Physical reality as perceived in science

Niranjan Barik

Abstract

'What is Truth', 'What is Reality' - This has been the perennial question which keeps the human mind engaged at all ages. Do they correspond to facts, phenomena, sense perceptions, objective existence or do they belong to the category of eternal, unchanging entities transcending space and time existing in their absoluteness? Prior to the advent of science, wise men and seers in all religious traditions searched for this Absolute Truth as the ultimate Reality within their own self; through deep contemplative modes and came up with a realization of it as the unit source, the ground of all beings and things in this whole creation. However, this revelatory knowledge belonging to the metaphysical or spiritual domain could not stand the scrutiny of the rational mind as it gradually raised its head with the emergence of science. Science on the other hand considered Truth as that which corresponds to Reality and to the scientific view, reality consists of the observable universe of material objects and natural phenomena all perceptible to our senses. This is the only Reality for a lay person in conformity with our common sense. However, science in search of Truth and Reality to its fullest extent, has gone farther in its understanding revealing various layers of this Reality. The Reality addressed by science in fact is the Physical Reality, which in the wake of the revolutions brought about by the theory of relativity and quantum physics, is understood as having layered structures, though no neatly stacked layers. These layers may be considered as different levels of description as one proceeds from the gross to the finer and deeper levels unfolding the enchanting and dynamic nature of the physical reality. We would like to give a brief account of this nature of the physical reality which would reveal such a sublime order in the design of the physical world that it often seems to suggest the divine hands of a single architect. Could this be the higher order Reality playing the role of some kind of a governing force as the ground of beings as apprehended by the ancient seers of all religious traditions!

Introduction

Let us start with the first layer of the physical reality, which is the only reality for most people. This is the observable universe of material objects including the natural phenomena surrounding us with which we interact through our five primary senses. This is the reality that seems to exist outside of us which brings forth a distinction between the mind and matter, between the perceiver and the perceived. This led the French

philosopher Rene Descartes and his followers to believe that there is a distinct separateness or split between matter and mind or between object and the observer. Science proceeded in observing nature with all its material bodies and all the phenomena happening in nature. Scientists like Galileo, Kepler, Newton and many more analysed the observed data and could see some underlying pattern or regularity in the structure or happenings in nature. They realized that instead of any divine hand propelling all this in the physical world, it is the physical forces like mechanical, gravitational, electrical or magnetic forces, which cause all the changes in rest, motion or structural configuration of material bodies. The regularities they found were encoded in precise mathematical expressions representing those causes as laws of nature. In this context we may remind Galileo's laws of falling bodies, Kepler's laws of planetary motion, Newton's laws of motion; besides several other laws deciphered from nature from other areas of study like gas laws in heat and thermodynamics, coulomb's Law in static electricity, Ampere's law, Boisvert's law, Faraday's law, and Lenz's law etc. in current electricity, Newton's laws of gravitation for planetary motion and many more. Also notable was the work of Maxwell on Electromagnetism who combined the earlier works in this field to arrive at the conclusion that light is an electromagnetic radiation always propagating as a wave with a constant velocity in vacuum. Such understanding of the physical reality at its most commonly perceptible level was prevalent almost for two centuries following Maxwell and Newton's work, which is known as classical science. Classical science dealt with the physical reality at this level adopting a mechanical world view. Matter as inert bodies exists as solid, static and separate bodies, which do not change their state of rest or motion unless impressed by external forces. This first level of reality, which appears as separate solid substantial concrete material bodies, does not reveal to our ordinary senses what lies inside. This is because our ordinary senses are not well equipped such as we are not outfitted with an x-ray vision to perceive what is inside this first level of reality. Therefore, it would require a great leap in our imagination as well as necessary tools as mechanical extensions of our senses, which include not only electron microscopes, particle accelerators etc. but also intricate mathematical constructs and abstract models for visualization.

Second layer of reality

As we have pointed out earlier, the second layer of reality requires a great leap in our imaginations since our ordinary senses are not equipped adequately to perceive it because of the conditioning we have gone through over millions of years of evolutionary process. Such a great leap in imagination happened for the first time all the way back in 3th century BCE with the Indian Rishi Kanada Kashyap in his Vaishika Darshana and subsequently by the Greek Philosopher Democritus, who proposed the 'atomic' structure of matter. Dalton used this concept to explain the chemical reactions through

his laws of mass-action. Avogadro formulated the fundamental law for the quantity of the material constituents existing in a fixed amount of a material substance which is well known as Avogadro's law. Assuming atomic and molecular structure of gaseous matter, Boltzmann formulated the statistical theory for explaining the gas laws and the laws of thermodynamics. Maxwell, following Boltzmann, developed kinetic theory of gasses and came up with the concept of equipartition theorem. Nevertheless, the atomic concept as the discreteness of material substance was not acceptable to a larger section of the populace who believed in the Aristotelian dictum that 'Nature does not take any abrupt jumps'. Boltzmann's work could not be acceptable without any scepticism. Finally, in the beginning of the twentieth century in 1905; Albert Einstein's mathematical formulation

explaining the Brownian motion of Pollen grains on the surface of a liquid could provide means for empirical evidence for atomic or molecular structure of matter. Today of course with the sophisticated technology providing electron-microscope, atomic force microscope etc. one can observe and manipulate these atomic constituents of matter.

The question however remains what is an atom of a substance? Nature had been kind to the queries of the inquisitive human mind in constantly sending signals and hints in various forms of natural phenomena. These are the emissions of electromagnetic spectra when matter is heated (such as Black body radiation spectrum), discrete and continuous incandescent spectra etc.; the emission of cathode ray by electrically heated filament as a cathode in a vacuum tube; the radio-active emissions as α, β and γ-rays by radio-active substances. When the human mind was sufficiently awake to listen to these signals coming from the inner layers of matter; J.J. Thompson in 1897 identified tiny electrically charged material particles called subsequently as electrons in the cathode ray. He concluded that these electrons must have emerged from the atomic constituents of the cathode, suggesting thereby a further structure of atoms. Matter consisting of atoms being ordinarily neutral, electrons must have been embedded in a positively charged thick soup like resins in a pudding. This was called Thompson's plum-pudding model of atoms. However, this idea could not be stretched to all extents to explain everything. In 1911, Rutherford's experiments of alpha particle scattering from a thin gold foil target established that the positive charge within the atom neutralizing the negative charges of the constituent electrons is not distributed continuously within the atomic volume as proposed by J.J. Thompson. Instead it was found to be concentrated at the central location in a tiny volume called the nucleus of the atom and the electrons must be revolving around this nucleus like planets around the sun due to the electrostatic force of attraction between the positively charged nucleus and the electrons. Thus, Rutherford proposed the planetary model of atoms. But there was a snag in this model. The electrons moving in their orbits around the nucleus would get accelerated to lose energy continuously since it was already known by that time that an

accelerated charge particle continuously emits radiations losing thereby its energy at a specific rate. In that case the orbital electron in an atom would spiral down continuously by losing energy to fall to the nucleus in no time and therefore the atomic structure could not be stable to form bulk matter as we see. To resolve this difficulty. Neils Bohr in 1919 proposed the idea of discrete orbits for electrons in a nuclear atom. Although for centuries it was believed that "Nature does not take any abrupt jumps" and therefore all changes and all phenomena must happen in a continuous manner; nature however was revealing its discrete action at this deeper level through black body radiation, photo-electric effect and Compton effects like phenomena. Max Planck in 1900 could explain the black body spectrum by proposing that matter in the black body emits radiation in discrete packets of energy proportional to the frequency of radiation. These packets of energy ($\varepsilon=hv$, where h is called Planck's constant and v is the frequency of radiation) were called energy quanta which were subsequently named as photons. In 1905; Einstein could establish further this idea by showing that matter not only emits radiation in discrete quanta but also absorbs it in like manners; explaining the phenomenon of photo-electric effect which fetched him Nobel prize in 1921. Finally, through the explanations of Compton scattering of high frequency x-ray or y-ray radiation by the free charge particles mostly electrons in a graphite target, it was further understood that radiation consists of energy quanta called photons which behave as particles exchanging energy and momentum during collision with targets. Thus, it was known that radiation, like matter, also has discrete structure with its constituents as photons of varying frequencies. On this background of understanding, the human mind was not rebelling anymore to conceive of any physical quantity at this level to take any discrete variations. Hence Bohr assumed that electrons around the nucleus of an atom do not take any arbitrary orbit except for those in which their angular momenta would be some integral multiples of Planck's constant divided by 2 (Angular momentum $L=nh/2\pi$, where $L=mvr$; m=mass of the electron, v=orbital speed, r=orbital radius). However, an atom can radiate energy only when the electron takes a jump from the higher orbit to the lower as a result of which the differential amount of energy ΔE (E-E), n>m; would be emitted as a photon. With these ideas Bohr developed a simple model for the simplest atom of hydrogen which consists of a positively charged proton as the nucleus and a single electron. By this model it was possible to estimate the size of the atom, the discrete spectra emitted by hydrogen that was observed and measured and recorded meticulously by Balmer and many other spectroscopists by that time. Following the success of Bohr's model of atom, many other new discoveries followed suggesting further structure of the nucleus which was found in general as a very strongly bound system of two kinds of particles called protons and neutrons. While protons are positively charged particles, each having a mass almost two thousand times more than the mass of an electron; the neutrons are neutral particles, each with slightly more mass than that of a proton. The force that binds a proton to a neutron or a proton and also a

neutron to a neutron is not the already known electrostatic force. It was found to be almost hundred times stronger than the electrostatic or electromagnetic force. Unlike electromagnetic force which is a long-range force; the nuclear force is a short-range force confined within the nuclear dimensions. This force is called the strong nuclear force as a result of which the mass density of a nucleus is immensely high. As a hydrogen atom is simply a proton at its nucleus orbited by an electron, other atoms are similarly built with a central nucleus consisting of neutrons and protons surrounded by an appropriate number of orbiting electrons. Electrons possess a quantum property called spin. Spin is the tendency of an electron in aligning itself parallel (called spin up) or anti-parallel (called spin-down) with respect to a chosen direction. Then the spin measure of an electron is given as half in the units of reduced Planck's constant ($\hbar$=h/2) and hence the electron spin S=1/2 $\hbar$. Such particles possessing odd-half integral spin (which is an intrinsic angular momentum of subatomic particles) belong to a specific class of particles called fermions, which are in a way quite anti-social. In a particular energy state with other quantum state parameters remaining the same, no two electrons would remain with similar spin orientation. This is called Pauli's exclusion principle. Electrons around the nucleus of an atom are therefore distributed accordingly in various orbits viewed in the form of shells. Protons and neutrons inside the nucleus also follow a similar pattern since they are also spin (-½) particles belonging to the fermion class. Within the space of the nuclear volume, these particles called nucleons move very rapidly under the influence of the strong nuclear force and they are distributed in appropriate shells satisfying Pauli-exclusion principle. Such nucleonic configurations inside the nucleus determine the stability or instability of the nuclei of different atoms. Heavier nuclei with more number of neutrons than the protons or even lighter nuclei with odd-even protons, neutron numbers are quite unstable. They are called radio-active nuclei inside the respective atoms which undergo radio-active decays. Neutrons and protons inside a stable nucleus are stable particles. But in a radio-active nucleus they can decay as well. As for example a neutron can decay to a proton, an electron together with another tiny neutral particle having very negligible mass called the antiparticle of electron-neutrino. A free neutron decay like this. The average time of such decay is around 900 seconds. This process of decay is called Beta-decay which is a very weak process governed by another kind of fundamental force called weak nuclear force. This force has strength which is almost one thousandth of the strength of electromagnetic force and about one by one lakh times (10^{-5}) weaker than the strong nuclear force. Compared to these three forces, the gravitational force is the weakest of all which is almost 10^{-39} times weaker than the strong nuclear force. Nuclei were bombarded with very energetic particles like electrons or neutrons or nuclei accelerated in particle accelerators. From the deep inelastic scattering of electrons, it was inferred that protons and neutrons inside the nuclei do have further structure. They are made up of other elementary particles called quarks, which are also spin (-½) particles like electrons

belonging to the group of fermions. Besides this, a host of new particles had been discovered and identified. We would not go into the details of these subatomic particles grouped into several categories as mesons, baryons or bosons and fermions etc. But we must mention here about the class of particles called bosons, which possess integral spin. Out of all the bosons, there is a specific group called messenger bosons which were found to mediate different types of fundamental forces of interaction between subatomic material particles. For example, photons, the energy quantum of electromagnetic radiation we have heard earlier, are responsible for electromagnetic interaction between two charged objects. The interaction proceeds via the exchange of photons between the charged particles. Thus, photons which are spin-1 particles mediate electromagnetic force. The strong nuclear force that we talked about at the level of protons and neutrons is in fact a residual force due to the primary one that operates at the level of quarks, which apart from their spin and electric charge, carry another kind of charge called colour-charge. Unlike electric charge that is realized in positive and negative varieties: there are three colour-charge states called Red (R) Green (G) and Blue (B). The strong interaction between the quarks is a colour-charge interaction mediated via the exchange of another kind of bosons, called gluons, which are eight in number carrying eight different combinations of colour charges each with spin-1. Similarly, the weak nuclear interaction is mediated by three kinds of bosons W. W and Z^o. Unlike photons and gluons which are massless bosons, W^+, W^- and Z^o are very massive. $W^{\pm}$ are almost eighty times as heavy as protons, while Z^o, which is a charge neutral particle like photon, is more than 90 times heavier than protons. Similar insight predicts gravitational interaction to be mediated by another kind of boson called graviton having spin-2.

Before we conclude the description of this second layer of the physical reality. We would like to point out a few important aspects of the nature of reality at this second layer. First of all, we may remind ourselves once again the relative size of the atom and its nucleus and their corresponding volumes. This would obviously reveal that almost 99.99999...% of the atomic volume is empty space. Atom's solidity is not a result of an actual content of matter, but rather a property resulting from the interactions of electrons which are anti-social entities refusing to buzz from their predetermined configurational states under any kind of squeezing or compressing actions. What a trick that the reality at this level plays by projecting the illusion of solidity of objects! This tangible aspect of material objects providing the very sensation of the physical is based astonishingly on nothingness. Secondly the gross material bodies which appear from outside as inert and static needing external impetus to be dynamic, its inner finer constituents at the molecular, atomic or nuclear level are ceaselessly moving quite vigorously. The molecules within a gas or a liquid, the atoms in the crystalline structure of a solid, undergo vibrations or other types of motions depending on their thermal state. Electrons inside atoms revolve around the nucleus or else jump from one orbit to another emitting

or absorbing radiant energy. The protons and neutrons inside the nucleus also do possess orbital motion of some kind. Again, the force carrying boson particles mentioned earlier are ceaselessly exchanged back and forth between two particles at these levels to generate the impetus for all these dynamisms. Nature at its finer level displays its utmost restlessness as if with everything in a constant state of flux everywhere. One more thing we find that not only is there discreteness at structural levels of matter as well as radiation, all interactions between material bodies at all levels are also generated by discrete impulses inflicted on two interacting bodies due to ceaseless exchange of appropriate messenger particles between them.

Ultimate layer of reality

Finally, we come to the most important aspect of the nature of reality at this level which is quite surprising and mystical as well. This is called dual nature. So far, we have been highlighting the particulate nature of matter as well as radiation. Coming back first to the nature of radiation; we must remind ourselves of the fact that light as radiation had remained most elusive in its nature through its various interplay with matter in phenomena such as reflection, refraction scattering, polarization, interference and diffraction. It was once thought to be corpuscular in nature by Descartes and Newton in order to explain reflection and refraction by its rectilinear propagation. Then it was found to be wave-like by Huygens, Young and Fresnel in the late eighteenth and nineteenth century to explain interference, diffraction and polarization. Later in the mid nineteenth century Maxwell showed that light is an electromagnetic wave capable of propagating in vacuum like X-ray, microwave, radio-wave, ultraviolet and infrared radiations. Finally, in the beginning of twentieth century, it was again found by Plank and Einstein that radiation behaves as particles in the form of packets of energy called photons in order to explain emission from a hot body (Black-body radiation) and absorption by a metal surface giving rise to photo-emission of electrons (Photo-electric effect) respectively. Then what is radiation, a wave or a particle? In fact, it is neither a wave nor a particle. In its quantum nature it is a collection of energy quanta called photons which has its dual nature both as wave as well as particle? depending on how and when it is observed or measured. Since radiation and matter are the two most important modes of manifestation of the physical nature, then it is very likely that like radiation, matter at its quantum level must possess such dual nature. This was the conviction of the young French scholar de-Broglie who envisaged in his 1924 Ph.D. thesis that a free electron should have the wave nature with its wavelength 'λ' inversely proportional to its momentum p = mv. This concept is known as the de-Broglie hypothesis as an example of wave-particle duality of matter which formed the central part of the theory of quantum mechanics. After its due verification in 1927 by Davission and Germer in the electron diffraction experiment through a crystal lattice, de-Broglie was awarded the Nobel prize

in the year 1929. Erwin Schrodinger in his formulation of wave mechanics in 1925 used this concept and subsequently this wave associated with a material particle was interpreted as a probability wave serving as the cornerstone of quantum physics. Now of course we know that not only electrons but also all subatomic particles including atoms and molecules have demonstrated this quantum property of simultaneously possessing the wave attributes like wavelength and frequency together with their particle attributes like energy and momentum etc. in the same way as that of photons.

As we have discussed earlier, all the matter that makes up our everyday world is composed of two kinds of fundamental particles: quarks and electrons. But through relativity ($E=mc^2$) and quantum Physics (wave-particle duality), we now know that quarks and other elementary particles are nothing but discrete packets of energy. Although the objects in our mind appear as solid and substantial as the rock, their constituent parts are in a constant state of flux characterized by a ceaseless interplay of energy at a microscopic scale at an unimaginably fast rate - a level that our senses are not equipped to perceive. Energy is an abstract and chimerical substance which reveals itself through the forms it takes in its manifestations. Then how is energy stabilized into quarks and electrons or other subatomic particles, let alone the complex structures like other gross bodies living as well non-living. Why don't the fundamental particles in the form of energy quanta simply fall apart? This may be because they are packaged forms of energy where energy is confined like a genie in a bottle. The bottles here are called quantum fields which are really abstract. This brings us to the brink of the third layer of reality. The fields at this level are as real as the particles we encountered in the second layer of reality. The fields are ordinarily known to us by way of the forces associated with them. We are familiar through our daily existence with the gravitational field, electric or magnetic fields. Einstein showed us that space, time and field cannot exist separately, they are always intertwined magnificently in their existence. A field is a physical state of space itself and space does not exist without a field. But these are the classical manifestation of fields, which arise from their respective sources and whose influences are felt only locally (we know that the gravitational as well as the electrostatic or magnetostatic forces decrease as the inverse square of the distance from the source). But the field we are referring to here is still stranger than the truth. Even if we take away the source; an unmanifest field having the blueprint for all its qualities will still remain in empty space, which would pervade all space and time, whose influence can be felt equally in all parts of the universe. Such fields are called quantum fields which are nonlocal in nature. Unlike classical fields, the magnitude of energy of a quantum field is not continuous but discrete or quantized. They are not in any geometrical sense locatable - yet they are everywhere.

This is because of Heisenberg's uncertainty principle. Hence a quantum field cannot have a fixed value at any given times; not even a value of zero. As a result, the

magnitude or size of the field must change all the time producing what is known as vacuum fluctuation (in the sense-now we see it, now we do not). But its effects can be observed as has now been validated providing strongest evidence of the actuality of the unmanifest quantum fields.

This fluctuation implies constant creation and annihilation of virtual packets of energy called virtual particles. This behaviour gets increasingly more energetic at smaller distances and smaller time scales. Thus, empty space is not empty at all. The unmanifest quantum fields interlace throughout the cosmos like multidimensional fabrics woven on a celestial loom and each infinitesimal weave of the fabric contains, so to speak, the whole cloth. These underlying quantum fields give birth to the elementary particles. Thus, according to quantum field theory; the primary elements of reality are not individual particles, but the underlying fields. For example, all electrons are but excitations of an underlying field called the electron field which fills all space and time. The same holds true for all fundamental particles of which matter is made. In addition to quarks and electrons there are a host of other fundamental matter particles like neutrinos, but they are either unstable or interact very weakly. These matter particles are the products of various other respective matter fields. Similarly, all the known force fields also have their respective elementary force particles such as photons associated with the electromagnetic force field and gravitons for the gravitational force field etc. We have already mentioned about all the various types of force carrying messenger particles corresponding to the four fundamental forces. Both these forces carrying messenger particles as well as the elementary matter particles are merely excitations of their underlying quantum fields. Thus, science has revealed that the world around us is one in which there is no such thing as empty space and the most crucial elements of our existence are the things which we cannot see.

Conclusion

Now a pertinent question to ask is that if everything is ultimately made of one substance called 'energy', why should nature provide so many different types of fields for energy to work its magic? Einstein envisioned that the known force fields that control all-natural phenomena ought to have a common foundation describable by tenets of a unified theory. Most physicists are now quite convinced that these diverse matter fields including all the force fields are nothing but different aspects of a single field. In that case the realization of a successful unification scheme would be the common key, the subtlest of all existence - the common source. It seems, as if in the pursuit of the nature of reality, science is approaching to realize the common ground at the most subtle level of the physical reality as the ultimate reality, the unit source. Ancient Vedic seers used

to call it the all-embracing 'Brahman' - the cosmic consciousness the supreme self. As stated in Chhandogya Upanishad 6.10.3,

'That which is the subtlest of all is the Self of all this.
It is the Truth. It is the Self.
You are that (Tat tvam asi)

References

1. Boorstin, D.J.; *The Seekers; the story of Man's Continuing Quest to understand his world*. Eck, Dina' India, A Sacred Geography. Harmony Books, New York (2013)
2. Bohm, David; *Wholeness and Implicate Order*, Routledge and Kegan Paul, London (1980).
3. Bhaumik; M.; *Code Name God*, Penguin Books, Random House, India Pvt. Ltd. (2006).
4. Glattfelder, J.B.; *What is Reality?* George and the Blue Moon, Random House, London (2016b).
5. Glattfelder J.B.; *Information - Consciousness - Reality - How a New Understanding of the Universe can Help Answer Age-Old Questions of Existence*. Springer Open Nature, Switzerland (2018).
6. Horgan, J.; Rational Mysticism; *Dispatches from the Border Between Science and Spirituality*. Houghton Miffin, New York (2003 b).
7. Penrose, R.; *The Road to Reality - A complete Guide to the Laws of the Universe*, Janathan Cape, London (2004). "Boisvert's law"