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More on Light

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Light is good from whatever lamp it shines.

Anonymous

Creation of Light: *Light emerges from the core of matter*.

We light a candle or an oil lamp, we flip a switch or press a button, and light is splashed. And, of course, we have the sun which, at every rising, floods our world with light. But, like the city kid who thought that the source of milk was the carton or the bottle, we would be mistaken to think that the source of light is the candle or the lamp, the light bulb or the sun.

In the eighteenth century it was thought that the sun is burning like coal or wood do. Knowing the mass of the sun and the rate of production of solar heat, one calculated its life to be of the order of 50,000 years. In the mid-nineteenth century Hermann Helmholtz proposed that the sun got its energy from the gravitational energy of its constituents. Based on this idea, he calculated the sun's life to be at least 22 million years and would be extinguished in some 1 million years[1]. From other considerations Lord Kelvin famously wrote: "It seems, therefore, on the whole most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years"[2].

It was only in the twentieth century that we came to the understanding that light is created in the physical world by complex processes at the heart of matter. After the discovery of the atomic nucleus in the 1920 and of nuclear reactions, one realized that in the core of stars there is the perennial transformation of matter into energy as per the famous Einstein equation $E = mc^2$. Substantial matter is transmuted into insubstantial energy: Electromagnetic waves of many different wavelengths emerge from the deep-down recesses of every star. Like aroma from brewing coffee, light emerges from the depths of stars as nuclear brewing goes on.

We note here how scientific perspectives change with time, always improving on the basis of newly acquired knowledge and fresh insights. It is important to distinguish this from the

1 David Cahan, *Hermann von Helmholtz and the foundations of nineteenth-century science*, University of California Press, p.569, 1993.

2 Sir William Thomson (Lord Kelvin), On the Age of the Sun's Heat, *Popular Lectures and Addresses*, Vol.1, 2nd Edition, pp.356–375, 1862.

framework in which ancient aphorisms uttered by the wise men of a bygone era are taken as ultimate scientific truths.

Within matter at far less fearsome temperatures than the core of the sun, processes occur which give rise to the emergence of light. This understanding was beyond the reach of the most penetrating thinkers of past eras. The discovery of these processes was based on carefully collected data from spectroscopy. It also resulted from the discovery of the electron. Thus was formulated the famous Bohr model of the atom, proposed almost a hundred years ago[3]. This was as major a discovery in the history of modern science as Einstein's ubiquitous formula, but is not universally recognized as such.

The idea is essentially simply this: The electronic orbits in the atoms of substances have several levels of energy. Normally electrons are circulating at the lower levels. They are whirling around in the atom, but if enough energy is imparted to any of them, it jumps to a higher orbit, and promptly jumps back to a lower one. In the process it releases the absorbed energy as electromagnetic waves. If the wavelength is appropriate, this is visible light. Whether it be light from a candle or an electric lamp, the waves result from electronic jumps or transitions. In the one case we make the electrons jump to a higher orbit by giving them thermal energy through a match stick; in the other case, electrical forces accomplish this.

Creation of EM Waves: *We can generate EM waves artificially.*

If one is asked to name the most significant scientific achievement of the modern age, many items could come to mind. But few people would mention the artificial production of electromagnetic waves among them. And yet, the revolutionary impact of this achievement is incalculable. It is fair to say that no other scientific creation has had such a great impact on human civilization in the modern era.

Since the first Big Bang of Cosmic Creation – or, in the terminology of the Judeo–Christian tradition – since God first pronounced *Fiat lux*!, the universe has been inundated by electromagnetic waves which are as omnipresent as the God of any religion. But it was not until the nineteenth century of the Common Era that these were consciously produced by human beings. The credit for this goes to Henrich Hertz (born: 22 February 1857).

Hertz was a brilliant student who completed his studies when still very young. He had an uncanny ability to manipulate and devise gadgets. He enjoyed physics, and was familiar with the theory of J C Maxwell according to which there exist electromagnetic waves, of which visible

[3] Niels Bohr, On the Constitution of Atoms and Molecules, Part I, *Philosophical Magazine,* Vol.26, pp.1–25, 1913.

light was an example. This was a revolutionary theory in many ways, but it was a few decades before such waves were actually produced and detected (by Hertz) in a laboratory.

This happened in a simple classroom at the Polytechnic in Karlsruhe with the most meager instruments. The first electromagnetic waves were generated in 1888 by the discharge of a condenser through a loop with a spark gap, and were detected with a very similar device. Hertz had, in fact, produced and transmitted electromagnetic waves from one spot to another. This is at the very basis of all complex communication systems in today's world.

There is a story to the effect that Hertz's students were very impressed by what their professor had done, and wondered aloud what its applications would be. Hertz, perhaps out of modesty, made what may be regarded as the most serious blunder in predictions in all of history. "It is of no use whatever," he is said to have told his students. But he did rejoice over the fact that he had experimentally verified Maestro Maxwell's theory.

Indeed, a noteworthy aspect of Hertz's experiment is that is a historic example of an experiment verifying the existence of something that was predicted by a theory. A good theory in physics not only explains observed phenomena, but also predicts or reveals the existence of as yet unknown or unobserved entities or processes.

But it took some more years before Guglielmo Marconi would succeed in using Hertz's discovery for sending telegraphic messages without wires. Marconi[4] established his company in 1896. It should be recalled here that Jagdish Chandra Bose[5] generated EM waves and used them to ring a remote bell in 1895. The rest is history: Wireless telegraphy led to radio communication, then television, and then to all kinds of other applications of artificially generated electromagnetic waves.

Sadly, Hertz died at the age of 37 – of blood poisoning, it has been recorded. He did not live to see the enormous impact that his modest experiment had on the course of human civilization. He is remembered as a very unassuming and amiable man, loved and respected by all who came to know him. His interests went beyond his field of specialization: He is said to have studied languages as varied as Arabic and Sanskrit[6].

Another remarkable effect of our capacity to generate electromagnetic waves is that we have been able to send signals from earth into outer space. Should there be other intelligent and

[4] See *Resonance*, Guglielmo Marconi, Vol.7, No.1, 2002.

[5] See *Resonance,* J C Bose, Vol.3, No.2, 1998.

[6] For more on Hertz, see Davis Baird, R I G Hughes, and Alfred Nordmann, eds. *Heinrich Hertz: Classical Physicist, Modern Philosopher*, Springer-Verlag, New York,1998.

technologically advanced civilizations elsewhere in the universe – not an improbability – they would become aware of our existence.

Microwaves: ***There are invisible electromagnetic waves.***

In Samuel Coleridge' *Zalolya*, there occurs the line: "I feel and seek the light I cannot see." This is what physicists do in exploring the spectrum beyond the visible. Our eyes are sensitive to (i.e., we can see) only a very small window of the electromagnetic spectrum. But this is not to say that others are insignificant or that we cannot know only about them. One of the goals of science is to unravel every aspect of physical reality that can be perceived, either directly or indirectly.

Beyond red light, there are electromagnetic waves of longer wavelengths. These are the so-called infrared (IR) or heat radiations[7]. Further beyond these we have waves which we call microwaves[8]. They have come to play an important role in our current technological civilization, but in the first third of the twentieth century they were not even named.

Already in the 1930s microwaves were used in determining the location and motions of distant objects. The invention which accomplishes this is the radar. Like all inventions it has evolved to considerable complexity, used in planes that take pilots through thick and opaque clouds, and help ground controllers spot and guide them near airports. Soon after the Second World War, techniques were developed to generate intense microwaves in laboratories. Microwaves are the principal carriers of television signals and they serve in long distance telephony as well. They penetrate right through the reflecting layers in the upper atmosphere, and are thus useful in communicating with astronauts in space. They have come to serve computers and medicine, and they also help us heat foods quickly.

Thus, in just a few decades since we came to know about microwaves, we have been using them in a variety of ways and for a variety of purposes. The potential for prompt or eventual utilization to serve human ends is another important difference between the sciences of earlier centuries and the science of our own times. Indeed, this capacity to use every bit of scientific knowledge is an important characteristic of modern civilization. Science is no longer *natural philosophy*: love of knowledge about Nature, as it used to be called prior to the 19th century. It

[7] Infrared radiation was discovered in 1800 by William Herschel who is also credited with the discovery of the planet Uranus. Herschel was not only a remarkable scientist, but he also composed several symphonies. For more on his life see Micheal Hoskin, 'William Herschel' in *New dictionary of Scientific Biography* Scribners, Vol.3, pp. 289–291, 2008.

[8] Microwaves are EM waves in the frequency range: 300 MHz–300 GHz. Jagdish Chandra Bose was one of the first to demonstrate experimentally the production, existence and utilization of microwaves. See in this context, D P Sen Gupta, M H Engineer and V A Shepherd, *Remembering Sir J. C. Bose*, World Scientific Publishing Company, 2009.

is not even science in the etymological sense – pure knowledge. Rather science has become a tool for application and power, an instrument to exploit and control Nature in positive and in negative ways. This eagerness to make life more easy and comfortable, more physically enjoyable and materially fulfilling often loses sight of the grander vision of science which is to understand and contemplate the wonders of the world, to marvel at the splendor of the cosmos from the smallest to the grandest levels. The so-called practical and technological application of scientific knowledge has improved the human condition in many ways, but it has also resulted in some alarming dangers for the human family.

Radio Astronomy: ***We can know aspects of the universe sans visible light.***

In 1932 an engineer by the name of Karl Guthe Jansky, while trying to get rid of the hissing noise associated with radio reception, made a significant discovery: That the earth is being showered from outer space by electromagnetic waves of wavelengths much longer than the infrared[9]. Now let us think about this for a moment. We look at the sky and see the sun or the stars. It is clear that light reaches us from the heavens. But who would have thought that day in and day out we are also inundated with invisible waves which we now call microwaves? And if light can tell us so much about the sun and the stars, perhaps microwaves can tell us quite a bit too. Jansky thus unwittingly laid the foundation for what was to become *radio astronomy*[10]: the exploration of the universe, not with the aid of visible light, but by studying the microwaves that are continuously pouring in from every nook of the universe. In the mindless dimension of physical reality, waves are merely carriers of energy. But in the world of perceived reality, they carry information too.

Radio telescopes are essentially very large dish antennas hooked to complex electronic circuits and computers which record and interpret the microwaves received. Many of them have been constructed since the 1940s, and they are continually keeping a watchful eye round-the-clock on every sector of the skies above, swallowing every surge of microwave that falls into their trap. There are radio telescopes in Woomera in Australia and Arecibo in Puerto Rico, in Owens Valley in California and Gotherburg in Sweden, in Johannesburg in South Africa and Semiiz in Russia, in Fairbanks in Alaska and Jordell Bank in England, in Ootacamund, and in Khodad (near Pune) in India, to name a few.

The radio astronomical route has its advantage and disadvantage too. The advantage is that, unlike optical (light-based) astronomy, astronomers do not have to wait until it gets dark, or for cloudless skies to focus their instruments on stars and planets. The microwaves pouring in from

[9] Karlk Guthe Jansky, Radio waves from outside the solar system, *Nature*, Vol.132, p.66, 1933.

[10] See in this context, Woodruff T Sullivan III, *Cosmic Noise: A History of Early Radio Astronomy*, Cambridge University Press, Cambridge, UK, 2009.

the universe can be detected day and night, and they pass right through the clouds as light does through chunks of clear glass. The disadvantage is that we need much larger dishes (corresponding to lens size) to get clear pictures of whatever we are looking at. In other words two sources will be blurred together when observed with even quite large (diameter a hundred meters) radio telescopes. One ingenious way by which radio astronomers have considerably increased resolution is by linking up radio telescopes in different parts of the globe and using the pairs as one single mammoth instrument. This technique is known as *Very Large Baseline Interferometry* (VLBI). Thus, telescopes in Bonn (Germany) and in Goldstone (California) team up and pinpoint on the same source and manage to get a much sharper reading.

Radio telescopes have enlarged our vision of perceived reality in a number of ways. They have put into evidence a great many sources of microwaves. Microwaves arising from supernova eruptions, from electrons going amuck in interstellar magnetic field, and from transitions in the atoms of hydrogen spread all over space. They have detected carbon-containing molecules like cyanogen and formaldehyde, suggesting possibilities of organic structures elsewhere in the universe. They have revealed that elliptical galaxies emit considerably more radio waves than most others do. They have made us aware of thousands of incredibly powerful extra-galactic radio sources: some of the most fantastic objects in (from our perspective) the outskirts of our universe – mammoth star-like agglomerations spewing out incredible amounts of energy as they rush away at delirious speeds which are respectable fractions of the speed of light. These awesome things have been named *quasi-stellar objects* or *quasars* by radio astronomers. Their ultimate nature is still only faintly understood. Radio astronomy is like an extra window into the universe through which we have come to see many more wonders of perceived reality.

Then again, many astronomers are convinced that somewhere out there among the countless billions of globules there must be more mind-endowed entities, if not our clones, creatures more evolved than ourselves, thinking and feeling, probing and inventing. If intelligent beings they are, then they must have their radio astronomers too – sending knock-knock signals and expecting answers. So we need to be on the lookout for mail from extra-terrestrial, actually exta-solar intelligence, not in hard-copy format of course, but in the cryptic microwave-coding. So these eager radio astronomers have been spending countless hours (and lots of money), not as peeping Toms, but as seekers of cosmic pen-pals. Whether we succeed in this lofty quest is not as important as the fact that human ingenuity has come up with tangible ways of confirming whether or not there are other interstellar brain-based efforts. Like prayer, irrespective of whether it reaches a target, the effort itself enhances the human spirit[11].

[11] For more details, see Brian McConnell, *Beyond Contact – A Guide to SETI and Communicating with Alien Civilizations*. O'Reilly Media, Beijing, 2001.

Background Radiation: ***We can recognize the echoes of cosmic birth.***

According to an ancient Chinese legend to explain the origin of the universe, a supreme architect by the name of P'an Ku was born of the Cosmic Egg[12]. Working hard for eighteen thousand years, he built this grand universe of ours. The ripples of this momentous event have not quite died out: P'an Ku's breath and sighs are what we see to this day as winds and rising clouds, the roaring majesty of his voice resounds as thunder. His flesh congealed into our earth, on which we can still feel his lush hair as green grass and tall trees. As to the metals and minerals we see underground they are simply vestiges of his bones, while the abundant sweat of his lasting labors still drip down as rain. Yes, he too had lice infecting his body, and they may still be seen as swarms of humans populating the earth.

Picturesque fable this may seem, but it underscores the notion that what we recognize and perceive today are consequences of a distant event, a majestic primordial event of immense complexity that ultimately took shape into the forms and patterns that we see today.

In the first half of the twentieth century, if anybody had talked of the echo of the Big Bang (of modern cosmology), one would have considered it pure fantasy. But in 1965, two radio astronomers discovered precisely that: a microwave radiation of wavelength 7.35 cm that is all pervasive and isotropic[13]. They tried hard to see if what they observed, this utterly uniform background radiation, was perhaps due to local effects, like glitches in the telescopes or noises in the atmosphere. But after every precaution had been taken and every other reasonable possibility had been eliminated, they could come to but one conclusion: This is a remnant of the world-generating Big Bang. In other words, among other things, the enterprise of radio astronomy has put into evidence what may well be described as the first shriek of cosmic birth[14]. We are reminded of George MacDonald's lines in a poem for children:

Where did you come from, baby dear?
Out of the everywhere into here.

Gamma Rays: ***EM waves of incredibly short wavelengths emanate from the nuclei of atoms.***

At the lower extreme of invisible electromagnetic waves are the *gamma rays* which are so short

[12] E T C Werner, 'Cosmogony – P'an Ku and the Creation Myth', in *Myths and Legends of China*, pp.76–92, George G Harrap & Co.,London, 1922.

[13] A A Penzias and R W Wilson, A Measurement of Excess Antenna Temperature at 4080 Mc/s. *Astrophysical Journal*, Vol.142, pp.419–421, 1965.

[14] The existence of such a cosmic isotropic radiation had been predicted almost two decades earlier by George Gamow *et al*, See, in this context, G Gamow, *The Creation of the Universe,* Viking, (revised ed.) 1961.

in wavelength that atomic dimensions are large compared to them. This implies even more mind-boggling frequencies than light: of the order of 10^{22} Hz[15]. This is a number beyond the grasp of normal people, for it represents ten trillion times a billion vibrations a second. If a magical machine were to print out numbers at the rate of one a second, and if that machine had started functioning when the Big Bang burst forth, then by now the machine would have reached only up to 10^{17}. The number corresponding to gamma ray frequency is a hundred thousand times this!

Just as light emerges from the electronic transitions of atoms, gamma rays arise when atomic nuclei squiggle, an electromagnetic expression, as it were, of nuclear agitations. They are generated whenever there are nuclear explosions which civilized governments perpetrate for their supposed protection from potential enemies. These rays are like awfully penetrating bullets, going right through thicknesses of ordinary matter. Should they encounter a living cell, they will simply shatter it. That is why in nuclear reactors thick concrete walls are built to absorb them as they emerge from the core. This destructive capability is utilized in annihilating cancerous cells in the body: this is what is involved in some radiation therapy. They are also used in sterilization. Potatoes exposed to gamma rays do not sprout while waiting for customers.

All sorts of things are happening in the universe, creating all sorts of effects on a grand scale. In the 1970s astronomers detected, for instance, that some satellites launched for scientific purposes recorded gamma rays which seemed to be reaching us from heaven knows where. In fact, a satellite called CGRO (Compton Gamma Ray Observatory) was launched specially for the purpose of studying these in greater detail. In 1994 astronomers concluded from its data that way out there in very distant galaxies, gamma rays are being produced in abundance by some strange processes. There is no limit to the grand goings-on in this fantastic cosmos of ours, nor to the bits of data we keep continually gathering about them.

Polarization: ***An aspect of light not directly perceived by the human eye.***

Waves are disturbances in a medium that travel from one point or region of space to another. For every wave, there is a direction of propagation, and a line of oscillation of the traveling disturbance. If the line of oscillation is the same as the direction of propagation, the wave is described as longitudinal[16]. If the oscillations take place perpendicular to the direction of propagation, the wave is said to be transverse[17]. Thus, in transverse waves, vibrations can occur

[15] Gamma rays were discovered by Paul Urlich Villard in 1900. See in this context, Leif Gerward, Paul Villard and his Discovery of Gamma Rays, *Physics in Perspective (PIP)*, Vol.1, No.4, pp.367–383, 1999.

[16] Sound waves are longitudinal.

[17] Light waves are transverse.

along any line on a plane perpendicular to the direction along which the wave is propagating. If, however, there is only one line on this plane along which the vibration can take place, the transverse wave is said to be polarized. For example, vibrations on a taut string tied at both ends to two walls will be transverse vibrations: they vibrate along any line perpendicular to the string. If, however, the string passes through a long slit in a cardboard, its line of vibration would be restricted along the slit: we would have a polarized wave on the string.

Light is a transverse wave, and so can also be polarized, a property that was discovered only in the 19th century[18]. The normal human eye cannot distinguish polarized from unpolarized light, but the eyes of many birds and insects can do this. This faculty helps them in navigation and communication[19].

Laser: ***There can be light that does not spread out.***

Ages ago human beings invented fire, perhaps the very first light created by our ingenuity. Since then we have produced all sorts of light, both by chemical and electrical means, but invariably such light has been of the spreading out kind: that is to say, like the flash from a torch-light it becomes weaker and weaker as it moves farther and farther away. We call this incoherent light because it consists of various wavelengths which move along different directions, Moreover, the waves are not quite in step (in phase). This is natural if we recall that light emerges every time an electron jumps to a higher orbit and falls back to a lower. Since the atoms are distributed at random, the lifting-up energy reaches them in a random manner. The resulting light is somewhat like the random exit of a crowd from a theater, everyone moving every which way.

That was the only kind of light known to humans until 1960. In that year, Theodore H Maiman constructed a device, using a crystal of synthetic ruby, by which he created perfectly coherent light: i.e., light made up of identical waves in perfect step. Since the device caused light amplification by simulated emission of radiation, it received the acronym of laser[20]. It was as if he had arranged to have the crowd from the stadium walk in perfect step along a single path.

It started out as a contrivance to produce a narrow pencil of bright red light moving along a straight line like a long flashy arrow. It is used in lectures to point to diagrams or a statement on the screen. But in less than two decades the invention found the most unexpected

18 The polarization of light was discovered by Etienne Louis Malus in 1808.

19 For more on this, see G P Können, *Polarized Light in Nature*, (Trans. G. A. Beerling) , Cambridge University, 1985.

20 The theoretical foundation for the laser had been laid by Albert Einstein in 1927. Microwave versions of the device were constructed by Charles Townes in 1957. Theodor Maiman was 32 when he invented the first laser in 1960. For a history of the laser see, Mario Bertolotti, *The History of the Laser*, Institute of Physics, N.Y (English trans.) 2004.

applications. Today laser is used in compact discs and in check-out counters in stores; to clean paintings and for treating detached retinas; in communication systems and in detecting continental drifts. Lasers have come into our computers and are used in precise measurements: Thanks to lasers we can measure the distance of the moon with an error of just one foot.

Consider the gigantic gush of water, pouring down noisily at the Niagara Falls. Imagine that all this water can somehow be narrowed down to a very thin tube and made to hit the ground below. With what a tremendous force would the spot be struck! So it is with a concentrated beam of powerful light. Lasers have been constructed with powers of barely a tenth of a watt. But there is one called Nova whose power is a hundred trillion watts.

All the potential of lasers has yet to be realized. It is remarkable that human ingenuity has created a kind of light that, as far as we know, never before existed. There is both *jñána* and *karma* in science, for we are both knowers and doers in this world. When Thomas Gray, in *The Progress of Poesy* spoke of "blasted with excess of light", he did not imagine that it could some day describe the laser.

Photons: *Light may be looked upon as little bundles of vibrating energy*.

Thus far we have spoken about light as a wave that wings its way from point to point as electromagnetic vibrations. But light also behaves as if it was a volley of infinitesimally small specks of electromagnetic vibrations, carrying tiny bits of energy, miniature balls flying, as it were, while spinning furiously on a axis. We are reminded of the poet William Blake's lines in his poem *Jerusalem*:

I give you the end of a golden string;
Only wind it into a ball.

Light (any electromagnetic wave) behaves as if it is made up of innumerable little bundles of energy zooming with a speed of three hundred million meters per second in empty space, If we imagine light waves to be golden strings, then through one of her marvelous tricks Nature winds them into tiny balls.

Expressed differently, there is also a particle aspect to light. This particle aspect of electromagnetic waves is called an 'energy quantum' or photon. The energy carried by a photon depends on the frequency of the associated wave: the higher the frequency, the more the energy borne by the photon[21].

[21] The 'energy quantum' hypothesis was put forward by Max Planck in 1900. In 1905 Einstein introduced the term 'light quantum' (*Lichtquant*). The name photon was coined by Arthur Compton in 1927. The energy carried by a photon of frequency ν is given by: $E = h\nu$, where $h = 6.62606896(33) \times 10^{-34}$ J.s, is Planck's constant.

But then we recall that particle and wave are fundamentally different: one is localized, and the other spread all over. How can the same thing be both? The answer is, the same thing *can* be both because *that* is what we see. A logical and calculating mathematician can also burst into tears when the person faces a tragedy, because that is the wonder of being human: one is a thinking as well as a feeling creature. So too, light behaves as particle or as wave, depending on the circumstance. A coin has both head and tail; throw it and only one side will show up when it falls to ground. Light is both wave and particle; do an experiment, and only one aspect will appear in the experiment.

People behave in a certain way in public, and very differently in the privacy of their homes. Likewise, at the normal scale of experience light appears as a wave. At the microcosmic level of atoms and molecules, its photon aspect becomes predominant. This is one of the intriguing features of both matter and energy.

Effects of Light: *Light plays many roles*.

Light brings the far flung reaches of the universe together. Without it we will be earthlings condemned to perpetual isolation in a cold isolated niche, and we would have evolved in a darkness that would be as stifling as any self-centered existence can be.

Light is a major instrument in our interactions with the world. It informs us of the presence of persons and things beyond ourselves. It reveals their shapes and forms. It unveils their beauty. It is light that speaks to us of distant stars, of the nature and substance of unapproachable celestial entities. It tells us if a galaxy is receding and at what rate. Light is a silent messenger. It makes no noise, yet carries enormous amounts of information.

It is not only at the intellectual level that light serves us. The chemical constitution of Antares may be interesting, and the distance of the Andromeda nebula may be impressive. But there is more to life than knowledge and wonder. Enjoyment is no less important as a component to living. Here too light plays a role. For there is more to light than brightness. Light is not simply vibrations of varying intensities, but of satisfying shades and colors as well. Color adds splendor to the world.

Light displays all the properties that are characteristic of waves. It is reflected and refracted, it is deflected and diffracted. It is indifferent to things not on its path, and visible only to those that come on its way. The properties of light add to the charms of the visible world. The changing colors of the diamond beetle arises, for example, not from pigmentation, but because of diffraction. The glory of the rainbow and the colors of the icicle result from refraction. The blue of the sky is due to light scattering. Without light, diamond would be as inconsequential as a petty piece of charcoal; rubies, sapphires and emeralds would all be dark as the depths of hell. The effect of light on the world around us is of incredible variety. The magnificent aurora and patterned butterflies, the poetry of flowers and the canvas of artists, all depend on light. No wonder, language itself has been enriched by light: a source of light may glimmer or glow, it may dazzle or shine, twinkle or radiate.

Light is also a life-sustaining principle. It is light that transports sun's energy to here below, and by cleverly collaborating with the green plants, feeds that energy to living organisms.

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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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Errata

The portrait of Sophie Germain that appeared in *Resonance*, Vol.16, No.3, p.205, March 2011 is incorrect. The correct portrait is given here.