Illuminating the History and Expanding Photonics Education

An Interactive Qualifying Project

submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfilment of the requirements for the

degree of Bachelor of Science

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Date:
2nd June 2020

Report Submitted to:

Worcester Polytechnic Institute
Quinsigamond Community College

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Abstract

Photonics today is on the cusp of revolutionizing computing, just as it has already revolutionized communication, and becoming to this century what electricity was to the last (Sala, 2016). As the manifestation of mankind's millenia-spanning obsession with light, photonics evolved from optics, which itself developed over the long course of human history. That development has accelerated in the last several centuries, and today optics and photonics act as enablers for a variety of fields from biology to communication. Even so, most people don't know just how essential optics and photonics are, and today those fields face a major staffing shortage. Most people don't even know the basic principles of light's behavior, with few formal education programs that focus on optics and photonics.

In order to combat this, various initiatives have strived to drum up more interest in optics and photonics, with several focusing on pre-college age groups in order to get students involved sooner. To contribute to this effort, a partnership with the Boy Scouts organization is recommended. Given Boy Scouts focus on youth involvement and development, and current pivoting towards STEM skills, it seems like an obvious choice. For this purpose, a proposed 'Optics and Photonics Merit Badge' is a focus of this project, including requirements, educational materials, and criteria for awarding it. The idea is that these scouts may go on to pursue a career in optics and photonics, becoming the next generation of engineers, scientists and technicians that the industry needs.

Acknowledgements

Professor Douglas Petkie was the primary source for editing and review for this report. He looked over various parts of this report, both individually and in conjunction, and provided feedback on how they could be improved. Additionally, he provided necessary insight into what the final report might look like, at various points advising on how to proceed. In many ways, he was essential to determining the final form for this report, and it may not have been possible without him. Furthermore, he provided significant guidance earlier in the IQP process before the report took shape; for example, he was the one who originally introduced the two project partners who would work together on this project, and recommended their collaboration.

Executive Summary

Light has been a recurring obsession for mankind for millennia, and our understanding of it has evolved greatly over that time. Initially only philosophers, theologists and artists attempted to make sense of the light and understand its nature. But then, the very first scientists began to take light into their laboratories, and started unraveling its mysteries. Our understanding of light progressed from antiquity, through the Renaissance and the Enlightenment and into the modern day. Optics, the science of the transmission, reflection, and behavior of light was born, and we began to bend light to our will. But eventually, our increasing understanding of the nature of light as radiation and the discovery of its base particle, the photon, necessitated the development of a new field, photonics (Watson, 2016).

Today, optics and photonics employ light in ways the ancients could never have imagined, enabling many other fields of science and aspects of our everyday lives. From biology to communications, microscopes to fiber optic cables, optics and photonics underpin many things in our world. This is poised to grow only more true as this century continues; photonics is expected to be what electricity was to the prior century (Sala, 2016). Photonic Integrated Circuits (PICs) are expected to replace their electronic counterparts (EICs) that underpin modern computing, bringing about vast improvements in performance, speed, and more. Monolithic integration-the combination of photonic sources, processing, and transmission onto a single device-has proved a sticking point, but photonics may face an even more pressing obstacle going forward.

Despite its great importance to the whole of human society, many people do not know much about light and the principles that govern it; some do not even know its basic principles. Perhaps due to their role as enablers, optics and photonics are often overlooked in everyday life, and most people do not recognize their importance. As a result, these fields are suffering from a severe shortage of talented, dedicated students entering into their professions. The problem is not only a lack of educational opportunities; university classes on the subjects often go under attended, and several have had to close down due to lack of students (Loven, 2001). The problem is getting prospective students in these subjects interested and invested in optics and photonics. To this end, various programs have sprung up aiming to get kids interested in these areas at earlier ages.

This project proposes one such program, a partnership with the Boy Scouts organization to create an 'optics and photonics merit badge'. Created to help get young boys outdoors more, today the organization is pivoting towards more technical skills. In Boy Scouts, boys advance through the ranks by earning merit badges, each representing their study of a particular area. Introducing an 'optics and photonics merit badge' seems like a great way to introduce young boys to the field at an early age, hopefully setting the stage for a future career. Within this report are the details of this proposed merit badge, including requirements, experiments, background information, and more.

Authorship

This project was authored by Nicholas Marshall and Brandon McLaughlin, students of Worcester Polytechnic Institute.

Contributions by Section

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Introduction

Despite its wide-ranging applications, the field of photonics remains chronically understaffed, and the public at large seems largely uninformed. Photonics companies often struggle to find qualified employees, and many have taken to training new hires in-house, in order to fill their own demand. Perhaps this is due to a widespread underestimation of the importance of photonics to our wider world. Much like light travelling through the air is invisible until it hits our eye, we tend not to know how essential the field is to our modern world until it is called to our attention. Maybe as a manifestation of public disinterest, many college programs on the topic remain under attended, with several closing as a result (Loven, 2001). While many students seek to go into medical, electrical or mechanical, very few seem to seek a career in photonic engineering.

Attempts to stir up some interest in this largely overlooked field are currently ongoing; governmental, public, and private initiatives aiming to do just that have cropped up in recent years. Initiatives such as the AIM photonics academy endeavour to engage students with optics and photonics at all levels, K-12 through PHd, including technical programs for integrated photonics (*aimphotonics.academy*). Other endeavours, such as the recent partnership between the Massachusetts government and several colleges in the area to establish Labs for Education & Application Prototypes (LEAP) also aim to push the frontiers of this technology forward (Wallace, 2020). (Note: WPI is one of these colleges, and recently established a LEAP laboratory for integrated photonics.) This is nothing new; formal optics education in the US is said to have started with the announcement of a new Optics department in the University of Rochester in 1929, and has continued for almost a century since (Thompson, 1991). While several target the college-age demographic, many seem to have set their sights at K-12, aiming to get kids interested in the field at an earlier age. For instance, the ‘colors of nature’ initiative seeks to use art in order to teach optics (Pompea, 2015), among other subjects, as part of a larger push to get girls involved in STEM education. It makes sense; many students attending college already have an idea what they want to be when they graduate, and did when they enrolled. Why not put this idea into their heads when they are still younger, and let it have time to grow? STEM initiatives targeting k-12 are already ongoing, but what more ways are there to reach these future engineers? (Perhaps the NGSS could add it to one of their three dimensions of science learning, or maybe as a new field of interest (Next Generation Science Standards, nextgenscience.org).)

With that, we take our discussion on to the Boyscouts organization and their merit badges. Initially founded to get kids outdoors and teach them to ‘man-up’, Boyscouts today is going through a bit of a crisis. In our increasingly technical world, outdoorsy skills like camping and starting fire have become somewhat outdated. Youth today seems disinterested in learning to ‘rough it’ in the great outdoors, and their parents see learning technical skills like programming to be a more worthwhile use of their time. The Boyscouts organization struggles to attract a new, younger audience, and has added many merit badges in more technical areas, such as nuclear engineering, to cope. Why not kill two birds with one stone, and add one for photonics as well?

Within this packet is outlined this suggested ‘optics merit badge’. It goes over topics such as safety, the nature of light/photonic, and how to use them, as well some basic experiments to demonstrate the base principles of the field. Additionally, it contains the requirements to earn the merit badge, guidance for the instructors on how to proceed, as well as information on careers in optics. Also, some of the basic technical knowledge and equipment used in the field are introduced as well. For the next generation of photonic engineers, scientists, and technicians it should serve as a good introduction to the field.

But before that, it will go over the journey of light's discovery and exploration, which began with faith, developed into optics, and was refined into photonics. A history steeped in theology, theory, artistry, experiments, engineering, innovation, and creation. The tale travels across time and the Earth, from the philosophers of antiquity to the European Renaissance, Enlightenment, and beyond. Details of our fascination with light, and how it has followed us, inspired us, and guided us to today. Light's descend, from divine, to secular, to scientific, to tool, to a commodity; the history of how we discovered light's principals, and how we've used them (Watson, 2016).

Today, we can use photons to imprint patterns and run computers, and we are on the cusp of a computing revolution where they will replace the electrons in our circuits. Photonic Integrated Circuits (PICs) are heralded to be the natural successor to the Electronic Integrated Circuits (EICs) we use today (Sala, 2016). Already, photons carry information through fiber optic cables, much as electrons did in the telegraphs of old. The laser, an invention of the twentieth century, once called 'a solution looking for a problem', now has thousands of applications (Watson, 2016). College campuses across the country and the world offer photonics degrees, and a multi-billion dollar industry, with applications in almost every area of modern life, has developed. From communications to computation, transportation to medical applications, photonics and its uses are all around us. Massachusetts is among the most active areas in the world in the photonics industry, and our campus, WPI, recently added a LEAP photonics lab to facilitate further cooperation and innovation with companies in the area (*wpi.edu/+LEAP*).

Background

The History of Light, Optics, and the Origins of Photonics

Ever since the dawn of civilization, light has captivated humanity. It plays a predominant role in all our creation stories, and every year dozens of festivals about light take place across the world. It has taken three thousand years of our brightest minds to unravel its secrets (Watson, 2016). Even the great Galileo, storied though he was, never got the full story about light. Today, light has been commoditized, secularized, and commercialized, but it was not always this way. Once, light was a rarity, a luxury, a divine source. "Unlocking its secrets required an uncommon set of keys. Curiosity. Persistence. Mirrors, prisms, and lenses." (Watson, pg. xiii) Quantifying light took away some of its wonder, but even then poets and artists struggled to keep light mystical and alluring. But in my opinion, understanding the light does not diminish it, but emboldens it. There can be no more ennobling or enriching act towards the light than to understand it.

Today, light is still celebrated. Tens of thousands show up every year to watch the sunrise at Stonehenge on the summer solstice. It holds a place of privilege in all our creation stories, usually divine and perfect in its origin. Even in our modern understanding of the big bang, light is still prominent (Watson, 2016). The exact source of light still varied. In some tales, light was eternal, and it was darkness and night that had to be explained. Sometimes it came from within. Typically it was associated with joy, and greeted with reverence upon its emergence. Eventually, the written word would emerge, and all major world religions would make it a point to praise light, to varying degrees. No matter how hostile theological debates would become, light would always be universally revered.

The first to truly ponder light in an academic sense were philosophers, and they were an odd lot by and large. Though their actual 'discoveries' were questionable, and many still fell back on creation myths in their thinking. But eventually, they would set a more rational tone for discussions to follow, though scientific discussion was still a long way off. "And slowly, study by study, the divine light of creation met its match in human curiosity." (Watson, pg. 15) Empedocles, in the fifth century BC, was the first philosopher to dedicate himself to the study of light, although he could not decide whether it entered or exited the eye. Great thinkers traded jabs and theories across cultures and centuries (Watson, 2016). Such a distribution of thought is natural, for light is democratically distributed; every place on Earth gets the same number of hours of sunlight per year. From ancient Greece to India to China, various theories emerged. Aether theory, the idea that there was an invisible fluid that filled the space between worlds, became a favorite, at least until it was disproven in 1887.

Eventually, a new light would pave the way for what was to come. Beneath the glow of the Lighthouse of Alexandria (built in the third century BC), many discoveries, inventions, and fields of study developed, with optics among them. First codified in Euclid's *Elements*, light was brought into the realm of numbers. Ptolemy and later thinkers would later take these efforts into their own laboratories, building on Euclid's work with *Optics* and the like. In many ways, by explaining themselves and their discoveries, the students of light were far ahead of the rest of the world (Watson, 2016).

Even so, within the common mind, light remained the stuff of scripture and divinity, especially after the birth of Christ. From greatest religion to smallest cult, light was, if not god, than his self-portrait. The first major world religion, Zoroastrianism, believed god was light.

Though eventually devastated by rival religions and reduced to a shadow of its former self, today its new year is still celebrated with fervour in Iran. Buddhism, Hinduism, Christianity; all major religions would heap boundless praise upon the light. Visions of the light, called photisms, would inspire many prophets, preachers and believers over the years (Watson, 2016). Theological debates and conflicts would claim countless lives, the love of the light leading to some of humanity's darkest moments, as well as providing quite the obstacle to anyone seeking to study it in a secular sense.

During Europe's Dark Ages, Baghdad and Islam kept the light of knowledge and innovation alive. Theirs venerated light like no empire before, becoming both their symbol and a means of power projection, every avenue used to express and embolden it. “The various dynasties of Islam struggled for revenge and control, yet all agreed that light was to be cherished. Their holy book, sometimes called al-Nur, The Light, told them so.” (Watson, pg. 40) Even so, light was not as relished in the Qur’an as it was in other scriptures; being written by a single man, there were no disciples competing to heap praise upon the light. And unlike the Christian church at the time, the Islamic empires strove to study lights properties instead of just its theology (Watson, 2016).

Arabic philosophers would pick up where Greek ones had left off in their study and speculation of light. Later, as the Islamic empire fractured, the center of learning moved to Cairo, where light once again entered the laboratory. Ibn al-Haytham would determine, with finality if not definitively, that light did not emerge from the eye, as well as solidifying the study of optics. Although long dismissed by the west, Islamic optics laid the groundworks for the works of Kepler and Newton, setting the stage for the revolution therein. By adding experiments and subtracting speculation, they collected and refined the greatest thinking about light. Unfortunately, by the 1100's, Islamic patience for science and experimentation ran dry, and with religious conflicts like the Crusades soon to be in full swing, such secular endeavours met a swift end (Watson, 2016).

Meanwhile in Europe, light was not lost, even if its study was briefly abandoned. Abbot Suger remade Saint-Denis into the first gothic cathedral, and many others followed suit. They brought light and wonder to churches everywhere, ready to be read even by the illiterate masses. Later, in the thirteenth century, monasteries and monks took up the torch of optics from the Muslims. Though studies were as much theological as secular, theories began in this time that would be developed for ages to come (Watson, 2016).

Through the 1400s the Renaissance bloomed, and artists struggled to capture light on canvas. Long before Leonardo Da Vinci was born in 1452, artists had been struggling to tame the light. Books had already been written on the subject, but Leonardo was the first to really begin mastering light in art. He would not be the last; in the late 1500's and early 1600's, an delinquent artist named Cravaggio would bring the brightest lights and depths of darkness to new heights, and his style would prove infectious. In the 1600s, a Dutch artist, Rembrant, would follow in Cravaggio's footsteps, capturing light and shadow more elegantly than any had previously (Watson, 2016). He would perhaps be aided in these efforts by the camera obscura; a crude instrument, little more than a dark box with a hole and a lense, but being an essential precursor to photography.

Meanwhile, the study of light began again. In the century of Celestial light, beginning in November 1572, an unprecedented series of astronomical events would shake the world from the heavens, and Renaissance men would struggle to explain such phenomena. A century of religious rivalries, fledgling science, and widespread superstition, inquiry was ascendant, but ignorance was not going down without a fight. So-called 'natural magic' still provided a problem for students of logic, many of whom were not immune to its call. Even so, names like Kepler and Galileo would emerge to help lead people away from the dark ages (Watson, 2016). Descartes would champion skepticism and science, though he would fail to strip light of its wonder. "Centuries later, the complex science of optics has yet to dampen the marvel of light." (Watson, pg. 91) Even so, by the end of the age, as cities started lighting their streets to fight back the night, 'natural science' had gone the way of the dodo.

Next would come Newton, who would greatly contribute to the modern study of light, eclipsing perhaps all others with his papers, among his other notable contributions to science. During his year of prisms in 1666, he would unravel the mysteries of color, which had confused thinkers from Greeks to Romans. Indeed, he explained the behavior of particles of light so eloquently in his theories that they would stand through the eighteenth century (Watson, 2016). But petty rivalries would silence his discoveries for the rest of the century, as his *Opticks* was only published in 1704. Like most scientific theories, those about light advanced incrementally, creating feuds, fierce debates, and only slowly changing the paradigm. Debates of his theories would outlive Newton himself, though he would be remembered fondly. But though he reigned as godlike memory in the enlightenment, by the end of the eighteenth century, the Romantics would make Newton their nemesis. Musicians, artists, and even some scientists, some sought only to restore light's mysticism, though others loathed Newton for reducing the wonder of the natural world to mathematics. Eventually though, their only major achievement would be romanticising the moon (Watson, 2016).

However, that is not to say that they did nothing of value or note; in praising the light, they produced numerous notable works in all forms of art. It began in 1798 with Joseph Haydn's *The Creation*, and continued as, in the same year, a mild-mannered painter Joseph Mallord William Turner likewise became enamoured with light. While the latter's works would earn him no acclaim from his Victorian audience, he would inspire to French artists; Camille Pissarro and Claude Monet. Meanwhile, in their striving against Newton, some Romantics would go further; Goethe would conduct his own experiments on light, and form his own theory, with which he naturally attempted to counter Newton. Though of dubious merit, his work and theory does survive to this day, the precursor to modern color theory (Watson, 2016).

In the nineteenth century, as the Romantics struggled against Newton's grasp, a new dawn of knowledge about light emerged. Though largely a mystery up till this point, starting in 1801 newfound colliding and sometimes contradicting phenomena of light would be discovered that turned it from curiosity to tool. Although no new progress had emerged since Newton's *Opticks*, in 1807 Thomas Young would challenge his predecessors' conclusions and, as Isaac before him, was lampooned and laughed off for years to come. But then, from Ecole Polytechnique in Paris, France, would add optics to its curriculum. Although it initially championed Newton, its students would go on to refute and overturn his conclusions with groundbreaking discoveries of their own. Then, an upstart named Fresnel, a recluse to rival Newton himself, would apparently prove that light flowed in waves not particles (Watson, 2016).

Also during this century, light would become a master of spectacle and illusion as it never had before. As Paris was rebuilt to be worthy of its luminous title, and a lighthouse to rival Alexandria's was lit, various inventions came to tame light in their own right. From this era would emerge projectors, dioramas, the Daguerreotype (precursor to the photograph), and near the end, the very first movie (cinematographe). The impressionists would continue the idolization of light started by the romantics, this time taking the frontlines of the struggle to the canvas. Also during this time, startling new discoveries were being made about electricity and magnetism as well, which would eventually pave the way for bringing light affordably into everybody's homes (Watson, 2016).

Up until recently, making light indoors had been a chore, requiring slaughter of animals for their fats and oils, labor to turn that into candles, and the danger of fire just to fight back the night (Watson , 2016). Better lamps and fuels alleviated but not eliminated the issue. Nobody expected that electricity would eventually be the thing to bring light to the masses. Many civilizations had known about it, but they had not thought much of it. But in the 1800s, radical new developments in the understanding and deployment of electricity would change everything. New discoveries made by big names like Humphrey Davy, Michael Faraday, and James Clerk Maxwell would develop both instruments and an understanding of electricity (and magnetism/light) that continue to be used and built on to this day! It was their innovations that enabled light to be brought from the sky down into the home (Watson, 2016).

Even so, one need not be a great thinker to see that a cheaper, safer light would make someone very rich. Starting in the 1830's, inventors raced to make the first household incandescent bulb (light). Edison would win out because he had the best people and financial skills and backing, and was willing to dream big. He impressed the press with his prototype in 1878 and a viable bulb the next year, proving to be a PR genius in addition to his other categories. But eventually, even his phenomenal PR skills could not win him the war of the currents; he stubbornly stuck with direct current, while alternating current, championed by Nikola Tesla, was simply more economically viable. However, amidst this great struggle, the fight against the night was won, as electric light became practical and affordable, and those who made it possible became household names (Watson, 2016).

Then, near the end of this luminous century, another ingenious mind would emerge to make his name in the next; Albert Einstein. After the speed of light was measured definitively as a constant 186,139 miles/second around the start of the twentieth century (after centuries of refinement). Also around this time, the first evidence of photons and against aether theory (the idea that space was filled with an invisible fluid, a material that supported the travel of light, and not empty) emerged, and radio was discovered. Albert Einstein, free thinker that he was, also engaged in rigorous thought experiments around this time. In 1905, he would publish four papers that would change the field of physics forever. Relativity, photon theory, and other ideas that scientists would be debating for years to come. Within the decade, Neils Bohr would provide further evidence for his theory, and Einstein would go on to theorize about the shape of the universe (Watson, 2016).

The discovery of photons and other quanta revived the particle vs. wave debate that everybody thought was settled in the 1800s. Both theories were indispensable for explaining certain behaviors of light. This atmosphere of uncertainty bred a degree of exclusivity; few could handle the uncertainty, math and dedication solving these problems demanded; only a handful could handle them all. New discoveries would only feed this uncertainty further. Those who could handle it tried to reconcile this duality, as it challenged the then modern definition of science, which demanded certainty. Ironically, it would end up being that definition of science that was to be reconciled with the newly emerging duality theory. Doubt would become the word of the day, certainty forever elusive, and people would just have to learn to live with it (Watson, 2016).

At this point, light had been de-mythicized and mathematized to such an extent that when the recipe for sunlight (the process by which light/photons are produced from fusion in the sun) was discovered in 1938, it barely made a sound. By the time Hans Bethe unraveled the mystery of why the sun shines (why it produces photons), light had been mathematized to such an extent that vast oversimplification was necessary to explain it to the public, who were largely uninterested (Watson, 2016). Light had become a commodity, a convenience, its primordial battle with darkness won, and like all scientific miracles, had come to be taken for granted. That's not to say that light had no more miracles to give though. The laser (light amplification by stimulated emission of radiation), first theorized by Einstein's thought experiments and Bohr's model, was pushed for after the second world war. Eventually, it devolved into a search for the proper filler material, echoing the search for the proper filament for the lightbulb roughly a century before. Theodore Maiman would eventually win out with his crystal filler in 1960. The uses for this invention would come later-a few thousand of them. "By 1970, lasers were welding integrated circuits, guiding bombs dropped on North Vietnam, mending detached retinas, and measuring the distance to the moon within an inch." (Watson, pg. 202) The laser would leave its mark on the world, as it already had on pop culture as well (Watson, 2016).

The laser would also leave its mark on names as well. CD, DVD, and various aspects of the forthcoming quantum optics as well all owe their acronyms to the laser which inspired them. Photonics would also get its start around this time, with its forebears, quantum optics and quantum electrodynamics (QED) being the brainchild of Richard P. Feyman. Feyman was a man who reveled in the uncertainty of the era, especially that which begat from quantum light. By the mid-1970's, his pioneering theories had led to the birth of a new field-photonics-dedicated to photons and the physics of using them in technology (especially for communications) (Watson, 2016).

Light and its miracles are truly all around us, even if the artificial ones tend to overshadow their natural counterparts nowadays. Its festivals, old and new, flourish worldwide, as LEDs use Bohr's atom to make bright the night. However, this light pollution promotes its own problem, as now the stars are a foreign sight to most and unknown to some. There seems to be nothing we cannot do with light except get enough. Light was born with the universe, and now we are emerging into an age of light all our own. It has not lost any of its mystique, as the light divine lives on, despite the seculars who'd thought they'd killed it. We have always, as a species, been enraptured by light, from our earliest (known) ancestors to modern man (Watson, 2016). Yet even today, light has still more room to spread, and with the pioneering of photonics as a field, it seems that its advent in our everyday lives may indeed be very near.

The Future of Photonics

Already great strides are being made, and there is every probability that photonics will be to the twenty-first century what electronics were to the twentieth, especially in the realm of computing (Sala, 2016). Photons will replace electrons, as we switch to Photonic Integrated Circuits (PICs) from electronic ones (EICs). PICs are formed through a variety of methods, including photolithography and etching, where light is used to transfer a pattern onto the circuit, making it the means of information transfer in more ways than one. Even so, major obstacles to the advent of PICs remain, namely the difficulty of monolithic integration; the consolidation of optical sources, processing, and detection onto one device. Finding a material capable of all of these has proved difficult, and a search similar to those for the proper filler for light bulbs and lasers is still ongoing, i.e. the materials problem needs solved. Silicon remains a favored contender, due to the possibility of leveraging the existing electronics manufacturing infrastructure, though the impossibility of a silicon laser severely complicates these plans (Sala, 2016). Even so, photonics is still poised to topple electronics and usher in a new era in computing and other applications, with massive ramifications for fields from medicine to transportation to consumer products (Sala, 2016). This implies, however, that certain other, more personnel related issues can be remedied before this revolutionary technology can be implemented.

A Problem for Photonics

Currently, optics and photonics suffer from a shortage of talented and interested students who seek to enter the field, partially a symptom of a larger issue in the realm of STEM as a whole. Various attempts to counteract this have been made, focusing on getting students involved and interested in optics. This is nothing new; optics education in the US began in 1929 when the University or Rochester opened its new optics department, and has continued ever since (Thompson, 1991). Currently, the goal is to get more people interested in the subject to meet the growing demand for professionals in this expanding industry. These attempts have varied greatly, as have their results and even the targeted demographics. While several of these initiatives aim to target students at the college level, others have set their sights on the K-12 communities and aim to get interested children before they reach the college level. Many of these attempts rely on a novel angle to get younger kids invested in photonics, such as the construction of an optical device, or putting an artistic lens on it and learning about the 'colors of nature' (Pompea, 2015).

Some programs have attempted to use the rich history of optics and its development into photonics as a way to engage with students, an approach that has been seen to have several benefits (Mihas, 2003). Firstly, it has been noted that this approach results in a noted increase in student interest, probably due in part to the intriguing story of optics development, which goes back millenia. Furthermore, this approach also instills a considerable appreciation for the field, as it details how our understanding of optics and photonics evolved into the one that we have today. Additionally, teaching about how our optical knowledge developed over time gives insight into how our understanding of the field and science in general develops. This can help counteract the misconception that science is static and unchanging, disproven theories of the past are irrelevant, and that we now know everything there is to know about the universe (Galili, 2001). It also provides the opportunity for students to advance their understanding of optics alongside learning of our historical one, letting them progress together and see how we came to our current comprehension on the topic. The value of these advantages is hard to understate, as they can potentially greatly increase the interest of our youth in the field of photonics and their subsequent enrollment into programs dedicated to it.

Other educational efforts have likewise taken novel approaches to engage students. Some have sought to integrate general and professional education with experimental teaching, or to use problem-based learning to promote learning. For example, there have been efforts to integrate general and professional education on fiber optics communication with experimental teaching, in order to improve the quality of student learning (L. Lan, 2017). Several seek to leverage new technologies like the internet and computers to deliver content remotely, accessibly, and more engagingly than it would be possible to do so otherwise. Another recent initiative has sought to distribute a series of modules containing 'challenges' meant to mimic real life situations, in order to further engage students using problem-based learning (Massa, 2013). Also, several programs are part of an educational course stretching from K-12 education and continuing through graduate school to ensure that the diversity of workforce roles and positions can be filled. The University of Mexico, for example, has a complete set of programs that together provide all the levels of optics professionals necessary, from researchers to technicians, at a local level (Osinski, 2003).

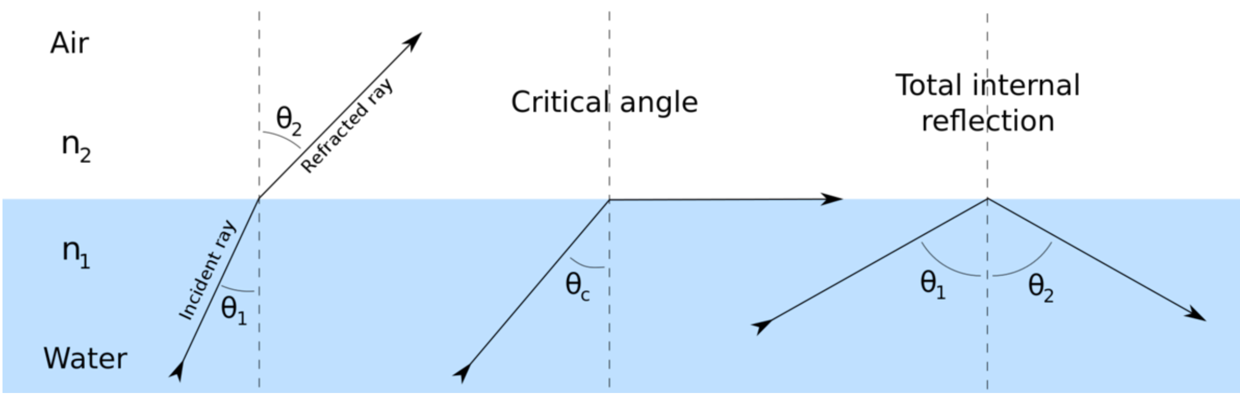
These measures are meant to address the challenges in teaching the field of photonics, such as the abstract and complex nature of the subject matter. The fact that photonics is often an enabling technology to many fields but rarely considered interesting in its own right, is another issue, and necessitates extra effort to engage students, such as with exhibits or experiments, to maintain their interest (Osinski, 2003). For instance, an exhibit consisting of displays on various aspects of the behavior, generation, or application of light has served as a starting point to get many future photonics students interested in the topic (Jean-Christophe, 2018). However, due to optic's ubiquity, some everyday objects can be used to introduce/demonstrate photonics concepts; a recent article describes a method for measuring the focal length of a smartphone camera (Girot, 2020). This could serve as an introduction to some photonic or optical concepts such as lenses and light rays to a beginner in the field. Additionally, given its nature as an emerging and essential science in many respects, industry is often involved in optics and photonics education as well, forming an essential exchange of experience and expertise that drives the field and the technology forward. Often, industry works symbiotically with government and academia to fill the needs of the sector, creating, transferring and applying knowledge to push the field forward (Pearson, 1989).

Fundamental Topics In Educational Programs

As stated previously, photonic integrated circuits (PICs) remain photonics' primary forte into the computation industry (Sala, 2016). They far outperform their rivals, electronic integrated circuits (EICs), and without such issues as heat generation and quantum tunneling. Photons do not interfere with each other or their carrier materials as electrons do, and travel at a faster speeds and with far less heating than electrons. If the industry hopes to continue to comply with Moore's law, then the advent of PICs is necessary. (Both types of integrated circuits could potentially even be combined to form hybrid circuits with improved functionality.) But in order to do so, these PICs will rely on optical waveguides, the basic element of all PICs. Unlike EICs, bound by Ohm's law and its endless struggle against Resistance, with the heat and performance losses it entails, PICs follow Snell's law, which is comparatively lenient. Their basic role is to guide and confine waves of light, similar to and including fiber optic cables (Sala, 2016). They do this using a fundamental optical property of the materials involved; their index of refraction (n), a measure of how light bends when passing from one medium to another, caused by its differing velocities within the media. Index of refraction (n), or refractive index of a material is determined by the ratio of the speed of light in a vacuum (c) over light's velocity in the material (v) ($n = \frac{c}{v}$).

The waveguide is composed of two separate material components; the core and the cladding. In order for the waveguide to work, the core must have a greater index of refraction than the cladding. This provokes a phenomenon known as total internal reflection (TIR), provided that the angle of incident between the light and the cladding exceeds a critical angle determined by the indexes of refraction of the materials of the core and cladding. As ruled by

Snell's law, the sines of the angles of incidence and refraction are related proportionally to the indexes of refraction of the incident and refracted materials ($n_1 \times sin\theta_1 = n_2 \times sin\theta_2$). If the index of refraction of the refractive material (the one the light is travelling through) is significantly higher than that of the incident material (the one the light would enter into), then it can be reflected back into the refractive media. TIR guides the light down the optical waveguide, while the numerical aperture (NA) measures the light gathering ability of the fiber, and is proportional to the difference in index of refraction between the core and the cladding (Sala, 2016). Often glass (also known as silica), doped or pure, is used as the materials for the cladding and core, though silicon can also be used.



Total Internal Reflection

This picture demonstrates the principle of total internal reflection based on snell's law ($n_1 \times sin\theta_1 = n_2 \times sin\theta_2$) using air and water as demonstration materials. The transition between materials is on the left, demonstration of critical angle is center, and the example of total internal reflection is on the right.

Restrictions on the angles used are imposed, as eventually light at any other angle will fade away except if the angle promotes constructive interference. The angles that do are called ‘modes’, and vary based on wavelength and polarization of light, materials used and their indexes or refraction, and dimensions of the fiber (Sala, 2016). Modes travel at different speeds, which can introduce distortion; this can be avoided by using only a single mode though, in which case it is called a single mode (SM) waveguide, as opposed to a multimode waveguide. Angles that promote destructive interference must be avoided. These principles are consistent within all geometries of waveguides; cylinders are typically used to make fibers, while rectangles are used to fabricate PICs.

Bend radii must be carefully considered; while necessary to route and connect portions of a waveguide, if the bend radius is too small it will violate internal reflection and allow light to escape. This happens because the angle of incident at the interface becomes less than the critical angle, and can create system losses that affect waveguide performance (Sala, 2016). Typically, this issue is represented by the minimum bend radius of a waveguide, and can be alleviated by using smaller waveguides and stronger light confinement (larger NA). Minimum radius can be a limiting factor on waveguide size, as the more space the bends take up, the larger the device; maximizing refractive index contrast can help increase this value/mitigate this issue. Another important limiting factor is propagation loss, which can be influenced by materials used, fabrication technology, and waveguide geometry (fibers fare better than planar). Losses from scattering (due to volume/surface scattering, sidewall loss) and absorption (depends on wavelength) are both constituents of this (Sala, 2016). Fabrication process and operating wavelengths, respectively, can be optimized to minimize these losses. Yet another complication comes from the Thermo-Optical effect; the change in index of refraction with temperature. Occasionally, this property has been exploited for usage in switches and modulators. More generally it is troublesome, causing tuning issues and necessitating thermal stabilization (Sala, 2016).

Similar manufacturing methods are used for EICs and PICs, though the same cannot be said for their materials. Though silicon plays a prominent role in both, PICs typically involve a wider variety of materials in their fabrication. The desire for monolithic integration of optical sources, processing, and detection has led to a search for a material to support this. Silicon occupies a role as a favored candidate in that regard, due to its promising properties and existing infrastructure, but the physical impossibility of a silicon laser hampers it significantly (Sala, 2016). (It might also allow for integration of electronic and photonic integrated circuits.) Efforts to integrate other materials onto silicon circuits to form a hybrid laser are ongoing, though unsuccessful as of yet. To date, no single platform or technology has proven to be capable of producing all the necessary photonic devices and integrating them into one circuit; each has their own advantages, disadvantages, and applications. For now, integration has been minimal, and devices are typically made separately and assembled into modules with fiber connections (Sala, 2016).

Manufacturing methods used to produce PICs, by comparison, are well defined and very similar to those used to produce EICs. Typically, PICs are formed on planar substrates, with planar optical waveguides forming their basis and manufacturing revolving around them (Sala, 2016). These PICs are limited to 2D configurations, with layers of materials grown or deposited on them; silicon wafers are the base components in high-volume production. In deposition, various materials are added to the silicon wafer through various methods. Photolithography and etching, on the other hand, define the waveguide core geometry, using light to imprint patterns onto the wafer. These processes correspond roughly to those used in the semiconductor industry to manufacture EICs. Direct laser writing, a more novel and recent method, uses a laser to etch a pattern in increased refractive index within glass (or another material). Although limited to low-volume production and subject to high propagation loss, it can easily produce 3D patterns in a cheap and simple way (Sala, 2016).

But even more than the impossibility of a silicon laser or the limitations of our current manufacturing technology, photonics is facing a more pressing challenge. Currently, optics and photonics is facing a severe lack of skilled labor required for this technical industry. This shortage starts in college, where very few students choose to specialize in photonics, and continues to be a persistent challenge in the industry. It has gotten so bad that many photonics companies choose to train their employees in-house rather than seeking workers who were qualified to begin with (Loven, 2001). Simple as it may seem, light is anything but; while it may illuminate our world, few people take the time to truly understand its complexities. For starters, the amplitude of light, the electric field, is a vector that can be separated into two components of polarization, acting somewhat like two waves. The electric field, and its corresponding magnetic field, oscillate in perpendicular directions while travelling in the third. The different polarizations do not interfere or interact with each other and this property of light allows an increase in the communication channels down a fiber optic or in a PIC. The electric field of light can interact with materials and once passed through a polarizing filter, the electric field will be aligned in a single dimension. Furthermore, not all light is equal; while some light may contain only one color (red, green, blue, etc.) white light contains all the colors of the rainbow, as you can see if you pass it through a prism. These multiple colors are another characteristic of light that allows additional communications channels that greatly increases data transfer and processing. Additionally, light is subject to the same principles of diffraction and interference phenomena that all waves are, spreading out (diffracting) as it passes through a narrow slit or grating and into its shadow where it can create dark and bright interference bands. One must wonder how the different types of light-both single color and white light-would behave once they passed through a diffusion grating, but the answers to such questions and the concepts behind them are unknown to most people. The main problem seems not only to be a lack of opportunities for education, but also lack of interest by prospective students. One way to combat this issue would be trying to get people interested in this area at a younger age. That way when they get to the college level, they may already want to be a part of the photonics industry, or at least have a greater inclination to enter the field further down the road.

Our proposed solution is to implement an optics merit badge into the Boy Scouts of America. This badge will introduce youth to the science of light and hopefully create an interest that will show them new opportunities available in life. The scouting program gives youth the chance to discover future hobbies and even areas of interest that they follow to find a future job. The main method of finding these hobbies tends to be merit badges. These badges will give them an introduction into almost anything and allow them to see enough to get interested in the topic. Because of this, the Optics merit badge should provide the opportunity for youth to find an interest in light and hopefully show them that this interest can be turned into a future job. The badge would have the capacity to expose many thousands of scouts across the United States all at once to the ideas of optics, potentially even more across the globe. The skill pool provided by the scouting program is immense and could find the talent, interest, and determination to advance this area of science faster than the average highschool class. The BSA (Boy Scouts of America) also has many future leaders go through the program. Whether they become anything from local leaders and national politicians to businessmen and even astronauts. Sometimes there is even one such as the “Nuclear Scout” who decided to salvage uranium from old smoke detectors to construct his own nuclear reactor, and succeeded. Scouts could be the perfect place to introduce this area for yet another reason. With the release planned around a national or even world jamboree tens to hundreds of thousands of scouts could be introduced all at onc. Then there is the competitive nature of many which will have them doing everything to earn the new badge as soon as possible. If those reasons weren’t enough, nearly all people who have gone through the program will have many good things to say about it and even better memories. Even if they do not reach the highest rank of Eagle Scout almost everybody who participates sees the value and how it has helped them in life. Looking at all of this, implementing a optics merit badge could be the perfect way to tap into a new pool of talent and bring out interests in areas people would otherwise have no idea existed.

Merit Badges & Scouting

Scouts is an organization that allows youth to learn a variety of life skills ranging from cooking to environmental science to engineering. The program also teaches the importance of working in a group and effective leadership skills. On a scout's way to earning the rank of Eagle Scout they will have to earn 21 merit badges which are awards that show they demonstrated required knowledge and skills. To earn these badges, they will have to answer questions and show they have learned about the topic in question. These questions could be the safety measures to be taken when shooting a shotgun, describing a large-scale project and its environmental impact, or even several paragraphs on first aid knowledge they have learned that might one day save somebody's life. Originally the only requirements to achieve ranks in scouting were these merit badges. As the program developed more requirements that had scouts demonstrate non-badge skills were added. Scouts would need to learn many knots and participate through leadership positions in their troop. Today the highest rank is Eagle Scout. The scout must have participated in the troop for years before completing the time requirements and holding their needed leadership positions along with the badges they need. The final part of any Eagle Scout's journey is the eagle project. This project must be designed from the ground up by the scout, fundraised by the scout, organized by the scout, and led by the scout. The project in its entirety is meant to teach the scout the process of larger scale projects and show them some of the highest levels of leadership at their age.

With a large quantity of merit badge scouts are able to complete them during a week long summer camp while others may take a single day or even three months of dedication and recording activities like exercise or your personal finances. The merit badges that take only a day to complete might include the citizenship in the world merit badge where the only requirement is research and being able to answer questions. Week long badges include those such as archery and first aid. These take more than doing a small amount of research to find answers to questions where in archery you need to meet a score minimum and with first aid demonstrate knowledge of many possibly life threatening ailments and how to respond if somebody shows symptoms. One example of a ninety day badge is family life where you need to record chores, but the rest of the badge is able to be completed in around a week. For resources needed to complete a badge, many might have a booklet to help the scout which can be purchased, found online, or borrowed from a troop library. Some badges such as cooking will need you to buy and prepare your own food while others might have them buying a weaving kit for the basketry merit badge. Below is a list of every merit badge as of May 2020 with those required to attain the rank of eagle scout starred. Some eagle required merit badges may have alternatives where you only need one of the two and other badges have old names listed.

In terms of merit badge options, there exist many within stem fields that can be found below. They include topics ranging from nuclear science to programming. Many of these badges have a similar format where the requirements ask about the same things such as safety because that is one of the first steps in nearly all badges, but also have a more interactive part that asks the scout to do something relevant to the skill. It could be designing a mechanism for an engineering badge, making a ball of crumpled aluminium foil sink in a water bottle by squeezing it for chemistry, or even one of the scout's first programs in the programming badge. Badges have the capacity to ignite an interest in their topic while also teaching them basic information that will be important to all from hobbyists to professionals.

List of merit badges

* Indicates Required for Eagle

American Business	American Culture	American Heritage
American Labor	Animal Science	Animation
Archaeology	Archery	Architecture
Art	Astronomy	Athletics
Atomic Energy (now Nuclear Science)	Auto Mechanics (now Automotive Maintenance)	Aviation
Backpacking	Basketry	Bird Study
Bugling	*Camping	Canoeing
Chemistry	Chess	*Citizenship in the Community
*Citizenship in the Nation	*Citizenship in the World	Climbing
Coin Collecting	*Communication	Composite Materials
*Cooking	Crime Prevention	*Cycling
Dentistry	Digital Technology	Disabilities Awareness
Dog Care	Drafting	Electricity
Electronics	*Emergency Preparedness	Energy
Engineering	Entrepreneurship	*Environmental Science
Exploration	*Family Life	Farm Mechanics
Fingerprinting	Fire Safety	*First Aid
Fish and Wildlife Management	Fishing	Fly Fishing
Forestry	Game Design	Gardening
Genealogy	Geocaching	Golf
Graphic Arts	*Hiking	Home Repairs
Horsemanship	Indian Lore	Insect Study
Inventing	Journalism	Kayaking
Landscape Architecture	Law	Leatherworking
*Lifesaving	Mammal Study	Medicine
Metalwork	Mining in Society	Model Design and Building

Motorboating	Moviemaking	Music
Nature	Nuclear Science	Oceanography
Orienteering	Painting	*Personal Fitness
Personal Management	Pets	Photography
Pioneering	Plant Science	Plumbing
Pottery	Programming	Public Health
Public Speaking	Pulp and Paper	Radio
Railroading	Reading	Reptile and Amphibian Study
Rifle Shooting	Robotics	Rowing
Safety	Salesmanship	Scholarship
Scouting Heritage	Scuba Diving	Sculpture
Search and Rescue	Shotgun Shooting	Signs, Signals, and Codes
Skating	Small-Boat Sailing	Snow Sports
Soil and Water Conservation	Space Exploration	Sports
Stamp Collecting	Surveying	*Sustainability
*Swimming	Textile	Theater
Traffic Safety	Truck Transportation	Veterinary Medicine
Waterskiing (Now Water Sports)	Weather	Welding
Whitewater	Wilderness Survival	Wood Carving
Woodwork		

Optics Merit Badge

Instructors Guide

Requirements:

1. Safety
2. What is Light
3. How we make us of light
4. What optics is used in
5. Simple optics experiments
    - Have the scout(s) perform two of the listed experiments
6. Careers in optics

Safety

The scout should be able to list at least one examples for each listed category:

a. Safety practices

    i. Different classes of lasers need different levels of caution

    ii. Don't leave lights unattended

b. Safety equipment

    i. Different lasers need different goggles for protection

    ii. Incorrect laser/goggle pairings can lead to disaster

c. Rules for equipment

    i. Follow proper storage rules for your safety equipment

    ii. Keep first aid kits ready to be used at all times

The safety practices can include any reasonable precautions that can be taken while working with light and what they might avert. These practices can include precautions for working with light or any device that works with light.

Safety equipment should just be two things you can use while working with light or other pieces of equipment to keep you safe. The scout should also give a reason as to why you would want to use or have this equipment around.

Rules for the equipment can include rules to prevent unwanted things from happening during their operation, ways to safely store them, and how to act around the equipment to prevent unwanted occurrences.

Ways we use light

This list can include any ways in which the scout can list light being used. After giving an example they should also describe to the best of their ability how light plays an important role. Their examples can range from using light to see to the transfer of information in the trans-Atlantic cable. There is no limit to the examples being provided as long as they involve use of light.

Advantages of communicating with light

Complete this requirement the scout should be able to list two different ways light is a better means of transferring information than electricity. Some examples are light transmits more information than electrical signals, electricity creates lots of heat in wires, the different wavelengths of light and using them to transfer information. The example should have a reason as to why it might be an advantage over electricity.

The Experiments

The scout only needs to perform two of the experiments. We recommend that the instructor have the means to perform any of them as to allow the scout to choose which they want to do.

The three-polarizer experiment: the scout should be able to describe what is happening when you look through one polarizer, with both the two polarizers rotated through a ninety-degree angle, and what happens when you put a third between two that are not allowing any light through (at ninety-degrees) them and rotate the middle polarizer. One polarizer will filter out half of the light. The two polarizers at ninety-degrees should completely block out all the light while when a third is added some should get through all three as the middle one is rotated. They do not need to tell why this is happening. An explanation for the effect is that the first polarizer aligns all the light with it, then the second and third will take the portion of the light pointed in the same direction of it while filtering out the rest. The scout may also be interested in what happens when putting a filter over their phone screen or what an image made by a projector looks like through a polarizing filter. Also looking at reflections can filter out glares.

The diffraction grating experiment has different results for both flashlights and lasers. The flashlight should produce a rainbow on the wall that changes size when the distance of the grating to the wall changes. The laser should produce a sequence of bright and dark sections where destructive interference has cancelled out all the light in some areas and constructive interference has made it brighter in others. With the same distance between the grating to the wall, the red light from the flashlight should be at the same spot as the red laser light.

The prism experiment should separate the white light out into the rainbow. The scout should be able to note the rainbow, and if you have access to other lights of a single color be able to give a prediction of what will happen if that light is used instead.

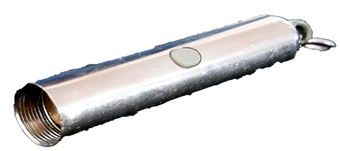
For the message experiment the message only needs to have at least three possible outcomes where the scout is then tasked to distinguish between the three how they would like. There are no answers that are too simple provided they meet the three possible outcomes requirement..

Careers in optics

The scout should do research by either reading the book or searching for jobs online to discover some examples. Their examples need to work with light in some manner and be able to describe who light is important to their profession. The scout should also be able to give a short explanation as to what the function of the jobs is.

Optics Merit Badge

Domain Merit Badge
-Remix



Laser Pointer

Requirements

1. Describe at least four safety measures that should be taken with working with lights to your counselor. These should include safety practices, safety equipment, and rules to follow when working with different pieces of equipment.

2. Give five examples of how we make use of light in everyday life and explain how light plays an important role.

3. List two advantages and ways we use light to communicate over long distances compared to using electricity.

4. Perform two of the following experiments
    a. The three-polarizer experiment explained in this book
    b. The diffraction grating experiment explained in this book
    c. The prism experiment explained in this book
    d. Find a way to send a message to your counselor using a flashlight

5. List three different career opportunities in optics

Safety

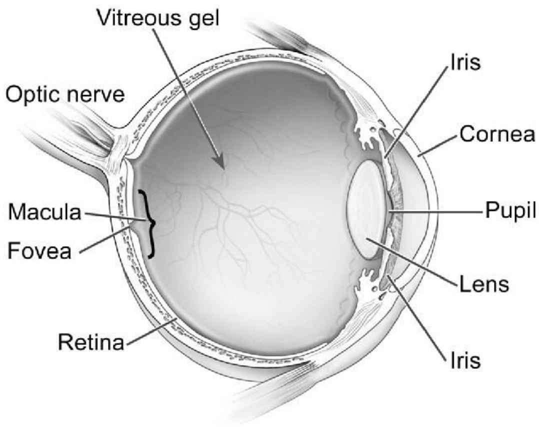
Just like all activities there are safety practices to be followed and then some equipment to be used to prevent accidents. One of the first practices is to view bright lights only when you have proper tools if they exist as the damage they can cause to your eyes could be permanent. These lights could range from flashlights, to solar eclipses, to light you cannot see. Light that is invisible to our eyes is still there and can cause damage to the cells in our eyes responsible for our sight. In the case of a solar eclipse one may use a simple pinhole camera to view the eclipse safely on a piece of paper, but for lasers special glasses or goggles are needed to block the light they create.

Search

Another practice is to not leave powerful lights unattended. Not only do they use power constantly and dangerous to touch, but they could start a fire with the light or the heat they make. Incandescent lightbulbs create heat to make light. Because of this they can get very hot if left on for an extended period, then if they come in contact with flammable materials a fire could be started. While most lasers will not be starting fires when pointed at most objects, a powerful enough laser can light very flammable materials on fire and precautions should be taken to make sure nothing likely to be burnt is in the way.

When you have lenses, made to be used in optics or simply a result of another factor, proper storage and practices to make sure they do not create danger is important. Some lenses will be able to focus the sun’s light enough to start a fire under the right conditions, or damage your eyesight when looking at light sources through them. Proper storage practices should be followed so that the lenses will not cause damage if light comes in contact with them and is focused to a point. When using lenses you should be sure that you know where the light will be going and that if it does not go where you expect it will not be focused at anything flammable. As a result of the focusing of lenses, proper conditions can start fires as is the case with a magnifying glass and paper, or damage your eyesight.

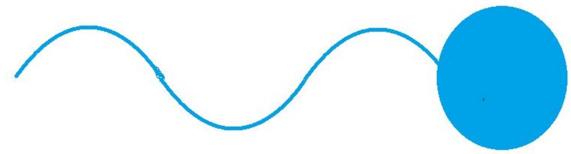
To go with safe practices, we also need safety equipment to prevent accidents. One of the most important is eye protection when working with lasers. They can cause permanent damage at high rates, or in a blink of the eye, so glasses or goggles made to block out the wavelengths of light they produce should always be worn. These eye protection tools will be able to block out the energy given off by the laser while still allowing the wearer to see.



Drawing of The Eye

As said before, lights can cause damage to eyes even if we are not able to see them. When working with infrared or ultraviolet light one should make sure they know exactly where it is going and be wearing eye protection that will block out the light in case the light goes somewhere unexpected and if possible, you should have extra equipment to know for sure where it is. Proper safety equipment is also necessary to view a solar eclipse as the light is just as bright, but less of it is reaching us so it seems darker, thus it can still be as dangerous as the sun on any other day. As always, be prepared for things to go wrong in an experiment and have the proper equipment and knowledge to prevent the unexpected from becoming a problem.

What is light



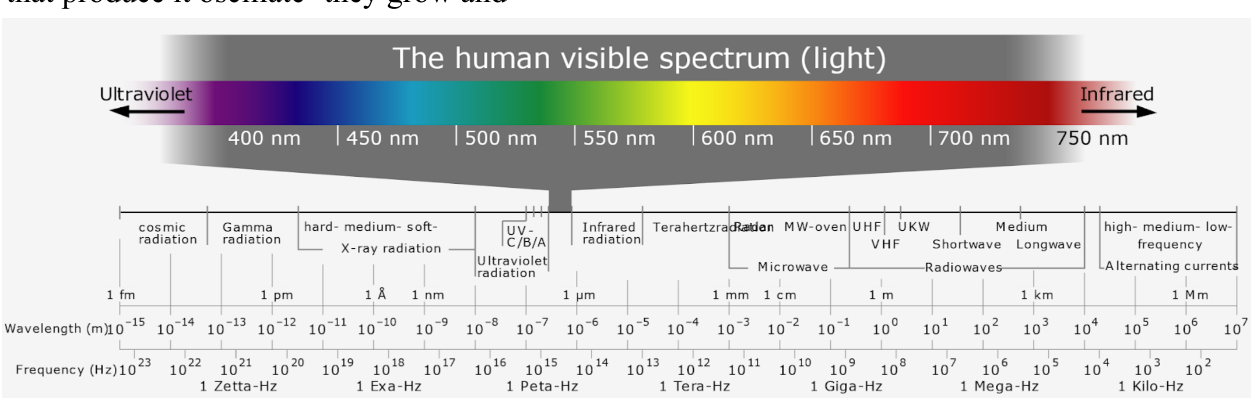
Physically light behaves as both a wave and a particle. The wave properties of light allow interference, which can be constructive or destructive. In constructive interference the wave nature of light causes the intensity, or brightness, of the light to increase while with destructive interference the light intensity can be decreased to even be nothing. Interference can be viewed in different ways. From one point of view the waves of light are either synchronized or out of phase which is to say they can be similar and add up or different enough to cancel out. From the quantum mechanical perspective, the individual photons have a probability of existing in certain locations in our world, and when the probability amplitude of some photons add to zero, they won't exist in that location. For constructive interference two light sources will have the probabilities add up and as a result of more light coming in the light can be brighter.

Light also behaves as a particle. This particle behavior is seen as the photons, which are packets of energy. Light has the ability to transfer energy and momentum to objects that they hit. Photons of light have energy of a specific amount depending on their wavelength or the color it determines. The more photons you have the brighter something appears. When light strikes a body, it can transfer its energy to it as heat or even reflect off of it and push it in return. The idea of solar sails for spacecraft would use the momentum of particles and light coming off the sun to push the spacecraft forward without using fuel. Interestingly the size of a sail that you need to counter gravity is independent of how far away you are, which is to say one size will always give the same ratio of sail force to gravity. Photons can also provide the exact energy needed to push an electron away from an atom which is called the photoelectric effect- which is what Albert Einstein won his Nobel prize for. The photoelectric effect will also increase in how many electrons are released when you increase the brightness of the light but changing the color could stop the effect no matter how bright it gets.

Light has intensity and color. Photons have specific energies to each color. The photons have wavelengths determined by the energy they carry. The wavelength of light is how far the photon travels in one cycle where the electric and magnetic fields that produce it oscillate- they grow and shrink. It is the changing of one field that creates the change in the other and creates the light. The intensity, or how bright, a light is will be determined by the number of photons coming from a source. The more photons the brighter the light appears to be, but each photon will still carry the same amount of energy as if it were less intense.

In one experiment the speed of light was calculated within 5% of its actual value by a French astronomer, Fizeau. He did this on Earth by using a cogwheel and a mirror 8 kilometers away. He would use the time it took to travel between the wheel and the mirror only to strike one of the cogs and be blocked from his eyes, the distance traveled, and how fast the wheel was turning. With this information he was able to calculate the speed of light to be 313,300 Kilometers per second.

Knowing light has a speed of around 300,000 kilometers per second, we can calculate how long it takes for the light to travel between locations. It takes only minutes to travel to earth while distant stars can take thousands of years. This means that all the stars we see in the sky are simply what we would have seen many years ago. Some of them could have died between the



Electromagnetic Spectrum

time we see them at and the present, and many more could have been born but too soon for us to be able to see them yet.

Light also played an important role in navigation before satellites and GPS. Stars were in predictable locations in the sky so one could learn to navigate the globe using what they see in the night sky to figure out where they are located and where they are heading.

Using light

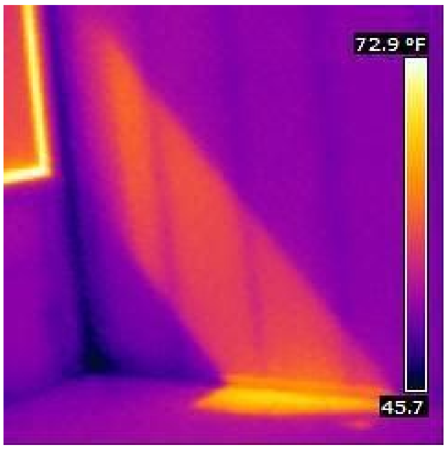
We make use of light in many ways. The most important tools we have to do this include mirrors, lenses, and sensors. By measuring the time it takes light to travel to an object and return we can calculate its distance very accurately. This requires that we use a sensor and a circuit to measure the time it takes the light to travel then multiply that by the speed of light. We also use light to send messages long distances. This can be done using cables that completely internally reflect the light within. This means that the light stays inside the cable and does not leave it allowing messages to be sent across continents. This is what we use for internet communications between the United States and Europe. We can also bounce light off of the atmosphere and send messages long distances as in radios. Lenses will focus light to a single point from a large area allowing one to better view distant objects. Two other uses of light include lightbulbs or light amplification by stimulated emission of radiation or lasers. Lightbulbs use resistance in wires to generate heat then the hot filament gives off light because of its temperature (well over 2,000 degrees Celsius!). Lasers use quantum mechanical effects to copy photons and release a straight beam of photons. One last way we commonly use light is to generate heat. You have probably seen this if you have a pet lizard or been somewhere with a buffet that needs to keep food hot. Lasers can have a manufacturing use in cutting away material to form a final product in subtractive manufacturing while you can also layer material and melt it together in additive.

Uses of Optics

Optics has been an important part of technology in recent times but has been in use for hundreds of years. Early uses have been important in navigation from using the stars to telescopes to see in the distance. To navigate using the stars people would use angles to calculate their position on the globe given where the stars were located in the sky. Telescopes were a much simpler application where lenses are used to focus light and allow a person to view objects very far. Modern telescopes will view different wavelengths of light than just what human eyes can see using computers to generate images we can interpret and use to better understand the universe. Modern telescopes will also make use of mirrors instead of lenses as all the light can be focused to one point then reflected into a sensor and unlike lens telescopes it has the capacity for much higher resolution. The telescopes that viewed the black hole at the center of our galaxy made use of many telescopes around the globe which effectively allows us the resolution of a telescope the size of the entire planet. While we no longer need to view the stars to find our way, we still use optics via a Global Positioning System (or GPS) which makes use of satellites and light to find our position on the surface of the earth and help us find our way. The way it works is by calculating different distances to several satellites and finding where we are because with information from at least three satellites we can narrow our location to a single point in space.

Optics also has an important role in communication. From the American revolution lighting lamps to signal how the British were going to attack or even car turn signals optics is very effective for communication. Sometimes the most important communications can be between machines where LiDAR could help a vehicle navigate on its own. While we lack the eyes of an eagle as humans, we still make much use of our visual sense to understand the world. Perhaps the most important methods of communicating with light actually use light we cannot even see. These would include the wavelengths used for radios, cellphones, satellites, wireless internet connections, and so on. These use light we cannot see, but with technology we can still interact with this light. These are very effective means of communicating across the globe as light travels at the universal speed limit. These devices will send out different frequencies of light to allow communication to occur between hundreds of devices and be able to pick which you listen to. An example is frequency modulated, or FM, radio stations. These use different frequencies of light to carry different channels. There also exists amplitude modulated, or AM, radio stations that use different amplitudes of light waves to differentiate radio stations. For television we make use of satellites to send information. This is possible without constantly turning the satellite dish on our houses because the satellites in space are in what is called geostationary orbits. This means that they always stay in the same point of the sky since they orbit the Earth at the same rate as the Earth rotates. Wireless networks for cellphones and in-home (i.e. 4G, 5G, …) are another example of long-range and short-range communication.

One of the most important properties for experiments is the ability of light to gather information for us about our surroundings. We detect heat, distance, velocity, gravitational waves, and even rotations using light. We detect heat by using the light coming off an object to calculate its heat using a circuit inside the device. The more light coming off of an object the hotter it is. We can calculate distance by using the amount of time it takes light to reach a distant object and return to us. One step away from distance is speed where we measure the distance many times and then see how fast it is changing to calculate speeds. Gravitational wave measurements make use of interferometers. In the case of gravitational waves a several kilometer long laser beam is used. This beam is split and allowed to recombine. When a gravitational wave compresses space it shifts the beams lengths and causes interferences to occur when the beams are recombined and sent to a sensor.



Infrared Heat on Wall

Photonics is a rising area of technology where we try to make use of light to construct a new type of computer. These devices will use light instead of electrons to do calculations allowing for much greater speeds in our devices. Electronics can only be so small and go so fast before problems arise. One of the most common issues is heat. The harder you work your computer the hotter it gets, decreasing its efficiency, and it can even cause damage. This is because you are putting more energy into the circuits and resistance is generating a lot of heat due to constant use. A less known phenomenon is quantum mechanical in nature. If the circuits are small enough, close enough together, and the electrons fast enough we can see quantum tunneling between the different elements of the circuits. This is when the electron effectively teleports between two locations because of the wavelike properties of matter. Such events will introduce noise and could bring on failures in devices.

Simple Experiments

Some simple experiments available for you to choose to do for this merit badge include the following:

The three-polarizer experiment:

You will need a flashlight and three linear polarizing filters.

- First, observe the change in brightness of objects when you look through one polarizer.
- Next, place two of the polarizers at different angles and shine the flashlight through them, or simply look through them, and observe the effect the polarizers have as you rotate them.
- Next you place the two polarizers at a 90-degree angle to each other and note the effect.
- ith two polarizers rotated to block out all of the light, place a third polarizer between the first two and change its angle and tell you merit badge counselor what you observed. Is it surprising?

Diffraction grating with lights and lasers

You will need the diffraction grating included in the workbook and a laser pointer or flashlight

- Point the laser or flashlight through the diffraction grating and at a wall from about 6 inches away.
- Then change the distance of the diffraction grating to the wall
- Tell your merit badge counselor what you observed

Prisms splitting light

You will need a prism and a flashlight for this experiment

- Point the flashlight and laser at the prism from varying directions
- Describe the effect the prism has on the light passing through it to your merit badge counselor

Careers in optics

There are many possible careers one may pursue in optics. These could range from an optometrist to an engineer designing advanced photonics systems. An optometrist uses lenses to help focus light to your eye so you can see properly. This is necessary as the lenses of your eyes can stop focusing light properly. Software engineers are also important in optics. They will design the software to interpret data that comes in from sensors among other things that allow us to better interact with light. Photonics engineers design circuits to use light to perform actions that currently use electricity like in computers. In the future photonics might be combined with electronics for more versatile computers. Optics also plays a major role in designing cameras, from expensive professional cameras to the compact lenses needed for a smartphone. Optical engineers are also needed to help construct satellites so they can communicate effectively with equipment both on earth and distant probes. Optics also plays a role in how engineers designed the Hubble telescope to use mirrors instead of lenses in order to view very distant objects.

Further Readings

Z. Choong, "Experimental instruction in photonics for high school students: approaches to managing problems faced," in ETOP 2017 Proceedings, X. Liu and X. Zhang, eds., (Optical Society of America, 2017), paper 104524B.

This article provides an example of an experiment that may be tried in a high school environment. It hopes to give you an introduction into formal experiments.

Jeff Hecht, "Short history of laser development," Opt. Eng. 49(9) 091002 (1 September 2010)

They provide an overview o0f the history of lasers and how they came to be. He hopes to give you an introduction to what lasers were and then an overview of how they evolved into the modern device.

M. McKee, N. Magnani, and M. Posner, "OPTIKS: Outreach for Professionals who Teach in Informal Environments and K-12 Schools," in Fifteenth Conference on Education and Training in Optics and Photonics: ETOP 2019, ETOP 2019 Papers (Optical Society of America, 2019), paper 11143_20.

The purpose of this source is to provide an approach for instructors which will allow them to teach about optics. The focus is for K-12 education.

M. Teng, A. Honardoost, Y. Alahmadi, S. Polkoo, K. Kojima, H. Wen, C. Renshaw, P. LiKamWa, G. Li, S. Fathpour, R. Safian, and L. Zhuang, "Miniaturized Silicon Photonics Devices for Integrated Optical Signal Processors," J. Lightwave Technol. 38, 6-17 (2020).

The authors aim to provide information on photonics- circuits controlled by light. It goes over the functionality of circuitry derived from the properties of light instead of electricity.

Discussion

Photonics has the potential to revolutionize modern computing and usher in a new era of faster and more powerful processing. Photonic Integrated Circuits (PICs) will leave their electronic counterparts (EICs) in the dust, and come without many of the laters drawbacks, such as quantum tunneling or heating issues. These two technologies, PICs and EICs, could even be integrated together for optimized performance, should it be desirable to do so. Monolithic integration (combination of optical sources, transmission and processing onto one device), while currently a sticking point, will enable massive technological advancements once achieved (Sala 2016). Already an enabling technology to many of our industries and much of our everyday lives, the advent of photonics in computing promises to yield benefits in a variety of fields, from biology and medicine to communication and transportation. This transformation would not be possible if it were not for our modern understanding of light's nature and the principles governing it, which evolved over millennium to become what it is today.

Initially, light was considered spiritual, sacred and divine, the domain of artists and theologians, not to be understood by the human mind. However, eventually philosophy, and then science and theory, began to push back against this cloud of ignorance and uncover light's true nature. With this newfound scientific discovery came theories, and debates: from what source, into the eye or out of it, particle or wave, and at what speed? Some of these could be answered with experiments, others took centuries, and one would provide an answer far more confounding than the question. Ultimately, the discovery of the particle-wave duality of light set the stage for further research and our current quantum understanding of light. That comprehension would enable modern miracles such as light bulbs, lasers, and LEDs, with more yet to come in the future (Watson, 2016). But if our understanding of light has proven one thing, it's that it is ever changing; just when we think that we've finally gotten to the bottom of it, we find further mysteries beneath.

There is still much to be discovered, much to advance in the technologies derived from light, but all the advancements in the world will be impossible if new generations are not brought in and new interests formed. The youth are the future, but what we do today forms the foundation from which they will build it. In creating opportunities for people in the future we have a responsibility to expose as many people to the potential of these technologies as possible. Just about everybody will see and act on areas with much quicker returns on investment such as research, but too few will see the significant impact of youth involvement. The methodology of this report demonstrated one such way the resource that is the younger generations may be tapped into allowing future advancements. The Boy Scouts of America is not the only group of people that can be exposed to this rising area of technology. Opening new afterschool clubs for those in primary school, adding new material to STEM class curriculums, or just a short video in a physics class could be enough to spark the interests needed to change the future. The only obstacle is that something must be done if youth involvement is to increase.

For the booklet included in this report distribution could be one step in increasing youth interest. While on a large scale would not be possible without the Boy Scouts Of America adopting this badge we can still distribute it to local troops. This could be done by packaging the instructor guides and merit badge as separate documents and emailing them out to troops that might be interested in it. Then the troop leaders may devote some time in a meeting or even a whole one to the materials they find most important. This will expose many scouts to the materials, but more importantly provide feedback in even greater quantities and diverse views for future iterations. On these future iterations could be the scaffold upon which the BSA constructs and adopts a new merit badge allowing youth to get even more involved on a scale that would not be as easily achieved with local classrooms. The potential reach of this badge compared to any local programs is huge, it may even reach a global scale with enough interest allowing scouts in all countries participating with similar programs to access the material and fuel the future.

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