Darshana Jolts

Light: The Revealer of Chromatic Splendor

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tamasomá jyotir gamaya
(from darkness lead us into light)

Brihadaranyaka Upanishad

Introduction

Have you ever been up and early outside in the pre-dawn hours when there is no moon in the sky? If you are away from the crowds and civilization, in a wood or on a hill, on the bank of a river or on a beach, there is only darkness all around, save the twinkling stars high above. You may wonder about the world around you. Then gradually, in the distant east the first rays of the sun appear. They give form and substance to things around. Your world is now lit with the effulgence of sunlight. Everything becomes tangible and clear. In the darkness before dawn you seemed to be all alone, even if you knew there was a landscape with trees, paths and other things.

The diurnal emergence of the sun all over the world has been happening for eons. For ages countless humans have woken up to the brightness of sunlight to begin another day of life and activity. The sun is our first and perennial source of light. We cannot picture life on earth with no sun in the sky. Without it this would be a world of pitch darkness for ever and ever. It is appropriate that ancient cultures have been reverential to our central star. Ancient Hindu sage-poets recognized the primacy of the sun, and paid homage to it every day[1].

Now consider twilight anywhere in the world. The sun sets and the world in our vicinity grows dark again. Today we flip a switch and there is light in the room; or perhaps a flashlight does this. In former times there used to be candles and bonfires which played a poor substitute for the sun. But it did not matter. All we need is a little light to see what is around so that we may not trip as we walk, or bounce on a wall, so that we may see the faces of people with whom we converse. Amazingly, even a small flame can do this for us.

But try sometime to close your eyes for a few long minutes and feel your way through, and you will discover how difficult life could be without this thing we call light.

[1] The Gáyatri (*Rig Veda* 3.62.10) mantra of the Vedic tradition is a homage to Savitr.
The *Vishnu Purana* says that Savitr is an Áditya (solar deity). Ancient Egyptians worshiped Amon-Ra as the Sun-God. For the Romans Sol Invictus was the Sun God. For the ancient Greeks Helios Panoptes (Sun All-seing) was the Sun-God, and for the Aztecs it was Tonatiuh.

What is Light?: *Ultimately light consists of waves.*

If we are born with normal eyesight, we may ask: What is the light that illumines the sky and all the world, the light that is a *sine qua non* for our life and its activities?

Some ancients believed that light came from the eyes[2]. As proof they said that we see nothing when we close our eyes. In a strange way, their view of light was not without merit. For, there would be no light in the universe if there were no human (or other) brains to interpret them as such. If we may adapt from the *Book of Genesis*, we might as well say,

God said, Let there be human brains,
And there was light!

Eyeless human beings, endowed with an otherwise powerful brain, may still do a lot of physics, but they will not speak of light as something special, as we do. They might have become aware of the electromagnetic spectrum, but would have categorized them on the basis of how they might be affected by them. In this sense our science is anthropic, for the notion of light makes no sense to any creature that does not experience it.

In the seventeenth century some scientific investigators imagined light to be made up of waves[3], but others maintained that it consisted of small particles[4]. It was difficult to decide which was the correct view because the laws of reflection and of refraction (the then known important optical phenomena) could be explained as well by one as the other.

However, by the beginning of the nineteenth century the phenomenon of light interference was discovered. This could be explained only by regarding light as a wave phenomenon. When streams of particles from different sources collide, that would affect their motion. However, waves can encounter, interfere, and continue. The establishment of the fact that light rays can interfere was decisive in favor of the wave picture of light[5].

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[2] The Sicilian philosopher Empedocles is known to have propounded the theory that light emanates from the human eye, and when it falls on an object, we see it [refer M R Wright, *Empedocles: The Extant Fragments,* (New Edition), Bristol Classical Press, London, 1995]. Sometimes known as the *emission theory of light* many ancient cultures subscribed to this view. Plato subscribed to it. In *Samkhya* philosophy, light is one of the five *tanmatras*: subtle primordial principles.

[3] Robert Hooke and then Christiaan Huygens in the 17th century were among the pioneers of the wave-theory of light.

[4] In the 17th century, Pierre Gassendi was a champion of the particle theory of light, as was Isaac Newton.

[5] See, in this context, Rochard J Weiss, *A Brief History of Light and Those That Lit the Way,* World Scientific Publishing Co., 1996.

The Ultimate Nature of Light-Vibrations: ***Light consists of electromagnetic vibrations.***

Besides the tangible matter that we see and touch there are also electromagnetic waves in this vast universe. These are rapidly varying intensities of intrinsically locked in electric and magnetic fields that propagate through empty space with incredible speed. They appear in a wide range of wavelengths and frequencies. When electromagnetic waves whose wavelengths lie within a narrow band impinge on the normal human eye, they are transmitted to the brain which changes them into the experience of light.

Expressed in nanometers (1 nm: a billionth part of a meter) we might say that these wavelengths range roughly from about 400 nm to 700 nm: small, very small indeed; it is remarkable that we have been able to measure them so accurately. It is important to realize that precise measurements of unimaginably small and inconceivably large aspects of the physical world were beyond the reach of ancient science.

The discovery of the electromagnetic wave nature of light is one of the greatest triumphs of nineteenth century physics. It came about from inquiries which had little to do with light: Those investigations were concerned with the basic laws of electricity and magnetism, each creating its own field. Ingenious experiments and careful observations in laboratories revealed that both electricity and magnetism cause fields which are intrinsically related. By expressing the laws of electromagnetism in a mathematical format it followed that electromagnetic fields must travel through space as a wave with a speed that turned out to be the (by then well established) speed of light. From this James Clerk Maxwell concluded that light must also be a form of electromagnetic wave. In 1865 he penned the memorable statement[6]: "The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws." In other words, there would be no light if there was no electromagnetic field.

The Human Eye and Its Role: ***There can be no light without the human eye.***

Actually, there cannot be any electromagnetic waves without the electromagnetic field, but there would be no light without the human optical system. Have you ever looked very carefully into someone's eye to discern its various parts, like the ophthalmologist does? If you do this, you will notice in the eyeball the central *pupil* surrounded by the lighter *iris* around which is the *conjunctiva* on which you can recognize faint lines that are nerves. This is all that you can see directly. The conjunctiva is actually covering the outer layer of the eyeball known as the *sclera*

[6] James Clerk Maxwell, A Dynamical Theory of the Electromagnetic Field, *Philosophical Transactions of the Royal Society of London*, Vol.155, pp.459–512, 1865.

whose front side is the *cornea.* This holds a watery liquid called *aqueous humor*. Smack in the center of the eyeball is a transparent semi-solid called *vitreous humor*. Just beyond this is the *choroid* replete with blood vessels.

About eighty percent of the inner layer of the eyeball, mostly in the posterior region, consists of the retina which is endowed with cells which are sensitive to light of different frequencies. It has light sensitive pigments in its rods and cones. This is the messenger screen for it conveys the impinging light impulses to the brain where the magic occurs: electromagnetic vibrations become light visible with all its chromatic magnificence. But only a hundred thousandth part of all the light energy reaching the retina gets interpreted by the brain. And it takes about half a second for the brain to process the information. Neuron impulses take time to reach the brain.

The system is impressively simple in its description**,** but wondrously complex in detail, and just miraculous in what it accomplishes. For it is this arrangement that turns vibrations into visual reality. All the beauty of forms and all the splendor of colors, all the shimmer and shade and brightness arise because of whatever the retina and the brain do. It is difficult for us to imagine that the cosmos in all its complexity would be plunged into dungeon-darkness if no eye ever responded to that narrow band in the electromagnetic spectrum. No glorious sunset or twinkling stars, no glitter or sparkle there would be, if the real vibrations palpitated unnoticed, unrecognized as light and color. How was the universe during those eons before life emerged? It certainly was not in this grand glory. Even when roses bloomed and leaves changed by seasonal stimuli, it must all have been bleak and insipid to eyes that had no rods and cones. Those multicolored fish we see in aquariums, the majestic rainbow, the yellow sunflower and the purple violet, all these were there for millions of years before the human retina evolved, but never recognized as such. Let us not underestimate our role on this insignificant speck of matter in a grandiose universe. Our little retinas add beauty to it all. They seem to make all of creation worth the time and effort.

White Light and Its Components: ***There is light that is of itself white.***

We are accustomed to associate white with purity; for generations it was imagined that white light was the purest of all. But white light arises from the mingling of every colored light there is. In the 17th century Isaac Newton uncovered this surprising root of perceived reality. He made this significant discovery from careful observations with prisms. One can never get to the heart of physical reality without interacting closely and steadfastly with the phenomenal world. So, in his *Opticks*, Newton could firmly state[7] that "Lights which differ in Colour, differ also in

[7] Isaac Newton, *Opticks*, Royal Society, London, 1704.

Degrees of Refrangibility," and that "The Light of the Sun consists of Rays differently refrangible." Now think of this for a moment: white light, the most colorless you can imagine, embodies every color from violet to red that spans the celestial bow!

Independent of human experiments with prisms, Nature reveals to us the composition of white light through the spectacular rainbow. The rainbow occurs in many mythologies. In Norse myth, the rainbow is the bridge 'Bifrost' that connects earth to heaven. The Greek goddess Iris wears a costume in the colors of the rainbow. The *Bible* says that there was a rainbow after God saved Noah and all creatures after the Great Flood. In the Indic tradition Indra used the celestial bow to slay Vrita, the demonic serpent. In later centuries some tried to relate the rainbow to the properties of light[8]. But it was Edmund Halley of comet fame and René Descartes who explored the matter further in scientific terms in the 17th century. Descartes wrote[9], "I took my pen and made an accurate calculation of the paths of the rays which fall on the different points of a globe of water to determine at which angles, after two refractions and one or two reflections they will come to the eye, and I then found that after one reflection and two refractions there are many more rays which can be seen at an angle of from forty-one to forty-two degrees than at any smaller angle; and that there are none which can be seen at a larger angle." A complete theory of the rainbow was given by George Airy two centuries later[10].

Here is a scientific conquest which has broken the hearts of some poets. There is a thrill in experiencing mystery which is rudely erased when logic and knowledge come to the fore. John Keats expressed it this way in his poem Lamia.

There was an awful rainbow once in heaven:
We know her woof, her texture; she is given
In the dull catalogue of common things,
Philosophy will clip an Angel's wings.

In 1853 Hermann Grassmann published a theory on the mixing of colors [11] in which he explained that the human eye perceived three different aspects of light: its *brightness*, *hue*, and *saturation*. Technically, the term color is a description of all these three components in an object (or image). It took more than a century before the three principal pigments in the cones of the

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[8] For details see, Carl B Boyer, *The Rainbow, From Myth to Mathematics*, Princeton University Press, 1987.

[9] René Descarte, *La Dioptrique*, 1637. This is an appendix in his *Discourse on the Method.*

[10] George B Airy, On the intensity of light in the neighbourhood of a caustic, *Transactions of the Cambridge Philosophical Society*, Vol.6, No.3, pp.397–403, 1838.

[11] We may recall here that there is a line in the Mahabharata (*Adiparva*, Book II, line 68) which has been translated as: "Mixing the three colors ye have produced all the objects of sight."

eyes were identified[12]. Hue refers to the basic colors of red, blue, and green, while saturation is a measure of how pure or uncorrupted a particular hue is.

Light Absorption and Colors: ***What seems to be blue is really not blue.***

The world is filled with chromatic splendor. Green grass and multi-colored flowers, brown mud and blue skies, yellow birds and the red sun ; one can go on and on listing the variety of colors in various shades. To dogs, this same world would be as drab as actions on a black and white TV screen, for they have not been endowed with rods and cones in their retinas to change various wavelengths into colorful magnificence.

How do objects acquire colors? Why does the leaf appear to be green and the apple red? This is because the atoms and molecules of most materials absorb some, and not all, the visible wavelengths that fall on them. Which particular ones they absorb will depend on their structure and constitution. Atoms and molecules have their characteristic tastes for waves, as it were. If a material sucks in every component of the light falling on it, it returns nothing, and appears dark itself, as is the case with charcoal, for example.

Thus, colored bodies do not *emit* the corresponding colors. Any color we discern is the one that is rejected by the atoms and molecules of the body. An orange pigment is one whose atoms absorb all but orange light. If we shine blue light or green or any light other than red on an apple it will appear to be black because no light will be reflected back from it. Ultimately, then, aside from the rods and cones and retinal neurons, the silent atoms are what cause the colors of bodies.

Speeds in the Universe: ***Everything is on the move and at various speeds.***

When you are driving on the highway, you may notice a speed limit sign: you are not supposed to exceed the 80 km/h limit. Is this fast or slow? Fast and slow have no absolute meanings, much less even than beautiful and ugly. The snail which was run over by a tortoise might complain that a speeding body stepped over it.

But we can compare speeds. The train is moving faster than the tramcar, and the buggy faster than the bug. Let us reflect a little on the kinds of speeds one encounters in the world. We can see little creatures crawling at less than a centimeter a second, a fast walker can cover a few kilometers in an hour, but jaguars dart at more than eighty. Racing cars may zoom at more than 160 km an hour, while jet planes fly at more than a thousand. Sound in air travels at greater

[12] Hermann Grassmann was a mathematician whose worth was not recognized in his lifetime. In frustration, he studied linguistics and Sanskrit, and brought out a German translation of the Rig Veda. See in this context, Hans-Joachim Petsche, *Hermann Grassmann – Biography*. Trans. M Minnes, Birkhäuser, Basel, 2009.

speeds, covering some 300 meters a second, but we have built aircraft that fly faster still. Molecules in air move much, much faster: molecules of hydrogen could ordinarily be moving at more than 4,000,000 km a second. We know of stars that rush through the cold expanse of space at more than twice this speed, while grand galaxies consisting of billions of stars are fleeing each other at speeds of the order of 20,000 km a second. On the other hand, electrons in atoms whirl around the core of atoms at unimaginable speeds of more than 10 million km a second! If the range and numbers are mind-boggling, it is even more remarkable that they have been tracked down by human ingenuity. It is difficult enough to recognize that sound and light travel with finite speeds, to know of hydrogen atoms and molecular motions, and to become aware of the existence of electrons and galaxies. But to compute their speeds is even more impressive. We have been able to accomplish all this only during the past three and odd centuries: a fleeting twinkle in the span of human history. These are no meager achievements of the human spirit. They are intellectual conquests in the face of which all the lofty proclamations about the limits of science and the philosophical indictments on reductionism and analytical approach pale into pathetic insignificance.

Speed of Light: *Light travels at a great speed.*

There was a time in human history when the flight of an arrow was regarded as very fast. Perhaps the swift darting of animals like the hare or the leopard were observed and considered fast also. Where else could pre-technological human beings observe motions so swift?

We have definitive records of the measurement of speed of light by a well-defined method only from the seventeenth century[13]. The credit for this goes to the Danish astronomer-architect Ole Rømer who was then serving as an assistant to the astronomer Cassini at the observatory in Paris. By careful observations of the regular time delays in the eclipses of the satellite Io of Jupiter, Rømer concluded that this must be due to the time difference between events, caused by the varying distances of Jupiter from the sun. From this insight, he could estimate the speed of light which was announced at a meeting of the French Academy of Sciences on August 22, 1676[14].

It has been determined that light covers three hundred million meters a second. At this speed one

[13] Professor Subhash Kak, a scientist and scholar of repute, has shown that certain passages in Sayana's interpretation of the Vedas lead us to the conclusion that Vedic rishis were aware of the value for the speed of light. It has been suggested that they might have arrived at the result via other modes of reckoning the world, unknown to us at this time. See, S Kak, The speed of light and Puranic cosmology, *Annals Bhandarkar Oriental Research Institute*, Vol.80, pp.113–123; archive:physics/9804020, 1999.

[14] "A demonstration concerning the motion of light, communicated from Paris, in the *Journal des Scavans*, and here made English", *Philosophical Transactions of the Royal Society of London,* Vol.12, pp.893–94, 1677.

can circle the earth more than seven times in less than a second: a rather mind-boggling feat indeed. It is difficult to believe that this is the most common speed in the universe, for more than anything else, it is electromagnetic waves that pervade the body and every nook and corner of the physical universe.

The speed of light is the fastest allowed speed in the universe[15]. No physical body, massive as stars or minute as electrons, no physical body whatever can ever reach a speed equal to that of light. We may, in theory, picture particles zooming with speeds very nearly equal to that of light, but never, never equal to it. Light speed is the ceiling that naught can break through. This is yet another of the "You can't do it" principles of 20th century physics[16].

Absoluteness of Speed of Light: *Measure of speed of light is independent of relative motions.*

The measured value of the speed of light will be completely independent of our own motion with respect to the light source. This is another remarkable, and at first blush unbelievable, aspect of the velocity of light: It does not depend in any way on the motion of the observer relative to the source of light. To grasp the significance of this utterly bewildering situation, just imagine you are riding your bike at 15 kph towards a car. If the car is approaching you at 60 kph, it will be appearing to be coming at 75 kph since every hour this is the amount by which the distance between the car and yourself is diminishing. Likewise, for an observer moving forward in the same direction as the car, the car's relative speed will be 45 kph. Only if you are stationary will the car seem to be moving at 60 kph.

But this common sense calculation simply will not work with light. Replace the car by a light wave, and the cyclists by very fast moving rockets, and everyone will find light to be traveling with the same speed (*relative to oneself*)! There will be not an iota less in the measured speed simply because you are whizzing towards or away from the source. The speed of light is an example of a *univseral* (*fundamental*) *constant*[17].

Faster Than Light: *Nothing can move faster than light*!

That nothing can move faster than light is a consequence (or premise) of Einstein's famous

[15] This is one of the consequences of the Special Theory of Relativity (1905) which made Einstein the best known name in modern science.

[16] Three other such constraining laws are: (a) The second law of thermodynamics: One cannot construct a 100% efficient steam engine; (b) The third law of thermodynamics: One cannot reach absolute zero; (c) One cannot measure simultaneously with 100% precision the position and momentum of a quantum particle.

[17] The universe is the way it is not only because of the particular laws governing it, but also because of the particular values certain basic constants of physics have.

theory of relativity. One may ask, what if something does move faster than light? If that were to happen, then you can travel back into the past. Here is one way of picturing it. When we observe an event, light from it reaches our eyes. We may picture the image of a scene now transpiring before our eyes to be traveling through space. Light from yesterday's event has by now traveled trillions and quadrillions of miles away. Light from events that happened a thousand years ago have moved even farther.

But now suppose that you can take off on a rocket which moves much, much faster than light. Then you will be able to overtake the light waves from earth and arrive at a planet before light from a past event on earth reaches it. From that vantage position you can see whatever happened in the past when the corresponding light comes there. This imaginary experiment indicates how faster than light motion is equivalent to witnessing past events. If this was possible, we will have a situation like the following limerick by Arthur Butler:

There was a young lady named Bright.
Whose speed was far greater than light;
She set out one day
In a relative way,
And returned home the previous night.

Theoretical physicists, like authors of science fiction, sometimes explore strange phenomena, as long as they do not violate known principles. Thus, Gerald Feinberg and E C G Sudarshan *et al* explored the possibility of faster-than-light situations[18]. This led them to a rather intriguing situation: There is nothing impossible in something moving faster than light as long as that something does not slow down to a speed equal to that of light. Let us clarify this a little: In order to accelerate ordinary material bodies we need to give them energy. It requires infinite energy to speed up a body to that of light. Likewise, if entities exist which are already moving with speeds greater than light, then such entities will require energy to speed them down, and the amount of energy needed for this would be infinite if we wish to slow them down to the light speed.

Such is the theoretical conclusion one can draw form an ingenious analysis of the mathematics of relativity. When the idea was conceived, physicists gave such (imaginary) entities a name: *tachyons* [19]. Tachyons are particles that (in theory) always travel faster than light and can never be slowed down to the speed of light.

[18] Gerald Feinberg, Possibility of Faster-Than-Light Particles. *Physical Review*, Vol.159, pp.1089–1105, 1967. P Olexa-Myron Bilaniuk and E C George Sudarshan, Particles beyond the Light Barrier, *Physics Today*, Vol.22, No.5, pp.43–51, 1969.

[19] From the Greek word *tachys*, meaning swift.

Scattering : *The sky is blue because of the scattering of light by air molecules.*

Ever since human beings turned their gaze skyward they have recognized the vast sky above and admired its soothing azure tint. It has been said that this was an inspiration for representing Vishnu and his *avatáras* (Rama and Krishna) in blue: In the symbolism, like the vast sky, Divinity pervades the whole universe.

Soon after sunset, after darkness sets in, all the blueness disappears. Even if the full moon shines bright the sky at night is never blue.

It was only in the 19th century that we came to understand why the sky is blue. When light waves fall on a smooth surface they are reflected. However, when they encounter very small particles they bounce back every which way. The phenomenon is related to a property of waves called *scattering*[20]. Light is thrown back in all directions – hence the name. Then again, not all wavelengths of light are scattered to the same degree. This depends on the structure and size of the scattering center. For example, consider a beam of white light hitting a molecule of oxygen or nitrogen. The blue component of this light is scattered away while the red and orange ones go undeflected. This simple fact has a dramatic effect on the nature of the perceived world. When sunlight enters the earth's atmosphere, its bluish components are scattered; these reach our eyes when we do not look directly at the sun. So the sky looks blue. Light-scattering accounts for the blue of the oceans too.

If our atmosphere were made up of some other (life supporting) gases which had the property of scattering the green component primarily, we would be enjoying a green sky. Who can tell what our poets would be singing then!

Light is Invisible: *Light which makes things visible is itself invisible.*

Strange as it may sound, light itself is invisible: we can never see a ray of light passing out there in space. The effulgent beam of light spouting out from a luminous source that a movie company displays as its logo[21] cannot be seen if that light were splashed into empty space, nor the laser

[20] The phenomenon of scattering was investigated in the 19th century by physicists John Tyndall and Rayleigh in particular. Thus scattering that occurs from colloids suspended in a liquid is known as the Tyndall effect. When the scattering particles are very small compared to the wavelength of the impinging light, it is known as Rayleigh scattering. Here the scattered light has the same frequency as the incident. In light scattering from a liquid, a small fraction of the scattered light results from the excitation of the scattering molecules, and often has a lower frequency than the incident light. This phenomenon is known as the Raman Effect. This is of enormous value in uncovering the structure of molecules. The phenomenon of scattering has also been a source of some of our knowledge of the substratum of matter. Thus in 1890 Lorenz used the scattering of sunlight in the atmosphere to estimate the number of molecules in a given volume of air.

beams in science fiction movies. Only when light strikes our retina do we become aware of light. Stare at the night sky: there is ample sunlight there in the void of space. But it is only when some of it bounces back from the moon or a planet do we perceive it, and in the process, become aware of the moon and the planets.

This brings us to another important consequence of light scattering. Much of the light that makes normal living possible arises from this property, for the visibility of things in the room when the windows are open and the visibility of objects in the shade under a tree are due to the face that light is scattered by the air molecules. Take away the air, and sunbeams will illumine only the patch of ground on which they fall. We can only see the reflections from objects.

It is somewhat like being on a volleyball court. If you are not in the court, you will never receive the ball. But if you are there, the ball will come to you now and again, as and when the other players 'scatter' the ball in your direction.

So now we come to this most unexpected realization: bodies are visible to us, not simply because of the light that falls on them, but equally because of the air around! Take away the light, and nothing can be seen. Take away the air, and not everything will be seen. Things will not be as visible in a room on the moon even in broad daylight because there is no air there.

This is only one example of many which reveals how the intertwining of factors – sometimes superficially unconnected – gives rise to the world of perceived reality. This is a very interconnected world, this complex and marvelous world of ours. Only thorough and careful investigations have been slowly uncovering its many by hidden aspects.

Spectroscopy: ***Light can reveal the chemical composition of distant objects.***

Jane Taylor famously wrote: "Twinkle, twinkle little star; how I wonder what you are". That perfectly legitimate wonderment, is still echoed by children in the English-speaking world to a happy and rhythmic tune. But it was answered a few decades after she passed away in 1824, thanks to the work of physicists.

The first stone on the road to this exploration was laid by a lens grinder called Fraunhofer who constructed some excellent prisms[22]. He attached them to a telescope and studied sunlight directly. He discovered that the analyzed light from the sun displayed some bright lines as well as some dark ones. In the decades that followed, other investigators explored the phenomenon,

[21] The company known as 20th Century Fox.

[22] See in this context, Myles W Jackson, *Spectrum of Belief: Joseph von Fraunhofer and the Craft of Precision Optics*. MIT Press, 2000.

and it was established that light from any source, when analyzed through a suitable optical device, gives a pattern of colors, be it of discrete lines or broader bands or continuous patches. This pattern is referred to as a spectrum [23]. What is still more significant is that the spectrum revealed by light from a source is characteristic of the chemical composition of the source. In other words, the spectrum is a sort of fingerprint of the chemical elements present in the source of light [24]. Soon it also became clear that the spectrum can tell us about the temperature of the source, and even about its motion or rest relative to us.

These discoveries opened up a whole new world for physics. For think of this: all you can get from the sun and the stars is light, but light can tell us about the constitution of the matter at the source! Just analyze the light from a distant source, and like a letter from a friend, you can know a good deal about the state and substance of the source.

There is a related story that is very interesting. The instigating actor was Pierre Janssen who traveled to many places for the cause of science[25]. In 1868 he was in India where a total solar eclipse occurred. He studied the solar prominences which are particularly visible during eclipses. Here he was puzzled by a strange line in its spectrum. This was like finding the fingerprint of an individual that is not in the police records. He sent his finding to Joseph Lockyer, an expert on solar spectra. After careful study of the line, Lockyer concluded that this must be a new element, hitherto unknown to earthly scientists. He called it *helium* in honor of the sun[26]. If detective stories are fascinating, this one can beat any. Consider the tortuous route: a lens-grinder recognizes the spectra of elements in the 1820s, an astronomer discovers a new element in the sun in the 1860s! The existence of helium, the gas we use to fill birthday balloons, was first noticed in the sun during a solar eclipse observed in India. Light revealed to us knowledge of the existence of an element that is out there, almost 150 million km away!

So we see how physicists have a way of finding out what the sun is made up of, or Polaris or Betelgeuse or whatever else in high heavens. It gradually became clear that stars and planets, high and mighty as they are, are made up of the same sort of stuff as this our modest planet here below. Aristotle and other ancients were not quite right when they preached that celestial bodies consist of incorruptible matter while earthly ones degenerate and decay. No, all bodies are

[23] The word spectrum simply means an *appearance* or an *apparition* in Latin.

[24] Anders Jonas Ångström was the first to study the solar spectrum systematically. His pioneering work was extended further by Robert Bunsen and Gustav Kirchhoff.

[25] Between 1867 and 1875, Jules Janssen traveled to Algeria, Japan, Siam, Peru and Guntur (India) for studying the solar spectrum. All this, before air travel.

[26] The Greek word for sun is *helios*. Next to hydrogen, helium is the most abundant element in the universe. Here on earth we now collect it from radioactive emissions (alpha particles).

created equal, though not all possess equal amounts of every kind of matter. Analysis of light gives lots and lots of fascinating information about the world.

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The Physical World: Vol.15, No.12, pp.1132–1141, 2010; Vol.16, No.1, pp.76–87, 2011;
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