LIGHT

A tale about rainbows and the northern lights,

flames and fireflies,

and the human struggle to ward off the dark

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INTRODUCTION

Sunlight and moonlight. Northern light and southern light. Bonfire and candle, lamps and nightlights. Light bulbs, oil lamps, traffic lights, and lasers. Dawn. Twilight. Stars and comets. Shadows and mirages. Rainbows. Colors.

 Light is all of this—and much more. It is everywhere.

 If you look at nighttime images of the earth, it is easy to see where we humans live. Our cities are pin pricks of light. Roads spread out like gleaming cobwebs. Whereever we go, we take the light with us, in the form of everything from living room lamps and streetlights to cell phone screens and blinking LEDs. It would almost make one believe that modern humans are collectively afraid of the dark. We have covered the planet with so much light that it has become difficult to avoid it. Doctors and psychologists have begun to warn about it. Do we understand the effects that a ceaseless glow might have on us? Astronomers have also begun to raise the alarm. They are no longer able to clearly observe the night sky. The message of the universe, which radiates down to us from the stars, is becoming less and less apparent.

 Culturally, light stands for good things. It represents safety around the campfire, the warmth of the sun, and even the symbol for life. Darkness, by contrast, is frightening. Where there is darkness, there is danger, cold and monsters under the bed. Light covers our basic needs, such as the need for warmth and safety. Light also comprises the colors that give nature its magnificence. Light is communication and closeness, technology and entertainment. Light is even health, both physical and mental. Perhaps this is why those of us who live in the dark, northern hemisphere cannot resist the urge to go outside whenever the sun is shining or find ourselves manically checking the weather forecast for a potential crack in the cloud cover. And maybe this is why we love the northern lights, which flicker above the Arctic night sky like the torch of the gods.

 Life on earth is dependent on the sun’s energy. Light is one of the conditions for our existence, and it has played a part in shaping the course of nature. Photosynthesis and photosensitive organisms are some of the most crucial steps in evolution. A complex visual sensibility provides one with enormous advantages in the struggle to survive.

 But what *is* light? When we switch on a lamp in the dark and are suddenly able to “see”, what is it that actually takes place? Science has been occupied with the study of light from the time of the ancient Greeks up until today, via Isaac Newton and Albert Einstein. And yet there is so much we still do not know.

 This book will take you through the history of light in its many different forms—as a phenomenon in nature and as a prerequisite to human existence. You will be invited to view the colors in all their glory and learn about how nature creates colors, from flames to fireflies. You will encounter the dark, which plays a more significant role than many of us realize. And you will be given a glimpse into how light functions as our best teacher in learning how nature works, both on our own earth and outside of it in the farthest reaches of the universe.

 Lux Aeterna.

Bjørn H. Samset, July 2018

**CHAPTER 1**

**Light and Humankind**

*Lead, kindly light, amidst th’encircling gloom,*

*Lead Thou me on!*

*The night is dark, and I am far from home,*

*Lead Thou me on!*

Text: Cardinal John Henry Newman

Melody: Traditional hymn

Light has always been.

 When the universe was formed 13.8 billion years ago, light was present and spread out together with time, space, particles and energy. It slowly but surely participated in giving shape to reality.

 Five billion years ago, when the sun caught fire in a nuclear inferno, the light carried the energy out into the solar system—among other places, to our earth. Here, light became a tiny source for germinating the conditions necessary for life, and it later contributed to developing it further.

 Two million years ago, *Homo erectus* evolved in Africa. They tamed fire and thus ensured early humanity’s dominion over its two greatest enemies: darkness and the cold. Since then, light has been a companion and friend: our gathering hub, our most valuable resource and our defense against the many dangers of nature.

 Two hundred years ago, a Scottsman had a genial idea and stretched pipes containing flammable gas through his house in Cornwall. Not long after, gas lamps were common domain in the West, more practical and much safer for indoor use than fireplaces, tallow candles and oil lamps. From that point on, the course was already set toward a global society in which night is optional and light is never more than a switch away.

 Two minutes ago, I turned on a light over my desk. Light from modern, effective diodes filled my office, as warm and pleasant as a sun beam. My PC screen glows toward my face and translates my thoughts and formulations into crisp patterns of black on white. And while I write, light is at the center of a technological revolution that is taking place around me. I can hear some people putting solar panels up on my neighbor’s roof. With the click of a few keys, I can call up articles about the development of enormous solar power plants on every continent across the globe—information that is conveyed to me through cables that are no longer filled with copper and slow electrons but with pure, efficient light.

 Light is our best friend. It is always with us, and it always will be. For better or worse.

 In five billion years, the sun will balloon and swallow the planets Mercury and Venus. On our earth, the light will become so intense that everything will be consumed by flame, an truly inevitable Armageddon. Humankind—our descendants—will be forced to find another home, somewhere orbiting another star. We do not know much about how such a journey will come about, but three things are certain: we will take light with us on our way through the darkness between the stars. Light will be our source of energy for the journey. And wherever we end up, light will be there to meet us when we arrive.

 And when the universe one day expires, as cosmologists say it will, it is most likely light that will be the last thing to go.

*Light and life*

We humans depend on light.

“I picture the following idea,” writes the bookkeeper Oskar Kittilsen in the local newspaper *Rjukan* on October 30, 1913: “One raises large, moveable reflective mirrors on the ridge on the north side of the valley, mirrors that first gather the sunlight and then spread it as a flood beam down over the city of Rjukan and its happy inhabitants. (…) Just imagine the splendor for Rjukan.”

 Rjukan is a contrived city. It was founded in the early 1900s when the engineer Sam Eyde—who established Norsk Hydro together with the inventor and researcher of the northern lights, Kristian Birkeland—obtained the rights to extract power from the mighty Rjukan waterfall. Eyde first planned on moving the energy to other places, but due to a conflict between the parliament regarding concessions, he instead ended up starting the production of chemical fertilizers in the small village of Saaheim at the foot of the waterfall.

 The Rjukan Potassium Nitrate Factory (Rjukan Salpeterfabrikker) was the start of a new industrial adventure. The town was given its name and eventually grew to 12,000 inhabitants. It boasted everything that we humans crave: safety, employment, opportunity, and incredible nature to boot. And yet the people who lived there were unsatisfied.

 Because Rjukan was lacking in one thing: light.

 The city is situated in its location because this is where the power of nature has allowed for an enormous waterfall to drop down to the valley below. The valley is in fact so deep that sunlight is unable to penetrate to the bottom in the winter. The town is thus encased in darkness for the entire season, even though it is located well below the polar circle. The result is cold, sad, and depressing.

 We don’t know whether Sam Eyde understood the conditions under which he constructed his factory, but the people who moved there reacted. The letters to the editor section, from which the above comment is taken, was already being printed in 1913, early in Rjukan’s history. The solar mirrors were never realized in those days, but the thought had been sewn: the people need light. And if the light could not come down to them, perhaps they could come to the light? In 1928, Norsk Hydro instead constructed a cable car—the Krossobanen—running from the bottom of the valley 500 meters up to the foot of the Hardangervidda plateau. The track was gifted to the city so the inhabitants and workers could get some of the sorely needed light during the long, dark winters.

 The idea about the solar mirrors, and about eternal light down in the center of Rjukan, never died. One hundred years after the suggestion was initially published, it was revived and by the fall of 2013, three enormous reflectors had been fixed high on the ridge. 600 square meters of warmth and cheerful sunlight is now able to shine down into the depths of the valley and straight onto Rjukan’s center square. Finally, the city has its winter sunlight.

 Further north, above the arctic circle, people are used to the period of darkness. Mirrors are no good here. The dark winters are inevitable, just a part of the life cycle, and the further north one gets, the longer it lasts. “The Sun Festival” is therefore an important holiday. It celebrates the day the sun finally reaches above the sharp peaks or horizon after having been absent for so long. People welcome its return in much the same way as the biblical prodigal son, with song, dance and good food and drinks.

 And once the light has finally returned, it pulls out all the stops. The reward for an extensive, dark winter is a summer season during which the sun refuses to set. Maybe that is why we are able to survive? Our bodies may not be able to store light, but they can store memories. It also helps that nature has placed another source of light precisely where the dark season has the strongest impact: the green, blue and red northern lights flicker and burn above the northern region’s winter sky. In fact, the northern lights can be visible in both the day and the night, summer and winter, but they appear so weak compared to the sun that they are only really glorious when conditions take a dark turn.

 Light and life. They are so closely connected that they are nearly two sides of the same coin. Just look at the history of life on earth as we understand it today.

 Five billion years have now passed since the sun came into being. The pressure and temperatures at the core of the enormous ball of hydrogen became so extreme that the atomic nuclei were pressed together. Through a series of intricate natural processes, the hydrogen was gradually converted to helium while at the same time saving energy from the process. And energy in this case was nothing other than light. For five billion years, our sun has beamed out its light into space, steadily, day in and day out, bombarding the planets with life-giving energy.

 The planet Earth is special, at least in our solar system. It has an atmosphere that allows a bit of sunlight to seep through, warming the surface, but which then does not allow the warmth to easily escape again. Warmth is also light, of a variety we cannot see. It is captured by the greenhouse gasses and stored for a while, similar to the way our clothes store the warmth from our skin. This is why the Earth is able to maintain an even and comfortable temperature in contrast with, say, the moon, which has a very different atmosphere.

 It was here, in the nice, warm atmosphere of the Earth, that life evolved. First the single celled organisms, then plants, thereafter marine life, dinosaurs, primates, humans and mammals. One of the most important events in the history of the Earth occurred when life learned to use the light. Photosynthesis developed around three billion years ago. Single celled creatures learned to make sugar and to store it in their bodies for later use. The method was to draw carbon dioxide from the air and to combine it with the energy from sunlight. The result was that oxygen was spit out again. This further influenced the atmosphere and paved the way for new life forms.

 The sun gives us energy in many different forms, but the form we most often think about is so-called visible light. For most of the four billion years that have passed since life first began, the word “visible” would have been meaningless because there was nothing here that could “see” the light. It was only five hundred million years ago that an organism developed something that we could recognize as an eye. Some species of course had sensory proteins long before that, but a visual sensation in our modern definition has only existed for the last two percent of our planet’s history. The eye originated during the Cambrian explosion, a period that lasted for around twenty million years and in which the foundation for our modern nature was made. If we look at the phrase “the tree of life” and consider our current day biological species, families and genera as thick and thin branches on this tree, it was during the Cambrian explosion that these branches grew out from the main stem.

 The eye is an evolutionary revolution. It allows us to sense something that is far away, whether it is food, enemies or a potential mate, and to react to this stimulus. The ability to see, to focus sharply and distinguish colors opens opportunities for hunting, communication, partner rituals and much more. But the eye does not come without its costs. It is vulnerable and must be protected. It has to be kept moist and takes up resources that the body might otherwise use for other tasks in tough times. The only reason that the evolution of the eye has been a practical development is because the earth’s atmosphere happens to allow radiation to seep through, which becomes what we experience as “visible” light. Just imagine if light was stopped by the air, as most of the sun’s energy is. The atmosphere would continue to be warm, and maybe life would have developed anyway, but it would not have visual sensibility. Perhaps in that case we would have developed much better audio sensibilities? Ears that covered our entire head? It’s impossible to know. The only thing we know is that we call “visible” light visible precisely because we are able to see it—and we have this ability because our visual sense gives us an enormous evolutionary advantage.

 Light has also played a part in how quickly life has developed on earth. The Cambrian explosion occurred when it did because the earth was finally emerging from an especially long ice age in which conditions for the development of life were grim. The earth’s orbit around the sun changes slowly over the millennia, both because the planet’s spin is slightly lopsided and also because the larger planets—such as Jupiter and Saturn—tug on it with their gravity. Over time, these random factors nudged the earth slowly closer to the sun, and that extra warmth caused the ice to melt. Evolution then kicked into high gear, not unlike the way that crocuses and dandelions stick their heads up throughout the last snow of the spring, and life took its next, enormous leap.

 After that, slowly but surely, five hundred million years and several ice ages later, modern humans were born. Within only a few hundred years—a mere blink when compared to the entire history of life—we transformed the planet from a dark rock to the illuminated ball it is today. Employing an almost endless creativity, we taught ourselves to exploit the light and all it can do. From campfires and torches that give us warmth and safety, to lasers, fiber optic cables and technology that helps improve our quality of life in a society that is more closely linked. Light and life have continued to go hand in hand, almost like a symbiosis.

 However, from our point of view, the path from the first hand held torches to the LED bulbs of today was neither brief nor simple. Because in order to use the light, to learn from it, we also had to first understand what it actually *is*. And the hunt for the nature of light would turn out to be both one of the most frustrating and one of the most fulfilling occupations of all time.

 The intrinsic value of light is enormous. That alone is a good enough reason to pursue an understanding of what light is. But there is one further reason: curiosity. Light is everywhere, all the time, interwoven throughout existence like a rainbow-colored thread. Of course, we want to know what comprises it and how it works. Or, if we skew the question somewhat: if we are unable to understand light, we also won’t be able to comprehend the universe—or ourselves. Look up into the night sk. You might guess that one of those tiny pricks of light is a star like our own, but do you know for sure? A lot of information is stored in the light that shines down to us, but we are only able to use it if we know what it is out there that emits light. And then we also have to know what light is. Or, think about your own visual sense. Within your mind, you are constantly shaping images of how the world around you “looks”. The images are the brain’s interpretation of signals from your senses, which in turn are electrical currents created by light sensitive cells inside your eyes. Somewhere or other along the way, the physical light turned into a mental image, and we are still very far away from understanding this transformation. Even if we are able to figure out what light is, it will not be able to solve this riddle of consciousness for us, but it will at least move us a tiny step further along the road.

*Light and curiosity*

As early as the year 450 B.C., we find an attempt to understand the origins of light and how it works. This is when the philosopher Empedocles theorized that light might be something we humans create ourselves and send out from our eyes. He believed that when we open our eyes in the morning, a “light substance” streams out from them and begins to bounce back and forth between the ceiling and walls. When the substance returns to our eyes, we “see” the room around us. Empedocles further thought that the light reacts differently when it comes into contact with each of the four elements of antiquities: fire, earth, air and water. Our eyes perceive these differences, and this is how we are able to discern what comprises the world around us.

 The idea is not half bad. Empedocles insisted he could use this description to understand both why light is reflected, such as on the surface of a calm glacial lake, and why it is broken, such as when an oar stuck down through the surface of the same lake appears to be distorted. These are two unique characteristics of light which had already been observed by humans in ancient times and which they wished to understand more deeply.

 At the same time, the idea is completely wrong. If light were to emit from our eyes, we would be able to see just as well at night as during the day, and Rjukan would not need any solar mirrors. It is not hard to poke holes in Empedocles’s theories; however they are useful to keep in the back of our minds because they mark the beginning of the long journey that our curiosity about light has sent us on. This journey runs through ancient times via the scientific revolution all the way up to our own time, and along the way it loops around many of history’s biggest scientific names. One example of this is that in 2000, a large group of physicists met to have an informal vote on the people who have most contributed to the topic throughout history. The significance of light for the natural sciences is apparent if we just look at who was able to snag a place on the podium: Albert Einstein, Isaac Newton and James Clerk Maxwell. The common denominator for much of the research conducted by these three were deep and revolutionary advances on the topic of light.