Physics Context: Apollo – God of Light

Submitted by: Jason van Tol
Student No.: 2597349
Submitted for: Dr. Richard Walding
Course: 7033CTL - Senior Science Curriculum
Date Due: 7 November, 2007
Pages: 1 – 27

CONTEXT[*]: APOLLO – GOD OF LIGHT

Foci	Key Ideas	Specific Content and Depth of Treatment	Learning Experiences	Possible Assessment Opportunities: Diagnostic and Summative
Greek mythology Wave nature of light Light as an EM phenomenon Constant nature of speed of light Types of bulbs The human eye Circuit analysis	F1.1,2 F2.3 F3.2 F4.2 E1.1,4,6 E2.2,3,5 E3.1,2,3,4 M1.2 M3.1	Wave nature of light Wave equation: $v=f\lambda$ and speed of light: $c=2.99 \times 10^8$ m/s = constant EM spectrum, EM Theory, & Maxwell's equations Interference analysis: path difference=dy_n/R, constructive: $d\sin\theta = n\lambda$, destructive: $d\sin\theta = (n - ½)\lambda$, $y_n = n\lambda R/d$ & destructive Particle nature of light and the photoelectric effect: $hf=W+E_{kmax}$ Principles behind incandescent and fluorescent bulbs Radiated power and the Stefan-Boltzmann Law: $P=e\sigma T^4 A$ Photometric law of illuminance (E) at a distance r for a point source: $E = \frac{I\cos(\varphi)}{r^2}$ (foot-candles or lm/ft^2) Revision of voltage, current, and resistance Ohm's Law: $V=IR$ & $P=VI=I^2R=V^2/R$ and Kirchoff's Loop and Junction rules Series and parallel circuit analysis.	Brief foray into Greek mythology and Apollo as the God of light as an introduction to the context Demonstration of Young's double slit experiment Class discussion on the nature of waves as lead in to the Michelson-Morley experiment and link to EM nature Class discussion of solar panels as lead in to the particle nature of light and the photoelectric effect Teacher led exposition of history of measurement of speed of light as well as the peculiarity of its constant nature Principles of incandescent and fluorescent bulbs Short investigation of temperature differences between incandescent and fluorescent bulbs and then link to Stefan-Boltzmann Law Short investigation of students' ability to detect differences in colour in light and dark environments to probe the difference of rods and cones in the human eye Problem solving activities with an emphasis on constructive and destructive interference, power, illumination, and circuit analysis	**Supervised Assessment** (stimulus-response item), (1 week preparation, 60 minutes response time): Article on light pollution used as the stimulus item with students being asked to answer, both qualitatively and quantitatively, questions regarding the problems and possible solutions of light pollution. **Supervised Assessment** (quantitative test question), (45 minutes): Design an experiment to satisfy certain properties of diffraction patterns. One two-part question. **Extended Experimental Investigation** (~5 weeks total): Being done right at the end of year 11, it would be possible for this EEI to be considered a summative item. Students are asked to investigate alone, or in groups of 2 or 3, using both research and experimental methods, the answer to: what is the best way to light a doll house?

[*] This unit is meant to be situated in term 4 of a year 11 physics class.

CONTEXT[*]: APOLLO – GOD OF LIGHT

Time: 12 weeks – ~40 hours
Overview: Apollo was the ancient Greek God of light. The Greeks conception of light, as espoused by Empedocles, was that our eye emitted the light which we used to see things. Since then, our conception of light has evolved greatly. Our sense of sight is the most precise way we can gain information about the world around us. Of course, we need light in order to use this sense, and so lighting design is of utmost importance whether it be for an art display, a surgery room, or simple task lighting for reading and studying. This context is comprised of three main topics:

1. The nature of light.
2. Different types of light bulbs, with a focus on incandescent and fluorescent.
3. Circuits which can utilize light bulbs.

Nature of Light:
Exploration will include light's particle-wave duality which is a result of our different ways of understanding the way light travels as opposed to the way it interacts with matter. Reference will be made to the famous Michelson-Morley experiment which led to the idea that although we can conceptualize light propagation as a wave, it doesn't require a medium. This phenomenon can be explained as a result of Maxwell's equations which show that a varying electric field produces a magnetic field and vice versa. The electromagnetic spectrum will also be considered. Other topics which will be investigated in order to understand the nature of light include: the nature of colour and its relation to frequency, polarization and the colour of the sky, single- and double-slit experiments to demonstrate the wave nature of light, and solar panels and the photoelectric effect to demonstrate the particle nature of light.

Types of Bulbs:
The invention of the light bulb ended the use of candles and gaslights as the primary way people lit their houses and towns. The two main types of bulbs that will be investigated are incandescent and fluorescent though reference will be made to LEDs too. The Stefan-Boltzmann Law will be included as a heuristic device for investigating and comparing the difference in power radiated from the two types of bulbs. The photometric inverse-square and cosine laws will be combined in the so-called photometric law of illuminance which links the illuminance of an object with the distance from and angle of the light source. An examination of the human eye will be made, including how it detects colour with cones and how it differentiates between light and dark primarily with rods.

Circuits:
Advances in electric circuits were necessary in order to power the invention of light bulbs. Parallel and series circuits will be investigated with an emphasis on the use of light bulbs as the load. Ohm's law and Kirchoff's loop and junction rules will be used in order to assist in analyzing such circuits.

---

[*] This unit is meant to be situated in term 4 of a year 11 physics class.


Apollo – God of Light

YEAR 11 PHYSICS
Supervised Assessment: Light Pollution

This is the stimulus component of a 60-minute stimulus-response task to be taken individually in class next week. Attached is an article entitled 'The Dark Side: Making War on Light Pollution'. You are to read through the article and *highlight* certain parts which you feel are important. No notes may be written on the article as you will be allowed to bring it to the assessment.

There is also a glossary attached with words, some which appear in the article and some which don't, for which you should find definitions, as they will assist you in your response. You should bring the glossary to the assessment as well as a pencil or pen, and a calculator. The glossary will be handed in with your solutions along with the original article.

You will be asked to answer three questions, each with multiple parts. There will be both qualitative and quantitative analysis involved.

The Dark Side

Making war on light pollution.

by David Owen

In 1610, Galileo Galilei published a small book describing astronomical observations that he had made of the skies above Padua. His homemade telescopes had less magnifying and resolving power than most beginners' telescopes sold today, yet with them he made astonishing discoveries: that the moon has mountains and other topographical features; that Jupiter is orbited by satellites, which he called planets; and that the Milky Way is made up of individual stars. It may seem strange that this last observation could have surprised anyone, but in Galileo's time people assumed that the Milky Way must be some kind of continuous substance. It truly resembled a streak of spilled liquid—our word "galaxy" comes from the Greek for milk—and it was so bright that it cast shadows on the ground (as did Jupiter and Venus). Today, by contrast, most Americans are unable to see the Milky Way in the sky above the place where they live, and those who can see it are sometimes baffled by its name.

The stars have not become dimmer; rather, the Earth has become vastly brighter, so that celestial objects are harder to see. Air pollution has made the atmosphere less transparent and more reflective, and high levels of terrestrial illumination have washed out the stars overhead—a phenomenon called "sky glow." Anyone who has flown across the country on a clear night has seen the landscape ablaze with artificial lights, especially in urban areas. Today, a person standing on the observation deck of the Empire State Building on a cloudless night would be unable to discern much more than the moon, the brighter planets, and a handful of very bright stars—less than one per cent of what Galileo would have been able to see without a telescope. Amateur astronomers sometimes classify nighttime darkness on the Bortle Dark-Sky Scale, which is based on a number of criteria, among them "limiting magnitude," or the brightness of the faintest celestial objects that are visible without magnification. The scale, composed of nine points, was devised in 2001 by John E. Bortle, a retired Westchester County fire chief and a monthly columnist for *Sky & Telescope*. "One of the problems I was addressing was that younger amateur astronomers, especially east of the Mississippi, had never seen a dark sky at all," he told me recently. "People will sometimes come up from the city and call me and say, 'John, I've found this fabulous dark site, it's totally black, you can't imagine how good it is.' So I'll go and have a look, but it's always poor. They have no comparison to work against."

In Galileo's time, nighttime skies all over the world would have merited the darkest Bortle ranking, Class 1. Today, the sky above New York City is Class 9, at the other extreme of the scale, and American suburban skies are typically Class 5, 6, or 7. The very darkest places in the continental United States today are almost never darker than Class 2, and are increasingly threatened. For someone standing on the North Rim of the Grand Canyon on a moonless night, the brightest feature of the sky is not the Milky Way but the glow of Las Vegas, a hundred and seventy-five miles away. To see skies truly comparable to those which Galileo knew, you would have to travel to such places as the Australian outback and the mountains of Peru. And civilization's assault on the stars has consequences far beyond its impact on astronomers. Excessive, poorly designed outdoor lighting wastes electricity, imperils human health and safety, disturbs natural habitats, and, increasingly, deprives many of us of a direct relationship with the nighttime sky, which throughout human history has been a powerful source of reflection, inspiration, discovery, and plain old jaw-dropping wonder.

David L. Crawford earned his Ph.D. in astronomy in 1958 and spent nearly all his professional life at Kitt Peak National Observatory, on a mountaintop fifty-six miles southwest of Tucson, Arizona. By 1970, he had noticed, with alarm, a significant decrease in astronomical visibility. Tucson was growing rapidly, and so was its sky glow. With a colleague, he persuaded the city to adopt an ordinance governing exterior lighting, and later they persuaded other Arizona cities and counties to pass similar regulations. In 1988, Crawford and another friend formed a nonprofit organization called the International Dark-Sky Association. “We’re sort of a nighttime Sierra Club,” he told me, during a recent visit to Tucson. He retired from Kitt Peak in 1995 and has worked full time for the I.D.A. ever since, often putting in sixty-hour workweeks. He has the complexion of a man who doesn’t spend a lot of time outdoors during daylight, and speaks in the modulated tones of someone accustomed to talking while others are asleep. “We’re on a mission to change the world at night,” he said.

The I.D.A.’s headquarters is a warren of small offices, accommodating a dozen or so staff members and a shifting group of volunteers and researchers, around the corner from a (non-related) store that sells light fixtures. Crawford and his staff devote much of their time to proselytizing for dark-sky regulations and working with manufacturers to improve lighting products. Hanging on a wall in a conference room is a map that shows the geographical distribution of the organization’s eleven thousand members. The states with the highest representation are California (fifteen hundred and thirty), Arizona (six hundred and seventy), New York (five hundred and one), and Massachusetts (four hundred and eighty-two). The I.D.A. also has members in seventy-eight foreign countries, including Iraq and Iran, where astronomy is a popular hobby, especially among girls and young women. Authorities in Sa’adat-shahr, about four hundred miles south of Tehran, periodically cut off all electric power in the town in order to improve visibility at nighttime “star parties” conducted by a local teacher.

When the I.D.A. began, Crawford’s interest in outdoor lighting was limited to its impact on observatories; today, the organization’s brief covers everything from advising law-enforcement officers to assessing the effects of artificial lighting on wildlife. On the evening of my visit, while Crawford and I waited for the sky to grow darker, we went to dinner at a relatively new shopping mall on Tucson’s outskirts. As we drove up, Crawford explained that the mall had been of particular interest to the I.D.A.: “The original lighting system for this mall was put in by somebody from out of town, and it didn’t meet the Tucson code, so the developer had to call in a consultant and change it all. Now it’s one of the best in town, and we actually gave them an award a few years ago.”

The mall’s large parking lot was fully illuminated—as we walked from the car to the restaurant, I had no trouble reading notes that I had scribbled in my notebook—but it was free of what dark-sky advocates call “glare bombs”: fixtures that cast much of their light sideways, into the eyes of passersby, or upward, into the sky. Tucson’s code limits the brightness of exterior fixtures and requires most of them to be of a type usually known as “full cutoff” or “fully shielded,” meaning that they cast no light above the horizontal plane and employ a light source that cannot be seen by someone standing to the side. These are not necessarily more difficult or expensive to manufacture than traditional lights, and they typically cost less to operate. Calgary, Alberta, recently cut its electricity expenditures by more than two million dollars a year, by switching to full-cutoff, reduced-wattage street lights.

Diminishing the level of nighttime lighting can actually increase visibility. In recent years, the California Department of Transportation has greatly reduced its use of continuous lighting on its highways, and has increased its use of reflectors and other passive guides, which concentrate luminance where drivers need it rather than dispersing it over broad areas. (Passive guides also save money, since they don't require electricity.) F.A.A.-regulated airport runways, though they don't use reflectors, are lit in a somewhat similar fashion, with rows of guidance lights rather than with high-powered floodlights covering broad expanses of macadam. This makes the runways easier for pilots to pick out at night, because the key to visibility, on runways as well as on roads, is contrast.

After dinner, Crawford showed me his home, in a subdivision of small, closely spaced, desert-colored stucco town houses. Tucson gives individual neighborhoods the right to choose whether they want street lights (and to pay for them if they do). Most of the newer, more affluent residential areas, and a number of commercial blocks, have elected to do without. Crawford's subdivision, to his annoyance, does have street lights, and the fixtures, though technically shielded, have frosted-glass side panels, which diffuse the light in a way that turns them into glare bombs. Crawford pointed out a cluster of mailboxes across the street from his garage. The lighting near the mailboxes was of a type that Crawford calls "criminal-friendly": it was almost painful to look at, and it turned the walkway behind the boxes into an impenetrable void. "The eye adapts to the brightest thing in sight," he said. "When you have glare, the eye adapts to the glare, but then you can't see anything darker." The human retina contains two kinds of photoreceptors—cones, which react quickly to fine details and colors, and rods, which, though slower and bad at colors, are far more numerous and many times more sensitive to light. It's mainly the rods that enable us to see at night, and they are so sensitive that they can take up to an hour to recover their full function after exposure to a light source no brighter than a desk lamp. Deer, which have an even higher proportion of rods to cones, have excellent nighttime vision but appear extremely vulnerable to temporary blinding by bright light—perhaps a reason that they have difficulty in getting out of the way of cars on dark roads. People may experience a similar phenomenon driving away from a highly illuminated outdoor area, such as a gas station with an intensely bright canopy.

Much so-called security lighting is designed with little thought for how eyes—or criminals—operate. Marcus Felson, a professor at the School of Criminal Justice at Rutgers University, has concluded that lighting is effective in preventing crime mainly if it enables people to notice criminal activity as it's taking place, and if it doesn't help criminals to see what they're doing. Bright, unshielded floodlights—one of the most common types of outdoor security lighting in the country—often fail on both counts, as do all-night lights installed on isolated structures or on parts of buildings that can't be observed by passersby (such as back doors). A burglar who is forced to use a flashlight, or whose movement triggers a security light controlled by an infrared motion sensor, is much more likely to be spotted than one whose presence is masked by the blinding glare of a poorly placed metal halide “wall pack.” In the early seventies, the public-school system in San Antonio, Texas, began leaving many of its school buildings, parking lots, and other property dark at night and found that the no-lights policy not only reduced energy costs but also dramatically cut vandalism.

Most people don’t notice bad nighttime lighting; if you do, it can make you slightly crazed. When I’m driving at night, my wife has to tell me to watch the road instead of looking back over my shoulder at a yard whose trees have floodlights in their branches, or at an empty parking lot so bright that you could deliver babies in it. The Connecticut town where I live was incorporated in 1779. Many residents are protective of the village green, and become agitated if anyone suggests doing something to it that they consider unhistorical, such as painting a house a color other than white. Yet the green’s focal point, the two-hundred-plus-year-old First Congregational Church, is lit up at night like a convenience store, and with two jarringly different types of illumination: the broad portico is lit with warm incandescent lamps, while the steeple and the clock tower are bathed in the icy glare of six mercury-vapor spotlights. A friend lives across from the church, and the lights give her living room a cold glow, as though someone had forgotten to close the door of a refrigerator. Obviously, Americans two centuries ago didn’t point spotlights at their buildings (and therefore enjoyed the extinct pleasure of seeing those buildings by moonlight and starlight), yet I would bet that most of my town’s residents, if they think about it at all, consider lighting up an old New England church not an offensive anachronism but almost a matter of civic duty.

I’m the chairman of my town’s zoning commission, and we recently adopted our first regulations governing residential outdoor lighting. The rules prohibit unshielded exterior lamps and limit the lighting of trees and other vegetation, but, like all our regulations, they apply only to installations made after the date of the change, and they will be difficult to enforce. It doesn’t help that the town itself is a conspicuous offender. A walkway near the town hall is lit by pole-mounted “Colonial” lanterns of a familiar type, with unshielded lamps and poles a bit less than six feet tall, so that most of the light is projected into the eyes of pedestrians. When the lamps are turned on, the base of each fixture casts a dense black shadow, about sixteen feet in diameter, onto the grass and pavement directly below it, as though the purpose of the lamp were to shed darkness rather than light. Some residents have objected that the new lighting regulations unnecessarily limit the freedom of individuals to do as they like on their own property. But photons don’t stop at lot lines. (If someone installed a basic Home Depot wall pack on the moon and aimed it at the Earth, you’d be able to see the light, when it wasn’t itself in direct sunlight, with a moderately powerful hobbyist’s telescope.) People who decide to illuminate their trees at night, or to install unshielded floodlights on the corners of their garage, shining into a bedroom in a house next door, are making a decision for their neighbors as well as for themselves.

My friend Ken Daniel is a lighting designer. About a decade ago, he told me something that changed the way I think about the night. It was early evening, and we were sitting with some other people in an unelectrified barn on Martha’s Vineyard and looking out at the ocean, and he observed that we were doing something that Americans almost never do anymore: watching it get dark. In the early nineteen-nineties, Daniel worked in Los Angeles and he and his family lived in Glendale. His wife, Gina, told me that the street lights and other lights in their neighborhood were so bright that their bedrooms never got fully dark at night, even though they had curtains. When the Northridge earthquake struck, in 1994, the first thing she noticed, after the shaking had awakened her, was that she couldn't see. "The earthquake had knocked out the power all over the city, and everything was black," she said. "When we got the kids and ran outside, we found all our neighbors standing in the street, looking up at the sky and saying, 'Wow.' "

Growing numbers of us pass most of our waking hours "in a box, looking at a box," as Dave Crawford put it: we spend our days inside offices, looking at computer screens, and our evenings inside houses, looking at television screens. Fewer and fewer of us spend much time outside at all, except in automobiles—and when we do venture outdoors after dark we are usually just stepping into yet another box, the glowing canopy that our lights have projected into the sky.

The twenty-four-hour day/night cycle, which is also known as the circadian clock, influences physiological processes in virtually all living things. Pervasive artificial illumination has existed for such a brief period that not even the species that invented it has had time to adapt, biologically or otherwise. The most widely discussed human malady related to the disturbance of circadian rhythms is jet lag, but there are others. Richard Stevens, a cancer epidemiologist at the University of Connecticut Health Center, in Farmington, has suggested a link between cancer and the "circadian disruption" of hormones caused by artificial lighting. Early in his career, Stevens was one of many researchers struck by the markedly high incidence of breast cancer among women in the industrialized world, in comparison with those in developing countries, and he at first supported the most common early hypothesis, which was that the cause must be dietary. Yet repeated studies found no clear link to food. In the early eighties, Stevens told me recently, "I literally woke up in the middle of the night—there was a street lamp outside the window, and it was so bright that I could almost read in my bedroom—and I thought, Could it be that?" A few years later, he persuaded the authors of the Nurses' Health Study, one of the largest and most rigorous investigations of women's medical issues ever undertaken, to add questions about nighttime employment, and the study subsequently revealed a strong association between working the night shift and an increased risk of breast cancer. Eva Schernhammer, of the Harvard Medical School, and Karl Schulmeister, an Austrian physicist, analyzed the work-shift data from the Nurses' Study several years ago, and wrote, "We hypothesize that the potential primary culprit for this observed association is the lack of melatonin, a cancer-protective agent whose production is severely diminished in people exposed to light at night."

Although nighttime lighting has seldom been a priority of environmentalists—one of whom described it to me recently as a "soft" issue—bad or unnecessary lighting not only wastes billions of dollars' worth of energy every year but also can wreak havoc on ecosystems. Migrating birds can be fatally "captured" by artificial lights, a fact that was made obvious a half century ago, when early versions of a common meteorological device called a ceilometer—which used a powerful vertical beam of light to measure cloud ceilings—sometimes killed thousands of migrating birds in a single night. Artificial light can be especially lethal to insects. Gerhard Eisenbeis, a German entomologist, has written that outdoor lighting can have a "vacuum cleaner" effect on local insect populations, causing large numbers to be "sucked out of habitat." An earlier German study showed that new, brightly lit gas stations initially attracted large numbers of insects, but that the numbers fell rapidly after two years, presumably because local populations were decimated. One of the several ways in which light fixtures kill insects is by causing them to rest on the ground or in vegetation, where they become easy prey. In Florida, artificial lights have had a disastrous impact on sea-turtle populations. During the summer and the early fall, hatchlings, which emerge primarily at night from nests on Florida beaches, are often fatally attracted to street lights, house lights, and other sources of unshielded artificial illumination, dying after being drawn into open areas, where they are easily attacked by predators, or onto roads. The problem is that newborn sea turtles instinctively move toward the brightest part of the horizon—which, for millions of years, would have been not shopping malls and beach houses but the night sky over the open sea.

The day after Dave Crawford and I inspected nighttime Tucson, I drove five hundred and fifty miles north to Bryce Canyon National Park, in southern Utah. That evening, I joined about two hundred people, including many children, outside the visitors' center, where telescopes of various sizes had been set up in the parking lot. Several were equipped with computerized tracking devices, which could be programmed to find and follow interesting objects in the sky. At one station or another, I saw the four Galilean satellites of Jupiter (tiny dots in a line), Saturn (with rings), a dense group of old stars, known as a globular cluster, a pair of twin stars (one blue and one gold), and the mountains and valleys that Galileo saw on the moon. With just my own eyes, I saw the orbiting Hubble Space Telescope, which rapidly crossed the sky just before eleven o'clock, and, a little later, I saw the meteor-like flash of a passing Iridium satellite.

I spoke with Chad Moore, the program director of the National Park Service's Night Sky Team. "Many people who come to our programs have never really looked at the night sky," he told me. "A woman once came up to me and said, 'The moon was out during the day this morning—is that O.K.?' " Moore, who is in his mid-thirties, created the Night Sky Team in 1999. Its mission, he said, is not just to increase interest in stars but also to remind people, including higher-ups in the Park Service, that national parks don't go away when the sun sets.

Moore and I met back in the same parking lot about three hours later, long after the other stargazers had gone to bed. The moon was going to set at about three-forty-five, and at that point there would be an hour of deep darkness before sunrise. We drove to another parking lot, near the rim of the canyon, and walked up to Sunset Point, one of a series of lookouts linked by a walking path. Moore said that he and his fellow-rangers usually have to urge first-time participants in the park's nighttime programs to resist turning on flashlights the moment they step out of their cars, and to instead allow their eyes to become accustomed to the darkness. "When the moon is low in the sky like this, there's about two-thousandths of a foot-candle of light on the ground," he said, referring to a measure of illumination. (Full sunlight on a clear day has an intensity of about ten thousand foot-candles; nighttime city streets are typically lit to about one and a half foot-candles, seven hundred and fifty times brighter than the moonlit path.) "You and I don't have supernatural vision," he continued, "but we're able to see the path just fine, because our eyes evolved to see in these conditions. I can see individual pebbles on the ground, and if I dropped a quarter I could find it."

We walked north along the rim trail, on which the setting moon cast long shadows. The canyon's edge was just a few feet to our right, but I could easily tell where the path ended and the abyss began. The canyon itself was transformed. In bright sunlight, Bryce's orange-and-white limestone hoodoos, which look a little like enormous drip castles, are so vibrant that they almost shimmer; by night, the formations are virtually monochromatic, like mountains at the bottom of the sea. Nightfall inverts the park: the cliffs draw inward, and the sky becomes almost topographical, a canyon turned upside down.

At last, the moon disappeared below the horizon. I could see, at various compass points, little bulges of sky glow projected by a couple of nearby towns, by one or two more distant cities, and by Ruby's, the famous, light-encrusted Bryce-area motel and campground, a few miles away, but the sky directly above us was very dark and was filled with stars. I had no trouble seeing the Milky Way, a broad, densely speckled stripe extending across the sky. Moore pointed out the Great Rift, a cluster of dark patches caused by clouds of light-blocking interstellar dust, and the constellation Sagittarius, toward the luminous center of our galaxy. I lay on my back on a bench and watched for meteors, which streaked past every few minutes: in a truly dark sky, shooting stars are too numerous to bother wishing on. We stayed until we noticed the first glow of the approaching sunrise. Stars near the eastern horizon melted away ahead of it, as though the darkness itself were dissolving.

The next afternoon, Moore and I drove across southern Utah to Natural Bridges National Monument, in the southeastern corner of the state, two hundred and seventy-five miles away. This past March, the I.D.A., relying partly on darkness measurements collected by Moore and his team, selected Natural Bridges as its first International Dark-Sky Park. (Additional sites will be chosen within the next year.) At the time of the designation, Christian Luginbuhl, an astronomer at the U.S. Naval Observatory station in Flagstaff, Arizona, and a longtime dark-sky advocate, said, "In plain English, that means it's the darkest or starriest sky they've seen while doing these reviews."

We arrived at the park just as the summer sky was beginning to deepen, and toured the facilities with Corky Hays, the park's superintendent. Hays came to Natural Bridges in 2004 partly because her previous Park Service posting, Death Valley, had begun to feel too cosmopolitan to her. "Our buildings were pretty dark already," she said, "but Chad and his team have helped us make them even darker, by upgrading a lot of our outdoor lighting. That's let us cut our energy use and operational costs, too, which is important, because the entire park is solar-powered." Moore pointed out several newly installed full-cutoff light fixtures, and found a few older lights, which still needed to be replaced. He asked for the removal of two of the four tubes in a fluorescent ceiling fixture near some public rest rooms, which are kept open all night and are used by after-dark visitors to the park. "The darker the area, the less light you need," he said. "People coming here at night will be dark-adapted, so having more light would actually make it harder for them to see when they leave."

A couple of hours later, after the sun had set completely, Moore and I headed for Owachomo, one of the park's three natural bridges—which were created, thousands of years ago, by fast-flowing streams that undercut the sandstone walls of their canyons. Owachomo, at its midpoint, rises more than a hundred feet above the canyon floor and is almost two hundred feet across. As we turned a corner on the path, it suddenly loomed before us, a startling black void against a field of stars, like a long, ragged strip torn from the sky. After checking the ground for rattlesnakes (we had encountered one already), Moore and I leaned against some big rocks and simply looked. If I stood still, I could see stars apparently blink off, as the earth's rotation caused them to be occluded by the sandstone bridge, while, on the other side, others seemed to blink on. The park is so remote that there is little artificial noise, especially at night, and the silence deepened the darkness. Thinking about the incomprehensible distances above us made me remember nights forty years before, when I was twelve years old and lying on my back in a mountain meadow at summer camp in Colorado, watching for shooting stars in what was probably the darkest sky I've ever seen, or will ever see.

Moore and I stood like that, not saying much, for more than an hour. Then we returned to the visitors' center and said goodbye. I drove east to the nearest town, where I hoped to get some sleep before continuing to Salt Lake City and my flight home. Moore, who had brought a sleeping bag, went out into the park to spend the night under the stars. ♦


Apollo – God of Light

Name:__________________________

Date:__________________________

YEAR 11 PHYSICS
Supervised Assessment: Light Pollution

Time for completion: 60 minutes

This is a response task to the article given out last week entitled ‘The Dark Side: Making War on Light Pollution’. You are allowed the original article *with highlighting only*. No notes may be written on it. You may also have a pencil or pen, calculator, and one side of one A4-size paper with your glossary. The glossary is to be handed in with your solutions to the questions below, along with the original article.

Question:

1. List at least 3 problems or phenomena associated with light pollution. Give detailed answers using any relevant physical concepts and terminology, and in addition any pertinent social or environmental factors.

2. Propose solutions to the problems or phenomena you described in question #1. Again, reference should be made to any relevant physics.

3. Consider the information in the article on the association between artificial lighting and its effects on people’s health.

a) Suppose you were a health specialist and wanted to investigate these effects. Using terminology listed in your glossary, and any other relevant concepts, describe and justify what you would measure to help determine the causes of the health problems associated with people’s melatonin levels.

b) Consider the passage from the text: “‘When the moon is low in the sky like this, there’s about two-thousandths of a foot-candle of light on the ground,’ he said, referring to a measure of illumination. (Full sunlight on a clear day has an intensity of about ten thousand foot-candles; nighttime city streets are typically lit to about one and a half foot-candles, seven hundred and fifty times brighter than the moonlit path.)”

Suppose it was found that a person’s melatonin increased to a level where there was no appreciable link to cancer when the level of illumination from night time lighting was decreased to only 50 times that provided by moon light. Using any relevant relationship, law, or calculations, show three ways you could adjust the lighting to bring about this change. Also, state which of these three ways would be the least feasible, and give a reason why.

Glossary:

1. Illumination:

2. Lumination:

3. Contrast:

4. Lumen:

5. Candela:

Supervised Assessment – Light Pollution

Question	Criteria	A	B	C	D	E
1	KCU1,2			Reproduction of at least 3 pertinent problems or phenomena with details which include reference to physical concepts	Reproduction of 2 pertinent problems or phenomena with details	Reproduction of problems
2	KCU3		Application of concepts and terminology to find solutions to complex situations	Application of concepts and terminology to find solutions to simple situations	Application of concepts and terminology	Application of simple ideas
3(a)	EC2, KCU1	Exploration of work or home scenarios, using complex and challenging terminology and concepts of light, to find possible outcomes with justification of conclusions and/or recommendations	Explanation of work or home scenarios, using complex or challenging terminology and concepts of light, to find possible outcomes with discussion of conclusions and/or recommendations	Description of work or home scenarios, using terminology and concepts of light, to find possible outcomes with statement of conclusions and/or recommendations	Identification of work or home scenarios or possible outcomes, using simple terminology and concepts of light	Statements of work- or home-place outcomes, using isolated concepts of light
3(b)	KCU1,3, EC1,2	Application and interpretation of law of photometry to find three distinct and appropriate solutions with justification of feasibility of solutions*	Application of law of photometry to find at least two solutions with discussion of feasibility of solutions*	Application of law of photometry or other concepts of light to find a solution with statement of feasibility*	Reproduction of concepts of light to identify a possible outcome	Identification of simple isolated facts or concepts of light to state an outcome

* It's conceivable that a student may instead answer this question by applying the Stefan-Boltzmann Law: $P=e\sigma T^4A$, and making some assumptions as to the area being illuminated, as well as the relative visual sensation of the eye to an appropriately assumed frequency, in order to convert the given foot-candles into Watts. As unlikely as this may be, it could then be argued that we could adjust the variables corresponding to e, A, and T to bring about the appropriate changes. Should this be the case, students could certainly score an A-level grade for doing so, and if done properly would likely even score an A+ grade.

MODEL SOLUTIONS

1. List at least 3 problems or phenomena associated with light pollution. Give detailed answers using any relevant physical concepts and terminology, and in addition any pertinent social or environmental factors.

<u>POSSIBLE ANSWERS</u>

a) Astronomers cannot see the stars so well due to the lumination of artificial light. That is, the contrast is too low. Many suburban skies are now class 5-7 on the Bortle scale.
b) Energy and money considerations. Increased and unnecessary lighting uses energy and costs money.
c) Health and safety factors affecting people, animals, and insects. Some of which are associated with disrupted Circadian-rhythms, increased cancer rates due to lack of melatonin, disruption of habitat to insects, and adverse affects on hatchling sea-turtles.
d) Safety factors associated with being blinded by excessively bright light which can actually increase crime. This is due to the fact that visibility depends on contrast and that the human eye adjusts to the brightest source, and therefore the human eye is unable to see anything in shadow or in relatively low intensity light.

2. Propose solutions to the problems or phenomena you described in question #1. Again reference should be made to any relevant physics.

<u>POSSIBLE ANSWERS</u>

a) Use shielded lights to minimize sky glow. Use well placed lights so they are task specific, rather than lighting huge expanses. Turn off lights when not needed. All of these will help to reduce luminance and increase contrast so the stars are more visible.
b) Use compact fluorescent lights instead of incandescent since they use less energy, produce more light within the visible range, and last much longer and therefore save on maintenance and replacement costs.
c) Match Circadian-rhythms with natural sleep patterns by going to bed earlier, and not staying up too late using artificial light. Shield outdoor lighting to keep from affecting local insect and animal populations.

3. Consider the information in the article on the association between artificial lighting and its effects on people's health.

a) Suppose you were a health specialist and wanted to investigate these effects. Using terminology listed in your glossary, and any other relevant concepts, describe and justify what you would measure to help determine the causes of the health problems associated with people's melatonin levels.

<u>POSSIBLE ANSWER</u>

I could try to determine the number of lumens being emitted in a person's workplace. Lumens are a measurement of the power of visible light and so I would assume that the more powerful the light in a person's workplace, the higher the chance of their melatonin being broken down, and thus the increased chance the person would get cancer. This may be simply a function of the bulbs used in the workplace, but it's also possible that outdoor light passing through a window would be a contributing factor. I could also try to measure the number of candelas roughly across the area where the person normally works (this would be easier at a desk job where the person is relatively stationary). In this way I could measure the amount of power passing through the area where a person's eyes would normally be (approximately) and based upon this could recommend ways of reducing the radiated power across that area, for example by using different bulbs or shielded monitors for the computer.

b) Consider the passage from the text: "'When the moon is low in the sky like this, there's about two-thousandths of a foot-candle of light on the ground,' he said, referring to a measure of illumination. (Full sunlight on a clear day has an intensity of about ten thousand foot-candles; nighttime city streets are typically lit to about one and a half foot-candles, seven hundred and fifty times brighter than the moonlit path.)"

Suppose it was found that a person's melatonin increased to a level where there was no appreciable link to cancer when the level of illumination from night time lighting was decreased to only 50 times that provided by moon light. Using any relevant relationship or law show three ways you could adjust the lighting to bring about this change. Also, state which of these three ways would be the least feasible, and give a reason why.

<u>POSSIBLE ANSWER</u>
As stated in the article, the ratio of illumination of night time artificial lighting, E_n, usually at 1.5 foot-candles, compared to that of moon light, E_m, usually about 0.002 foot-candles, is $\frac{E_n}{E_m} = 750$. We want this ratio to no more than 50, so what must E_n be so that this is true? $\frac{E_n}{E_m} = \frac{E_n}{0.002} = 50$ and solving for E_n gives: $E_n = 0.002 \times 50 = 0.1$ foot-candles. Now, by what factor must the current value of E_n(=1.5) be reduced to give 0.1 foot-candles? Denoting the factor *x*, $1.5x = 0.1$ we find $x = \frac{1}{15} = 0.0\overline{6}$. Thus we must reduce the illumination E_n, by a factor of $0.0\overline{6}$.

Now consider the law of illumination for a photometric point source, $\mathrm{E} = \frac{I\cos(\varphi)}{r^2}$ which is often a very good approximation for finite sources so long as the distance *r* is greater than 10 times the largest dimension of the source. By varying the luminous intensity *I*, the distance *r*, or the angle at which the light strikes the surface φ, we can decrease the illumination *E* by a factor of $0.0\overline{6}$.

If E_i is the present or initial level of illumination and E_f the final level, then we want $E_f = \frac{1}{15}E_i$. The first way we can achieve this is if we treat φ and *r* as constants and let $I_f = \frac{1}{15}I_i$, then $E_f = \frac{1}{15}\frac{I_i\cos(\varphi)}{r^2} = \frac{1}{15}E_i$. Next, by treating φ and *I* as constants and letting $r_f = \sqrt{15}r_i$, then $E_f = \frac{I\cos(\varphi)}{(\sqrt{15}r_i)^2} = \frac{I\cos(\varphi)}{15r_i^2} = \frac{1}{15}E_i$. Finally, by treating *I* and *r* as constants, $\cos(\varphi_f) = \frac{1}{15}\cos(\varphi_i)$. However, the amount that we should vary φ will depend on its value and thus there is no single solution. However, suppose that in the first case that the light is normal to the surface. Then $\varphi_i = 0$ and thus $\cos(\varphi_i) = \cos(0) = 1$. Then we would have $\cos(\varphi_f) = \frac{1}{15}$ and so $\varphi_f = \arccos(\frac{1}{15}) \cong 86^{o}$. The last change, by varying the angle φ would be the least feasible since we would have to design the bulb in such a way that it emitted light at almost right-angles to the ground, which would be an enormous waste of light, and so energy and money too. The first two cases amount to reducing the luminous intensity of the source and the distance from the bulb to the ground, both of which are much more effective.

<u>Glossary:</u>

<u>POSSIBLE DEFINITIONS</u>

1. Illumination – the amount of light received on a unit area of a surface. Measured in lumens per square meter or lumens per square foot, historically called the meter-candle and foot-candle respectively.

2. Lumination – the amount of light emitted or re-emitted from a unit area of a surface; formerly called the brightness. Measured in candela per square meter or candela per square foot.

3. Contrast – the difference of luminance levels between two objects.

4. Lumen – a measure of luminous flux (Φ), abbreviated lm, and analogous to the unit of radiant flux (Watt), differing only in the eye response weighting.

5. Candela – a measure of luminous intensity (I), abbreviated cd, and often referred to as candle-power; the luminous intensity (cd) is equal to the luminous flux (lm) per steradian (sr). That is Φ/w=I (lm/sr)=I (cd), where w is the number of steradians. Monochromatic light at 555nm (green light to which the eye is most sensitive during daytime) at a radiant intensity of 1/683 Watts/steradian is defined to be one candela which approximates the output of one candle.

Apollo – God of Light

Name:________________________

Date:________________________

YEAR 11 PHYSICS

Assessment #2 – Supervised Assessment

Time for completion: 45 minutes

This is a multi-step test question. You are allowed, a pencil or pen, calculator, and one side of one A4-size paper with *formulas only*. No solutions are allowed on the formula sheet, and the formula sheet is to be handed in with your solution.

Design an experiment that produces a diffraction pattern with the 6^{th} bright band of one colour in the same position as the 5^{th} dark band of another colour. In so doing:
a) Draw and label a diagram which shows all the necessary components of your apparatus and all important parameters as well as the diffraction pattern for each case.
b) Specify values of all parameters in your apparatus, showing any necessary calculations, and identify your two colours by name and by wavelength. Use the table below to help you identify your colours' names:

Name	Wavelength (nm)
Violet	400 – 440
Blue	440 – 480
Green	480 – 560
Yellow	560 – 590
Orange	590 – 630
Red	630 – 700

Supervised Assessment – Diffraction Experiment

Question#/Topic	Criteria	A	B	C	D	E
a) Apparatus Design	IP2	Apparatus described contains: only the equipment appropriately labeled and in correct relation: laser, screen, double-slit screen, as well as all the parameters d, R and y_m and the diffraction pattern shown in appropriate positions on diagram*	Apparatus described contains: at least two pieces of equipment appropriately labeled and in correct relation: laser, screen, double-slit screen, as well as all parameters d, R and y_m and the diffraction pattern shown in appropriate positions on diagram*	Apparatus described contains: at least two pieces of equipment appropriately labeled and in correct relation: laser, screen, double-slit screen, as well as at least two of the parameters d, R and y_m and the diffraction pattern shown in appropriate positions on diagram*	Apparatus described contains: at least one piece of equipment appropriately labeled: laser, screen, double-slit screen, as well as at least one of the parameters d, R and y_m and the diffraction pattern shown in appropriate positions on diagram*	Apparatus described contains: any labelled equipment, as well as any parameters*
b) Procedural Calculations	KCU1,3 EC1	Calculations contain: reproduction and application of wave-properties of light to calculate wavelengths of two different colours and satisfy all other criteria of the experiment including $R >> y_m >$d	Calculations contain: reproduction and application of wave-properties of light to calculate any two different wavelengths, one of which is in the visible range, and satisfy all other criteria of the experiment including $R >> y_m >$d	Calculations contain: reproduction and application of wave-properties of light to calculate at least one wavelength in the visible range and at least satisfy the criterion $R >> y_m$	Calculations contain: reproduction and application of wave-properties of light to calculate at least one wavelength and at least satisfy the criterion $R > y_m$	Calculations contain: reproduction and application of wave-properties of light to calculate any wavelength

*Note: if a student uses a single-slit screen before the double-slit screen as Young originally did with an incoherent source of light, and is appropriately positioned and labeled, this setup may be substituted for the laser.

MODEL SOLUTIONS

a) Draw and label a diagram which shows all the necessary components of your apparatus and all important parameters as well as the diffraction pattern for each case.

<u>POSSIBLE ANSWER</u>

b) Specify values of all parameters in your apparatus, showing any necessary calculations, and identify your two colours by name and by wavelength.

<u>POSSIBLE ANSWER</u>
Using a double slit setup with monochromatic, coherent light (possibly from a laser), we know that constructive interference, and hence bright bands occur when:
$d \cdot \sin\theta = n \cdot \lambda$ for n = $0, \pm 1, \pm 2, \ldots$

while dark bands occur when: $d \cdot \sin\theta = (n - \frac{1}{2}) \cdot \lambda$ for n = $0, \pm 1, \pm 2, \ldots$

Assume that for our apparatus $R >> y_m$. Then $y_m = R \cdot \tan\theta$ or $y_m = R \cdot \sin\theta$

Combining this result with that above we find: $y_m = R\frac{n\lambda}{d}$ for constructive interference and $y_m = R\frac{(n-\frac{1}{2})\lambda}{d}$ for destructive interference. Let's suppose we choose violet light with a wavelength of 400 nm which produces the 6th bright band. Then: $y_6 = R\frac{6 \cdot 400 \times 10^{-9}}{d}$. We want this to be equal to the 5th dark band of another colour light. We can find this colour by setting $y_6(constructive) = y_5(destructive)$.

So: $R\frac{6 \cdot 400 \times 10^{-9}}{d} = R\frac{\frac{9}{2} \cdot \lambda}{d}$ and solving for λ, we find $\lambda = 5.\overline{3} \times 10^{-7}$ or λ = 533nm which corresponds to green light. Now all we need to do is ensure that we choose $R >> y_m$ >d. So for example choose: R = 1m, y_m = 5mm, and d = 0.1mm.


Apollo – God of Light

YEAR 11 PHYSICS
Extended Experimental Investigation: How to Light a Doll House

Overall Task[*]:
You are to determine the most 'effective' way to light a doll house using the materials described below.

1. TASK OUTLINE:
The task you are to complete is to make an experimental investigation of the most 'effective' way to light a doll house. You may work alone or in groups of two or three, but the work done in class must be shared evenly and each student will hand in their own report at the end.

The equipment you have available to make your investigation includes, but is not limited to:
- connection wires
- switch
- DC power source
- incandescent light bulbs (3)
- light dependent resistors
- multi-meter
- cardboard box to simulate a room

If you wish to use any other materials you will either have to ask you teacher or the lab technician for them or if they are not available gather them yourself.

2. TIMELINE:

Phase 1	Week 8	Plan
Phase 2	Week 10	Results
Phase 3	Week 11	Draft
Phase 4	Week 12	Final Report

You must keep to the timeline as it will assist you in organizing your investigation.

3. JOURNAL
You must keep a journal to record any information, calculations, thoughts or reflections throughout the duration of your investigation. It will not be marked but it may be used to authenticate your work and to ensure that you have engaged with the research process. *Plagiarism will not be accepted.* To this end, you must hand in your journal at the end of each phase along with the checklist provided which will be used to provide some basic feedback.

4. PROCESS

[*] Much of this task description was adapted from Richard Walding's example EEI handout from Moreton Bay College.

While you will be given time in class to plan and carry out your investigation as per the timeline above, understand that additional work will need to be done outside of class.

Though some of the concepts already covered in this unit on light may be applicable to your investigation, you will likely need to do some research to inform your understanding and development of the investigation.

Finally, keep in mind that this is a major assessment piece for the year so make sure you do enough quality work to achieve at the best of your ability.

PHASE 1 – PLAN

Step 1 – Decide on a group and alert your teacher as to who you will be working with.

Step 2 – Research your topic using books, internet, journals, or any other resources you can find. You *must* record your sources as you go and include them in a bibliography in your final report. A useful website on how to produce a bibliography using the Harvard System is given here: http://dicksonc.act.edu.au/Library/bibliog.html. You may use another system if you wish, but be consistent and be precise. Make sure that you cover all the relevant physics.

Step 3 – Design your investigation. You must be specific about the variables or constants you will measure, a list of equipment you will use, and come up with an Aim for your experiment. The Aim will be a specific statement about what you plan to do with reference to the variables and constants you plan to measure. Taking care to formulate a good Aim will help guide the entire investigation.

Step 4 – Write up your plan and hand it in to your teacher by the due date set in the timeline. Remember to include your journal and checklist.

PHASE 2 – PERFORMING the EXPERIMENT

Step 1 – Assemble your apparatus using your materials.

Step 2 – Perform preliminary trials of your investigation and record in your journal all data and observations of, or changes you need to make to your experiment. This last point is important since you may find you overlooked something in your initial plan and need to modify your apparatus, measured variables, etc.

Step 3 – Perform you final experiment, again recording all your work in your journal.

Step 4 – Hand in your journal showing all your data and observations to your teacher along with your checklist.

PHASE 3 – DRAFT REPORT

Step 1 – Write up a draft report as per the guideline given for the final report.

Remember that each student is to hand in their own report and that you must reference all the sources you used in your bibliography.

Step 2 – Hand in your draft report by the due date set in the timeline, along with you journal and checklist. Your teacher will give you feedback to help guide the preparation of your final report.

PHASE 4 – FINAL REPORT

Title Page – Include the subject, course code, assessment task type, title, your name, date, and the teacher's name.

Abstract – A paragraph outlining the main points of your investigation such that someone could read it in under a minute and get the gist of what your report is about. It should include a short description of what you were investigating, your method, and a brief statement of your results and conclusions.

Introduction – This should begin by giving the reader some background on your topic with reference to your research. Don't forget to reference your sources! It should also state your research question (i.e. some form of the given Overall Task) as well as your Aim and any hypotheses you have come up with. A hypothesis is an expected outcome of an experiment and should not be based on simple guessing, but upon reasons informed by your research.

Planning & Preliminary Trials – Here you should include the constants and variables you measured or calculated in your experiment, the method you used with a diagram of your apparatus, the preliminary data you collected in a suitable format (e.g. tables or graphs), as well as a discussion about the viability of your original plan; that is, did you have to modify your apparatus, measured variables, etc. Save any discussion about your results and conclusions of your final data set for the headings below. This section is meant to describe your experimental design only.

Method – A description of what you did during your final round of data collection. Use the passive voice, in past tense, without mentioning yourself (i.e. don't say 'I connected the wire to the battery', instead say 'the wire was connected to the battery'). If you must refer to yourself, do so in the third person using the phrase 'the researcher' (i.e. it is the opinion of the researcher that…).

Results – Display your results in suitable formats (i.e. tables, graphs, etc). You should show any necessary model calculations, though if you have performed the same calculation for a set of data you needn't show it for every datum.

Discussion, Interpretation and Error of Data – This is arguably the most important part of your report. You must critically analyze your data and discuss possible interpretations of it. Can you confirm or refute your hypotheses? Why or why not? Make sure that in answering this question you make reference to any pertinent physics. If you have collected data that seems to run contrary to anything you found in your research *do not fudge the numbers*; it shows a misunderstanding of how science operates and you forgo the opportunity to speculate on possible sources of error in your experiment. A common view of the nature of science which is promoted by Karl Popper is that it is a history of corrected mistakes, and while it's unlikely that you will overturn any accepted laws of science in your experiment, it's far more important that you give an honest account of your own possible errors than to distort your data to fit what you think it should be.

Conclusion – Briefly state any conclusions you can draw from your investigation, without sacrificing any special conditions or important details (e.g. 'using a DC source'). Also, make sure you use the correct units in reporting any numbers and a modest degree of accuracy. Though we haven't talked about how to calculate error, it is unlikely you will be able to quote a value of 1.897349271W, even if your calculator returns such values. A more reasonable value might be 1.9W or 1.90W. Finally, use cautious language in stating your conclusion, such as, 'the results supported…', rather than 'the results proved…'.

Bibliography – Be sure to include a bibliography referencing all your sources. Again, the website, http://dicksonc.act.edu.au/Library/bibliog.html is a good source on how to create one according to the Harvard System.

Final Step – Make sure you hand in your final report by the due date set in the timeline, along with your journal, checklist, and any other evidence that supports your work.

Name:________________________________

CHECKLIST FOR FEEDBACK

PHASE	TEACHER'S COMMENTS AND INITIALS
1 – PLAN Group members decided Evidence of background research Sources referenced Relevant physics Experiment design Development of Aim Journal received Completed on time	
2 – RESULTS Apparatus constructed Variables and constants identified Data trialing recorded Any necessary changes noted Journal received Completed on time	
3 – DRAFT Correct report format Proper use of language Appropriate data formats Bibliography Journal received Completed on time	
4 – FINAL REPORT Journal received Completed on time	

Comments:

Teacher's Signature:____

Extended Experimental Investigation – How to Light a Doll House

Topic	Criteria	A	B	C	D	E
Report Format	EC3	Mastery of report format which includes discriminating selection of appropriate language, grammar, data & bibliography	Confident use of report format which includes selection of appropriate language, grammar, data & bibliography	Competent use of report format which includes selection of appropriate language or grammar, data, and a bibliography	Use of report format which includes use of data and bibliography	Information communicated
Abstract, Introduction & Hypothesis	IP1,EC1	Abstract is clear and concise and gives an informative summary of the report Introduction develops a clear and valid focus question Hypothesis between variables and predicted results is clear and justified based on research	Abstract is clear and gives an informative summary of the report Introduction states a clear and valid focus question Hypothesis between variables and predicted results is justified based on research	Abstract gives an informative summary of the report Introduction states a valid focus question Hypothesis between variables and predicted results is based on research	Abstract gives a vague overview of the report Introduction states a focus question Hypothesis between variables and predicted results is presented	Abstract is presented Introduction is presented Hypothesis is presented
Background Research	KCU1	Reproduction and interpretation of complex and challenging physics concepts and theories	Reproduction and interpretation of complex or challenging physics concepts and theories	Reproduction of physics concepts and theories	Reproduction of simple physics concepts and ideas	Physics knowledge is displayed
Experimental Design	KCU3, IP1,2	Linking and application of physics concepts and theories to inform effective and efficient design and management of investigation	Linking and application of physics concepts and theories to inform design and management of investigation	Application of physics concepts and theories to select and manage investigation	Application of simple physics to manage investigation	Application of simple given procedures
Data Collection and Calculations	IP3, EC3	Data display formats are chosen appropriately, correctly constructed, and clearly display meaningful patterns in data Discriminating selection and use of appropriate calculations to support meaningful conclusions	Data display formats are chosen, carefully constructed, and display patterns in data Selection and use of appropriate calculations to support meaningful conclusions	Data display formats present data accurately Use of calculations to support meaningful conclusions	Data display formats present data Use of calculations to support conclusions	Data is presented Use of calculations

Topic	Criteria	A	B	C	D	E
Discussion, Interpretation and Error of Data	EC1,3 KCU2	Methodical comparison and explanation of data with reference to appropriate physical concepts and rational discussion of sources of error	Comparison and explanation of data with reference to physical concepts and discussion of sources of error	Explanation of data with reference to physical concepts and statement of sources of error	Description of data, physical concepts and statement of sources of error	Statement regarding data and sources of error is presented
Conclusion	EC2, KCU3	Aim and hypothesis are clearly and correctly discussed via justified conclusions supported by data	Aim and hypothesis are clearly discussed via conclusions supported by data	Aim and hypothesis are discussed via conclusions which reference the data	Aim and hypothesis are restated and a conclusions is drawn with reference to the data	Conclusion is stated

Bibliography

Bloomfield, L.A. 1997, *How Things Work: The Physics of Everyday Life* (2nd ed.), John Wiley & Sons, Inc., Brisbane.

Ditchburn, R.W. 1976, *Light,* volume 1, Academic Press Inc., London.

Eastwell, P.H., 1996, *Physics Spectrum*, McGraw-Hill Book Company, Sydney.

Freeman, M.H. 1990, *Optics* (10th ed.), Butterworths, Sydney.

Klein, M.V. 1970, *Optics*, John Wiley & Sons, Inc., Sydney.

Owen, D. 2007, *The New Yorker* [online], viewed 5 October 2007, <http://www.newyorker.com/reporting/2007/08/20/070820fa_fact_owen>

Pellegrini, G.A. 1718? *Apollo* [online], viewed 21 October 2007, <http://www.maicar.com/GML/000Free/000Apollo/source/13.html>

Popper, K.R. 1972, *The Logic of Scientific Discovery*, Hutchinson & Co. Publishers Ltd., London.

Senior Syllabus: Physics, 2007, Queensland Studies Authority, Springhill, Queensland.

Walding, R. 2007, *Moreton Bay College Work Program*, Unpublished.

Young, H.D., Freedman, R.A. 1996, *University Physics* (9th ed.), Addison-Wesley Publishing Company Inc., Sydney.