending of light around barriers placed in its path. Diffraction plates are used in newer spectroscopes. The most common experience we might have had is viewing the colored pattern when a bright light is seen through a fine screen. When we study wave action in water we will see a more concrete example of diffraction.

ACTIVITY : Examination of light behavior on a diffraction sheet.

Polarization is another characteristic behavior of light (waves). Beams of light actually emerge in all directions. By using a material termed a polarizer on a reflected source, and looking through the polarizer at different angles we may find the light "lightening" and "dimming". At one angle the light may actually be completely

absorbed. This can also be accomplished with certain crystals. This behavior indicates that if light is indeed in waves, they must be transverse waves since longitudinal waves would not be deflected by the polaroid but pass through undiminished.

ACTIVITY : Use of polaroids.

Interference is a phenomenon which is also exhibited by light. When we make soap bubbles we are creating a thin film of varying thickness and varying wave lengths will be reinforced or diminished and exhibit bands of the colors of white light. By reading through color filters students will get the idea of positive (reinforcing interference) and negative interference. Soap bubbles will be made with bubble pipes.

These characteristics and behavior patterns of light furnish us with some clues as to its nature. It would be nice in a science paper to give a definition of the subject. However, light is more primitive than any of the terms we might use to explain it. So we are describing its behavior and properties in order to compare them with better understood phenomena.

Early students of light have been quoted thusly: Plato said, “The law of proportion according to which the several colors are formed, even if a man knew, he would be foolish in telling, for he could not give any tolerable explanation of them.” c. 380 B.C. [1] Aristotle is quoted: “Color sets in movement, not the sense, but what is transparent, the air, and that extending continuously from the object to the organ, sets the latter in movement.” Aristotle, *On The Soul* , 11,7.2

Two men, not specifically in search for the nature of light, were responsible for giving others, who followed, invaluable gifts. One was Copernicus who in 1543 proposed that the sun, and not the earth, was the center of the solar system, thus setting the proper “frame of reference.” This was the heliocentric theory. Galileo Galilei, the other, in 1609, constructed a light gathering instrument which he called the telescope. In the 17th century two theories of light were proposed. Sir Isaac Newton thought of light as a beam of small particles which were emitted by all light sources and which travel in straight lines. Huygens, on the other hand, thought of the movement of light as an impulse moving in all directions of space, and with each wave generating new waves (fronts).

(figure available in print form)

ACTIVITY : Look up the definition of light in a two hundred year old encyclopedia.

This wave theory held sway for over one hundred and fifty years without modification. In the 19th century several new researchers in the field of light came forward. They included Young, George Green, and Fresnel. Fresnel, who like the others accepted the wave argument, established that the waves were transverse. He also deduced the laws of refraction and reflection in theory. Maxwell found that electrical oscillations would also have transverse wave form and would travel at the same rate as light. This established electromagnetivity as a theory and led to our present understanding of the electromagnetic spectrum.

Although Maxwell’s electromagnetic character of light gave more credence to the wave concept of light and explained many aspects of light’s behavior, we must still resort to the corpuscular, or particle, theory to understand other aspects. Those corpuscles, or particles, are now considered sophisticated discrete packets which have energy and momentum, and are termed photons. This dual nature of light exhibiting particle behavior and wave behavior is the basis of Quantum Mechanics. Many of the assumptions of Quantum Mechanics are based on findings of Einstein dating as far back as 1905 which indicated that light is

concentrated in photons when it interacts with electrons. The energy is proportional to the frequency (number of waves) of the light. All of the energy of one photon is absorbed by the electron and the photon is annihilated. Planck calculated constant of proportionality between the frequency and the energy. This is too complex for this study but students can see that the dual nature in the explanation of light's behavior has not yet been satisfactorily finalized.

ACTIVITY : Look at some pictures of the Balmer Series in Chemistry textbooks and discuss it.

Many of these characteristics of light may be explored by examining the actions of waves in water. We will use a shallow, clear glass platter evenly curved upward on the outer rim. (Clear plastic would do as well.) We will fill this with a thin layer of water and place it on an overhead projector so the waves generated will be seen as light. Wave behaviors, such as wave generation, interference, refraction, and diffraction may be observed. Students should be reminded that light waves extend in all directions from the source (three dimensional).

ACTIVITY : Lab writeup and drawings of the waves.

(figure available in print form)

1. Drop pebble

2. Drop 2 pebbles

3. Place cardboard with at same time 1/4" slit. Drop pebble in this location.

Wave length, frequency, and the speed of light can be related by the mathematical sentence C (Speed of light) = (Wave length* f (Frequency). The distance from the crest of one wave to the crest of the next (or one trough to the next) is one wavelength. It is signified by the Greek letter Iambda ( ). The number of wave lengths per period of time is the frequency. As Planck proposed energy is a function of frequency. The greater the frequency, the greater the energy. The speed of light is a constant, and is the product of the wave length times the frequency. The speed of light is approximately 186,000 miles per second or 300,000 kilometers per second. This is a good time to learn how to convert miles to kilometers by multiplying by 1.6.

MATH ACTIVITY : Find the frequency by knowing the wave length of the colors of the spectrum and the speed of light. Discuss the energy of the various colors. Are they in the order the students expected? Is red really a "hot" color? How does the energy or frequency of the wave length affect the refraction of that wave length?

Convert miles to kilometers.

Find the amount of time necessary for sunlight to reach the earth if the sun is at a distance of 93,000,000 miles sway.

Figure the distance in a light year. (The distance travelled by light in a year.)

Throughout these and other calculations students should be allowed to use a calculator and the computer to back up their work. The exponential function in the computer should be explained as well as the order of the functions of the computer. It should be impressed on the students that we use approximate values of the speed of light for convenience and that at this time the exact value of the speed of light is accepted as 2.997925+ or -0,000003 times 10^{10} cm/second. Interpret this number for them thus making a first encounter with scientific notation.

Visible light makes up a very small portion of the electromagnetic spectrum (one octave out of one hundred octaves). By examining the chart of the entire spectrum, students will discover that wave lengths much longer than those our eyes can perceive exist. They may recognize the terms infrared, radar waves, microwaves, and radio waves. On the other end past the visible range they will see there are ultraviolet, x-rays, gamma waves and cosmic waves, some familiar terms and some, more obscure. It should be pointed out that no one unit of measurement will suffice for the tremendous range of the wave lengths, so we use scientific notation. This is based on the powers of ten and the magnitude or power is more important for accuracy than the actual numerical value.,

ACTIVITY : Use of the book *Powers of Ten* to illustrate the dimensions of powers.

Consulting the electromagnetic chart, exercises in using scientific notation.

Light can be changed into other forms of energy. We have all experienced the warmth one feels in a black shirt on a hot sunny day, or sitting on the sunny side of a car with the solar insulation making us uncomfortable. The driver on the other side may not be uncomfortable at all and whether to use the air conditioner or open the windows becomes a matter for debate. A radiometer will clearly show that light energy may be changed to kinetic energy (energy of motion). Our calculators that derive their energy from light are other examples. We can also construct several devices using photovoltaic cells, such as music boxes.

How is energy lost when we produce light? If we turn on an electric light, the form of energy we wish is light. The electricity (a form of energy) is changed into light. But what else? Heat! All energy will continue to exist in one form or another. None of it can be created or destroyed. This is essentially the Law of Conservation of Energy. Students may be able to suggest other changes in forms of energy by following the path of electricity in their kitchen, for instance. They may also recognize wasted energy in inappropriate forms.

These conjectures about light are difficult to “see.” One of the limiting factors is, ironically, our connection with light and color, our eyes. How does the human eye “see?” A physiology teacher will say that the light impulses are changed to nerve impulses by receptors in the eye and are carried by the nerve fibers to the sight center in the occipital lobe of the brain where they are interpreted. This demands certain conditions. First: they eye must be so constructed that the light may reach the special cells that are the receptors and are located in the back of the eye. The light path must be through media that are transparent and translucent. By examining sheeps’ eyeballs, we may trace this path through the cornea (a type of lens), then through the anterior chamber, which is filled with a watery fluid called the aqueous humor (also a magnifier), the crystalline lens, the vitreous humor and finally reach the back of the sphere where the choroid layer acts as a shield that keeps the light from scattering and actually reflects it back to the receptors on the retina. Second: The light must be under control of some monitor so that one receives the proper amount of light. This is accomplished by a beautifully balanced set of muscles which comprise the iris, or colored part of the eye. It is innervated to open the pupil when the eye requires more light, and to constrict the pupil when the eye is receiving too much light. Third: There must be receptors to react to the light with “color” and light that can be described as “black and white” which really means shapes. The mapping of the receptors may be approximated by a simple diagram. Many excellent pictures of the rods (black and white receptors) and cones (receptors of color) are now available, thanks to the electron microscope. These visual aids and the tactile experiences of a lab with sheeps’ eyes should impress on students the suitability of the structure to the function. They can learn about accommodation and eye reflexes as well. A sheep’s brain would be helpful to show the crossover of the optic nerves and the area of sight interpretation in the brain.

ACTIVITY : Sheep’s Eyes Lab.

DIAGRAM OF THE EYE: Students should be able to match the names to the structure. The light path should be indicated by arrows.

(figure available in print form)

COLOR : Why do we see natural objects with one color or another? Why is the grass green? Newton said, "These colors arise because some natural objects reflect some rays, others other sorts, more copiously than the rest." In 1777 George Palmer said, " . . . each ray of light is compounded of three rays only one analogous to the yellow, one to the red and the other, blue." [3] In 1851 Maxwell constructed the color triangle, which is still used in art. However, only when light is composed of pure rays of light and free of our eyes' limitations can we discover that certain colors are truly complimentary, that is, when they combine they reconstruct white light.

White can be produce by combining:

Red and greenish blue

Orange and cyan blue

Yellow and indigo blue

and other combinations.

Although color can not exist without an observer, observers do not perceive identical color. Individual differences exist in color perception. Some things are the same in most peoples visual makeup. however. One area of the retina is especially sensitive to color. It is called the fovea. It actually contains no rods in some parts. The complete retina may have as many as 130,000,000 rods over the rest of its surface. Cones, the color receptors, are confined in the central part of the retina and the fovea. While the cones react to brightness and motion as well as to colors, rods react mostly to brightness and to motion in subdued light. The cones number about 7,000,000, so we find an area, small, but crowded with color receptors, each with a nerve fiber of its own. These nerve fibers are part of the optic nerve which goes directly to the brain, therefore, it is remarkably sensitive to fine detail. In the brain only a small area is devoted to peripheral vision (rods) and a large area to foveae or color vision. [4]

Although eyes are marvelous, some of them may cause the image to be misfocused, so that it does not focus on the retina for the best reception. The most common problems are:.

1. myopia—the image is projected by the lenses on a point in front of the retina
2. hyperopia—the image is projected behind the retina
3. astigmatism—improper fusion of the observed stimuli
4. presbyopia—"old-eye"—loss of the ability of the lens to adapt.

(figure available in print form)

Since we wish to have sight that is most useful, correction devices have become common. Optical devices are based on the use of lenses that refract light and therefore focus the image on the proper place on the retina, and otherwise adapt it to give the best vision possible.

ACTIVITY : Drawing of anomalies, discussion of vision and using glasses with an optician (interview on cassette), and playing with optical illusions. Charts for identification of color blindness or those in an encyclopedia should also be used.

Lesson Plan 2—Types of Lenses—Lab

(figure available in print form)

PURPOSE:

To learn the various types of lenses that are used, their diameters, focal points, f/value, and characteristic refraction patterns. To use units in both metric and English systems.

MATERIALS:

graduated cylinders, water, various lenses, rulers with markings in both systems, light sources we have constructed, (sample in institute kit,) envelopes for the lenses with the correct information about each lens. (These come with the lenses in the kit available at the institute.)

PROCEDURES:

A. 1. Partially fill your graduated cylinder with water. Draw a sketch of the top of the water line. This shape is called a meniscus. Examine your lenses to see if any are in this shape.
2. When you find it place this meniscus lens (now to be referred to as Lens #1) in your Shoebox/light source which is lying on its side. On the data table provided describe the image or images in the lens. Is it single or double? At what distance is the image most clear when you look at some letters on a page of print. Record that distance as the focal length. Please record in both inches and millimeters. Are the letters inverted backwards or normal?
B. 1. Find a lens that is flat on one side and curves outward on the other side. This lens is called plano-convex.
2. Repeat parts of procedure 2 above and record information.
C. Repeat with a lens that is straight on one side and curves in on the other. Plano-concave. What is different about this image?
D. Repeat with lens that curves out on both sides. This is Biconvex.
E. Repeat with lens that curves in on both sides. This is Biconcave.

TABLE OF INFORMATION ON LENSES

Type of Lens Image Single? Double? Normal? Diameter? Focal Length? F Value

F Value = Focal Length Divided by Diameter

Additional questions

1. Which lens is closest to those in my old glasses?
2. Return your lenses to the envelop with the correct information about type of lenses, diameter and focal length.
3. What do you think PCV stands for? PCX
What do you think DCV stands for? DCX

LENSES : *After* we have done the lab on lenses, students will draw these diagrams in their notebooks and label them and add a few notes. They may also peruse the manual and "play" with them and the optical bench and optical bench manual. One thing they may do is project an image of the writing on top of a light bulb on the ceiling with one of the larger positive lenses, thus seeing the principle of the overhead projector we have used previously in class. We will emphasize the difference between a negative, or divergent, lens which can not by itself project an image, and a convergent, or positive, lens which can project an image.

The designations of the simple lenses are:

(figure available in print form)

Further drawings should be made by the students showing the way light rays are bent by these *simple lenses* . Simple lenses are made from a single piece of glass and are used as magnifiers or condensers.

(figure available in print form)

(figure available in print form)

Meniscus Lenses

Meniscus lenses are convex-concave. If the outer curve is sharper than the inward, the lens has a positive focal length and magnifies. If the inward curve is greater, it has a negative focal length and acts as a reducer.

(Drawings courtesy of Edmund Scientific Company, Barrington, NJ) Since simple lenses are made from one piece of glass, they are taken from a surface which is part of a sphere. There are aberrations, or unwanted effects, in the refraction. That is also why we can buy second lenses at a reasonable price. Many of our glasses are made up of more than one lens and these multilens glasses may also have aberrations, so designers of

lenses are in business to prepare a lens for any given function or correction by minimizing the aberration within the restrictions of cost, size, position, loss of light, etc. [5]

The *focal point* , we may have figured out by now, is the lens-to-screen distance for the image of a distant object. The greater lens power, the greater is the concentration power of the lens. It is the reciprocal or l/f of the focal length.

In optics, a lens is defined as a device for forming an image, real or virtual, by the refraction of light. A real image is one which is where it appears to be and can be cast upon a screen. A virtual image is one such as we see in a mirror. It is not where it appears to be and it can not be cast upon a screen. Our single lenses are not good enough for most technologies. It is necessary to mount several lens elements, some convex, some concave, some of dense, high refractive and high dispersive glass, others low refractive or dispersive. [6] Lens blanks are ground by substances like carborundum, a very hard form of carbon, or curve generators equipped with diamond tools. Single vision lenses are usually in a meniscus (like the curve on top of water in a narrow tube) shape, the lens being very thin. For astigmatism, the lens is usually toric (like the shape of a section of an automobile tire). This gives two radii instead of one. [7] Ben Franklin is credited with coming up with the idea of combining a lower half lens for reading, and the top for distance . . . bi-focals. Now, lens designers either fuse two lenses or polish two different surfaces of the same lens in different ways. Of course, our students are familiar with the newer, very thin shell-like lenses that fit closely over the cornea of the eye. Hard or soft, these are contact lenses. They are usually molded in plastic material and then formed by heat and pressure to the exact shape of the wearer's eye. In this day and age, it seems almost all problems of vision can be helped. It's hard to remember that myopia might have caused hunters of early civilizations to lose their ability to hunt, let alone the limitations placed on the elderly without a means of preserving their sight.

ACTIVITY : Discussion of the limitations on students who need glasses in the classroom and don't have them or don't choose to use them. Perhaps some students would share the difference in perception, before and after, they started using glasses. (At least every student in my class is aware of my limitations without my glasses.) My own contribution would be to make the class aware that even they will need glasses at about the age of forty to make up for the failings of an "old-eye" problem.

The microscope and telescope present different requirements. For instance, the maximum useful magnification cannot extend beyond the limits of 30 times to 2000 times the size because the resolution, or clarity, is limited by the nature of light itself. For if wave motion comes upon very small objects, it bends around them (diffraction) and makes the very small object invisible. In order to get the degree of resolution required some microscopes have objectives with as many as fourteen lenses.

In order to study microscopes and telescopes we must also become familiar with the workings of a mirror. We have mentioned the virtual image that we perceive in a mirror. Mirrors, of course, do not refract, they reflect. That is, if an object is placed in front of a mirror, for every point (we'll call it P) light rays leave these points, fall on a mirror, and reflect in the same order in which they approach the mirror. The observer gets the impression that the object P is at the point P'—behind the mirror and the order of the rays is reversed. We are so familiar with looking in a mirror that we may have to be reminded that they are indeed in reverse order by holding up a sign to see that the image has reversed the letters. Therefore, the image observed in a plane mirror is as far back of the mirror as the object is in front of the mirror and it appears to be reversed from left to right. All rays would follow the law of reflection which says that the angle of incidence is equal to the angle of reflection.

ACTIVITY : Diagram of a reflected letter.

Examination of plane mirrors, making angles with mirrors, sequences of reflections, convex and concave mirrors.

ACTIVITY : Labeling of the structures in a microscope and a telescope.

Comparison with Hooke's microscope and Galileo's telescope. Attempt to duplicate Galileo's telescope with our equipment.

It may come as a surprise to students that reflecting telescopes have many advantages over refracting telescopes. First, the difference is, of course, based on the fact that reflecting telescopes principally employ mirrors and refracting telescopes employ lenses. Some advantages of reflecting over refracting are:

1. Refractors need longer tubes

2. Reflectors can have larger diameters

3. Refractors require lenses with two perfectly ground sides and reflectors' mirrors require only one perfectly ground side.

LIGHT TECHNOLOGY

Before starting on the advancements in the use of artificial light, let's examine some of human responses to light. Our eyes can respond well to one to one thousand foot-candles. [8] A foot-candle is the international unit of illumination. It is the illuminance of a surface located one foot from a one candle source. A standard candle is said to have an intensity of one candle power (cp). Therefore if a light source emits 120 times the power of one standard candle it would have a cp of 120. A surface one foot away would receive an illuminance of 120 foot-candles. We usually experience only certain ranges of foot-candles at any given time, although in an ordinary room there may be as many as fifty light sources. Our eyes are rapid in adjusting to brightness, and slow in adjusting to dimness. Our eyes prefer varying stimuli, monotony is very bad causing emotional rejection. Excessive contrast is also unacceptable. Color is important for an agreeable environment. Warm illumination is preferred and incandescent light is rated high. [9] Certain kinds of lighting such as mercury or sodium lighting can be horrible on the human complexion, making people appear ghoulish. Natural light has many subtle variations. The standard for white light in artificial illumination was decided to be that of the sunny midday in June, strangely enough, in Washington, D.C. [10] When we experience low level light (under 30 foot-candles) we prefer our light slightly pink or orange. In the higher ranges we are more comfortable with cooler light, with the bluish cast of skylight at noon. [11] These areas have been researched now that we have artificial light always with us, but choices were not always available. The illumination in use by the average person in even the more progressive countries has been with us for less than a century.

HISTORY OF LIGHT TECHNOLOGY :

When Copernicus expounded the idea that the earth revolves around the sun in 1543, man's outlook in the universe changed, even his outlook on space and his control of his own destiny were altered. Galileo's telescope, with all of its 32 power magnification, allowed him to see the moons of Jupiter, craters on the moon, and to ascertain that the Milky Way was composed of countless stars. Heavenly lights, indeed, but it remained for man to light up his own world. Open fires provided light along with warmth and protection against animals and enemies. In fact, even today, much of the light of the world is produced by open flame. The earliest lamps were to be found to be terra cotta bowls, dating back to 7000 or 8000 B.C.. Lamps have been found made of bronze and copper which date back to 2700 B.C. in Egypt. One thousand B.C. seems to have seen the advent of an oil lamp with controlled spouts and a type of wick. The Greeks and Romans had that modern technology. Leonardo da Vinci, that famous artist and innovator, used a glass chimney in a glass bowl of water around his flame to light his study area late at night. Incidentally he also used lenses to correct vision. It wasn't until 1859 that coal oil was replaced by the discovery of petroleum and many new lamps were patented. Man still had a smoke-producing, smelly light. Of course, candles of some kind went back to the birth of Christ at least. Wax candles were first used about 400 A.D. In fact, until the discovery of petroleum, candles were the only means of controlled artificial light the common man could aspire to, and then in very limited numbers, since they were always too expensive. A whole dwelling could never be lit by the average man. [12] By colonial times, every town in New England had a candle maker as one of its craftsman.

The course of lighting was different in China. The Chinese are believed to have used natural gas for lighting before the birth of Christ. Some attempts were made with gas in Western culture in the 1790's, and gas lights were installed in London in 1807. By the turn of the twentieth century gas lighting was commonly used in urban settings. [13] The use of kerosene in lamps produced an even brighter and less expensive fuel for lighting.

Progress in electrically supplied light was a contest between two main entrants, the arc-lamp and the incandescent lamp. Electricity itself had been known to be able to be transmitted and to be able to produce incandescence since Otto von Guericke generated electricity by friction and produced that phenomenon in 1650. [13] a The incandescent concept was based chiefly on filaments with a gap between them. A material which would not conduct electricity was used to bridge the gap. When an electric current was sent through the filament the nonconducting material would not carry the current, but heat to incandescence or glowing. On the other hand, the arc-light or the Jabochov candle (the hits of the Paris Exhibition, had two parallel carbon rods connected by a carbon rod or strip. [14]

When the graphite (carbon) burned away, an electric arc formed in the gap. Although it worked on alternate current and sustained itself, the arc-lamp produced a noisy hissing and the rods had to be changed every two days. Dynamos which were required to supply the electricity were now beginning to be produced and the stage was set for a new phase of light technology. The arc-lamps were not satisfactory in some respects but they were able to produce 500 candlepower and many uses were found for them. The arc-lamp and the incandescent light ran neck and neck through most of the nineteenth century. [15]

ACTIVITY : Reading by one candle-power and discussing a day and night in those conditions.

EDISON : In the year 1877 Swan made an electric light by placing a carbon rod within an evacuated glass bulb and passed a current through it. [16] A year later Edison entered the field. Thomas Alva Edison had many inventions to his credit in his early field of telegraphy and some new areas such as his phonograph, a real

sensation. On a field trip to recover his health he was inspired by the interest of Professor Barker who was keenly interested in the possibilities of an electric light. Edison went to Ansonia, Connecticut to view his first arc-light when he returned East. He was very excited when he recognized that for all its wonder, it had not yet been made practically useful. “The intense light had not been subdivided so that it could be brought into private houses.” [17] He dismissed gas thusly, “Gas will be manufactured less for lighting as the result of electrical competition and more for heating.” [18] How astute! He stated his objective in his notebook, volume 184, “Object, Edison to effect exact imitation of all done by gas. so as to replace lighting by gas by lighting by electricity.” It was easier said than done. It took his group from the autumn of 1878 until October 21, 1879 to find the right filament after trying carbonizing over 20 materials. [19] He decided on a voltage around 100 (110) because he found it the most economical. He decided on high resistance lamps because they cut down on the use of the very expensive copper. On October 21, he filed a patent for his carbon filament lamp which he had tested to the criterion of 40 hours of burning. It was the famous number 9 lamp.

He described it as “an electric lamp for giving light by incandescence consisting of a filament of carbon of high resistance . . . enclosed in a receiver made entirely of glass and conductors passing through the glass and from which receiver the air has been exhausted . . . .With a carbon filament or strip coiled and connected to electric conductors so that only a portion of the surface of such conductors shall be exposed for radiating light.” [20]

> However, “few people realize that he was also an astute promoter who, in order to gain acceptance for his lamp, had to invent dynamos, cables, insulators, conductors, voltage regulators, junction boxes. meters, fuses and fittings, everything, in fact,” [21] for a whole technology.

Lesson Plan 2 *LIGHT BULBS*

PURPOSE : To look more closely at the makeup and function of light bulbs and other parts of our lighting systems.

MATERIALS : Make-up mirror (if possible), new and used light bulbs, some clear and some smoked, one or two lamps, fluorescent light (usually source of classroom lighting), black light (if available), some cut wires from discarded appliances, wrappers from light bulbs.

> A. *TEACHER DEMONSTRATION OF A CIRCUIT* : Childrens’ toy where toy runs backwards when the batteries are in reverse position and with a single switch, 6-volt battery, leads, electrodes, large beaker 1/2 full of distilled water, one 1/2 full of salt solution, testing light.

PROCEDURE:

> 1. Show students that a circuit is necessary to have electricity useful.
> 2. Indicate the purpose of a switch to break a circuit.
> 3. By reversing the batteries show that the circuit may be made to flow in the other direction.
> 4. Set up a circuit with the distilled water first, then with the salt solution (with ions of different potential present). Emphasize that in the case of the distilled water the water acts to break the circuit and that the ionized solution completes the circuit.

5. Discuss circuits in the class, circuit breakers, and fuses.

B. STUDENT PROCEDURES:.

1. Students should examine electric wire from old appliances to see that it actually is two wires that set up a circuit through the appliance.
2. On a working lamp, students should trace the circuit, indicate the switch and draw the route. (Show electrical circuit drawings.)
3. Students should observe the use of new and used, clear and smoked bulbs.

Questions:

a. What can you observe about the used up bulb?
b. Why do you think people prefer the smoked glass in the bulb?
4. Examine the makeup mirror.

Questions:

a. How do the different lights affect your image?
b. Which one would you prefer to be seen by?
c. Which one woulever produced more entertainment and memory storage than photography. The transmission of images is direct contact with the thoughts of others. Actually, photography predated Edison's work in light technology but he later made outstanding contributions to its development, and to the motion picture. Photography itself is the projection of visible images on to sensitive surfaces, directly or indirectly, by the action of light. The sensitive surfaces are usually prepared with silver compounds. In some cases a ectricity?
c. Do you think the inner parts would work without the glass bulb?
d. Do you think the bulb was filled with normal air? e. Did the glowing part *burn* ?
7. Examine the cover of a light bulb package.
8. List the information it gives.

Questions:

a. What is a lumen.
b. How many watts would there be in a kilowatt?
c. How many hours is the bulb estimated to be good for?
d. How many did Edison use as a test for the first light bulb?
e. We measure our electricity use in terms of kilcwatt hours. How many kilowatt hours would you estimate this bulb is expected to use before it “burns out”?

Watts times hour = Kilowatt-hours

1000

(figure available in print form)

ASSIGNMENT : Write to General Electric for information about the light bulb’s discovery and on how they are presently produced. Also ask if there are any educational aids available for our school system.

PHOTOGRAPHY : Perhaps no technology has ever produced more entertainment and memory storage than photography. The transmission of images is direct contact with the thoughts of others. Actually, photography predated Edison’s work in light technology but he later made outstanding contributions to its development, and to the motion picture. Photography itself is the projection of visible images on to sensitive surfaces, directly or indirectly, by the action of light. The sensitive surfaces are usually prepared with silver compounds. In some cases a printout (polaroid, for instance) is the result. More often an invisible image is stored on the film and it is later developed by processing.

(figure available in print form)

ACTIVITY : Prepare a list of questions on photography. Demonstration by an amateur photographer or a visit to a dark room. Darkrooms could be of a professional photographer or at a school or college that offers photography as a course (Southern?) (E.C.A.?).

ASSIGNMENTS : To find out more about the scope of photography today. Students will be required to give reports from these headings from the Encyclopedia Britannica. They include: Photography through a microscope, Spectography, High speed photography, Infrared photography, Astronomical photography, Criminology and photography, Medical photography, Polaroid, Aerial photography, Photographic telescope, Celestial photography [23]

ACTIVITY : This would be an excellent time to show a movie and/or a VCR film on Edison or some other pioneer in light.

NEW TECHNOLOGIES :

Three new and often interlocking technologies of light with tremendous potential are LASERS, FIBER OPTICS and HOLOGRAPHY. Light brings us energy in a diffuse state. All the frequencies of the electromagnetic spectrum are jumbled together causing overlapping and interference. Einstein predicted forty-five years before the first laser that such a device could be made. He said that if electrons within an atom were excited (by infusion of energy) and were struck by an emitted photon, that excited electron would drop down to a lower energy level, and emit a photon in the same phase and moving in the same direction. These photons are now considered as having no mass, but behaving like particles. These photons released are now sent out in only one frequency, and the waves are positively reinforced. Thus, the laser (Light Amplification by Stimulated Emission of Radiation) acronym.

The atom, which has been taught in both the courses this unit pertains to, has its electrons arranged in a definite pattern of shells. The arrangement is that which requires the least energy, and therefore is the most stable. When the electrons are excited by an energy source these electrons may jump to a higher shell. They immediately release their new energy as photons and drop back down to that *ground state* .

The first successful laser was a ruby crystal with mirrored ends. Actually impurities of chromium make a ruby, which is aluminum oxide, take on its deep red color. A flash lamp provided light energy to be absorbed and thus the chromium atoms were excited. When the excited electrons within these atoms returned to their ground state, the emitted photons struck the mirrors, were reflected to strike more atoms, and thus the numbers were multiplied and the radiation was amplified. The radiation eventually became so intense that when it finally “escaped” it was an unbelievably pure ruby light. The scientist who first accomplished this breakthrough in light technology was Theodore H. Maimon, in the year 1960. [24]

The steps in the action of any laser are:

1. Atoms are excited.

2. Photons are emitted.

3. They are reflected back and forth.

4. A powerful beam is emitted. [25]

(figure available in print form)

Perhaps the most common laser the students encounter is the helium neon laser in the checkout counters at the supermarket which “reads” prices.

All laser lights are intense, directed and pure. The media may be crystals, glass, gases or liquids. The energy sources may be high intensity light, electricity, or nuclear radiation. The range of the frequencies has been extended from microwaves through the visible spectrum to ultraviolet and x-rays. Lasers can concentrate great power, equal to millions of watts and can also produce great heat. They are harnessing light, a basic form of energy, and they are the basis of a revolution in the use of energy. They can be directed very precisely. Their characteristics and their range of frequencies enable their use for such wide spread operations as bloodless surgery, precise and rapid measurement, tremendous strides in communication, even the ability

to probe the ocean and the atmosphere. Unfortunately. their potential for warfare and military expansion is awesome. [26]

FIBER OPTICS : Lasers are used as the transmitters in another new technology, or tool of light, fiber optics. Fiber optics are also referred to as lightwave transmission. The glass is the clearest in the world free of almost all impurities. The fiber is densest in the middle, and less dense on the outside. This area (outside) is called cladding. The sides of the fiber reflect the light and keep it inside even as the fiber twists and bends, thereby giving total internal reflection. The light sources are usually very small lasers that flash on and off sending messages. The frequencies of the light usually used are in the infrared range. [27]

Fiber optics are being used in communications (phones particularly) and medical photography (endoscopy), for connecting computers, video-telephones (Japan) and television and holography.

HOLOGRAPHY : Holography is the production of three dimensional photographs. The word holograph means "Whole message." Holography can actually work with any waves. First developed by Dennis Gabor to improve the electron microscope, the electron beams probe in all directions on an object getting all the information. This complete pattern it produces could be called a wave front but it produces no image or picture. However, when this wave front intersects with a second set of light rays—a reference beam—the wave front can be recorded and later reconstructed by the proper illumination. When we see it from the right angle we see the entire object. [28]

ACTIVITIES : Find Science World articles in last year's issues on these new technologies.

Viewing a light show if possible

Display of holograms

See fiber optics' transmission of light with fiber optic samples

VOCABULARY LIST—WORDS OF LIGHT

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astigmatism -a defect of vision commonly caused by irregular shape of the cornea (characterized by blurring)

diffraction curvature of waves around objects in their path Example: light rays through slits produce fringes

electromagnetic spectrum the entire range of wave lengths or frequencies of electromagnetic radiation from shortest gamma rays to longest radio waves where light comprises only a small part of range

fiber optics strands of clear material, glass or plastic which transmit images

fluorescent characterized by the emission of visible light as the result of radiation from some other source

focal point point of convergence of rays of light

frequency the number of complete oscillations per second of any component of an electromagnetic wave

holography study of or production of three dimensional images

hyperopia farsightedness, caused by focus of image behind the retina

incandescence the glowing of a body due to its high temperature

laser light composed of light of one wave length, coherent light

lens a piece of glass or other transparent material that has two opposite regular surfaces either one curved and the other plane or both curved used to form an image by the focusing of light rays

myopia -nearsightedness, caused by the image being focused in front of the retina

polarization process of affecting light or other transverse waves so the vibrations are confined to one plane

polaroid material that polarizes, used to prevent glare in optical devices

presbyopia condition of defective elasticity of the crystalline lens of the eye (usually in old age) resulting in poor accommodation and inability to attain a sharp focus of near vision

prism a transparent body bounded in part by two plane surfaces that are not parallel used to deviate or disperse a beam of light

physiology the study of the function of the body

Quantum Mechanics a general mechanical theory dealing with the interactions of matter and radiation in terms of observable quantities only (as the intensities and frequencies of spectral lines)

receptors parts of the body that are especially sensitive to some environmental factor (as light or sound waves)

reflection the partial or complete return of a wave motion from a surface

refraction the deflection from a straight line undergone by a light ray or a wave of energy in passing obliquely from one medium into another

spectroscope one of various instruments designed for forming and examining optical spectra

(figure available in print form)

Material List

Many of these materials will be available in an assembled kit available at the Yale New Haven Teachers' Institute Office at 43 Wall Street.

Light sources

Equilateral prisms

Color filters

Lens set

Fresnel lens

Optical clamps

Meter sticks

Rulers

Mirrors

Shees' Eyes for Lab (available through Carolina Labs catalogue)

Polaroids

Diffraction grating

Fiber optic samples

Instruction booklets from Edmund's Scientific

Lamps (2)

Light bulbs (new and used.

Notes

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3. MacAdam, p., 49.

4. Faber Birren, *Light, Color and Environment* (New York, 1969), p. 21.

5. Donald Clark (ed.), *The Encyclopedia of How It Works, from Abacus to Zoom Lens* (New York, 1971), p. 132.

6. Clarke, p. 130.

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8. Birren, p. 23.

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10. Birren, p. 25.

11. Birren, p. 24.

12. Cyclopedia Britannica, "History of Light," *Vol. 14* , p. 1 and 2.

13. Encyclopedia Britannica, Vol. 14, p. 2.

13a. Encyclopedia Britannica, Vol. 14, p. 3.

14. Robert Silverberg, *Light for the World* (Princeton, 1967), p. 75.

15. Silverberg, p. 90.

16. Silverberg, p. 115.

17. Silverberg, p. 90.

18. Silverberg, p. 91.

19. Silverberg, pp. 124-125.

20. Silverberg, pp. 126-127.

21. Silverberg, (inside cover).

22. Encyclopedia Britannica, "Photography," *Vol. 17* (Chicago, 1969, p. 944.

23. Encyclopedia Britannica, *Vol. 17* , pp. 951-955.

24. Boraiko, Allen A. (senior editor), "The Laser, A Splendid Light for Man's Use," *National Geographic* , Vol. 165, No. 3, March 1984, p. 335.

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28. Boraiko, Vol. 165, No. 3, p. 366.

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Attractive presentation of human response to color and light both emotional and psychological. Some good tips for their use.

Galilei, Galileo. *Discoveries and Opinions of Galileo* (translated by Stillman Drake), Garden City, New York, Doubleday and Co., Inc., 1957.

Primary Source.

Hastings, Charles S. *Light* , Cambridge: University Press, 1901.

An older simply written book, delightful for comparison.

van Heel, H. G., and Velzel, C. H. F., *What is Light?* , New York: McGraw-Hill Book Co., 1968.

Several ;chapters are clearly written explaining light phenomena in usable terms. Good diagrams and illustrations.

MacAdam, David L. (ed.), *Sources of Color Sciences* (Essays), Cambridge: The M.I.T. Press, 1970.

Collections of writings on color, mostly abridgements, from Newton to 1947 dealing mostly with physiology of optics.

Morrison, Philip and Phylis, *Powers of Ten* , New York: Scientific American Library, 1983.

Murphy, James T., *Physics, Principles and Problems* , Columbus, Ohio: Charles E. Merrill Publishing Co., 1982.

Good standard secondary physics text.

Silverberg, Robert, *Light for the World* , Princeton: D. Van Norstrand and Company, Inc., 1967.

Taylor, A. M., *Imagination and the Growth of Science* , New York: Schocken Books, 1970.

This small volume explores the qualities necessary for scientists who make breakthroughs: inspiration, imagination, boldness and perserverence. It includes short biographies of sixty-four such men.

Williamson, Samuel T. and Cummins, Herman Z., *Light and Color in Nature and Art* , New York: John Wiley and Sons, Inc., 1983.

Very up-to-date book on the subject, good for those who wish to study the subject in an attractive volume. Extensive, and expensive.

Wright, W. D., *The Rays Are Not Colored* , New York: American Elsevier Publishing Co., 1968.

Series of lectures prepared by a learned member of a color “group” on the philosophy of color. The last chapter is particularly interesting as it discusses an approach to teaching color (not as a branch of physics).

Articles:

“Image, Object and Illusion,” Reading from *Scientific American* , San Francisco: W. H. Freeman and Company, 1974.

One very useful article, others were too complex for our study.

Boreiko, Allen A., “Miracles of Fiber Optics,” *National Geographic* , Vol 156, No. 4, October, 1979.

Outstanding presentation of a new technology.

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Colorful, well diagrammed presentation, excellent photography.

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Mueller, Conrad G. and Rudolph, Mae, *Light and Vision* , New York: Time-Life Books, 1975.

Excellent visual material for both students and teacher.

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Simple book, not too technical. Mostly about applications of lasers.