Darshana Jolts

The Physical World – 1

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Introduction

Ultimately, all of science is an effort by the human mind to understand and explain the world around with all the resources of human intelligence and ingenuity. The world around us has two broad components: the vast, inanimate, (apparently) mindless physical part on the one hand, from imperceptible atoms and sand particles to immense stars and unimaginably grand galaxies on the one hand; and the marvelous, throbbing, rich variety of living entities, from minuscule micro-organisms to mammoth mammals which, thus far, have been observed with certainty only here on our planet.

The complex of lifeless entities and related phenomena constituting the world have been observed, studied, and interpreted since time immemorial. Over the ages ingenious and clever explanations were given to natural occurrences in various cultures. Most often, these arose from the speculative prowess of the thinkers. Quite a few of their ideas grew into rich and imaginative mythologies which had such appeal in the magical framework that they were generally regarded with the same seriousness with which current theories of modern physics are held by its practitioners. That appraisal is still widely popular all over the world.

The emergence of modern science not only uprooted or considerably modified little by little most of the ancient *darshanas* of the phenomenal world as articulated in the great civilizations of the past, but it also brought within the range and understanding of the human mind aspects of the physical arena that not even the most fertile minds of the ancient world could have woven or pictured in their rich and ingenious theories. No ancient thinker, however intelligent and keen-minded, could have surmised, by imagination alone, how the rainbow is formed, what fuels the sun, why diamond sparkles, or why water evaporates.

The foundations of the physics formulated in the 17th century were radically different from anything conceived or contrived before. This was because it arose from a methodology that was not common in prior efforts to unravel the world. That methodology involved three powerful ingredients: emphasis on observation, mathematization of the laws of nature, and the construction of instruments that reveal and that measure. The value of observational evidence and corroboration of proposed ideas was not recognized by the thinkers of the ancient world. Indeed, even today not many seek such evidence when they accept some beliefs and interpretations.

Many aspects of the physical world would have remained unknown to the human mind were it not for the use of mathematics. Ingenious instruments to extend and refine human faculties of perception opened wide realms of the physical world that had till then remained hidden from human comprehension.

Qualities and Quantities: *The phenomenal world has an inherent mathematical structure.*

Any thing or event in the physical world may be described using the words of a language. With some effort and imagination, it can also be described in terms of measurable quantities and mathematical relations. Thus, we may say that a book is large or small, but we can also state with numbers its length and width and volume. We may describe the moon as sailing in the sky, but also state in figures how fast it is moving. We may describe a musical piece as being short or long, but also specify how many minutes or hours it takes to perform it. In other words, descriptions may be *qualitative* or *quantitative*.

In ancient times too numbers and measures were used. One had to measure land, weigh grains, count cattle, keep track of weeks, buy and sell things, etc. These call for arithmetic and geometry. But not until the 17th century did the quantitative mode begin to be applied systematically in the exploration and investigation of physical phenomena. It turns out that quantitative descriptions endow us with predictive power regarding the course of natural phenomena. . Indeed, we have come to recognize its indispensability in uncovering some of Nature's profound features[1].

An essential difference between ancient interpretations and the modern consists precisely in this: all the theories and speculations about the world that came even from the most brilliant minds of the ancients were by and large qualitative, whereas no hypothesis or principle in the physics after the 17th century has carried much weight if it was devoid of a mathematical component[2]. It is doubtful that (the physical) sciences would have advanced to their current sophisticated stage without the elaboration and application of mathematics. This point must be borne in mind in the context of claims to the effect that the insights of the ancients embodied the findings of modern science.

[1] Many aspects of the physical world would have remained unknown to the human mind were it not for the use of mathematics. For example, it would be impossible to know about the structure, behavior, and size of atoms without mathematics.

[2] A hallmark of any theory in physics, valid or not, is that some mathematical formula or measurable feature should be associated with it. On this basis it is easy to determine whether or not any imaginative proposal about how the world functions need to be considered seriously from the scientific perspective.

The fruitfulness of mathematics in the physical sciences has been so spectacular that many other branches of science, and even some non-scientific ones, have been trying, sometimes successfully, sometimes awkwardly, to incorporate numbers, formulas, and equations in their efforts to understand and interpret the world.

In the *darshana* of modern science, underlying the order and harmony of the physical laws which activate the phenomenal world are precise mathematical laws, the slightest violation of which would wreak havoc in the world. These laws operate in the esoteric mathematical framework of differential equations, symmetry groups, Hilbert space, curvature tensors, and such[3]. Take away these, and we may be able to experience, appreciate, and describe the world through great poetry and magnificent art, but we simply cannot explain any aspect of it except in rather simplistic terms, and through mythology.

This is not to belittle the intellects of ancient thinkers, but to recognize that they did not have for use the essential tool of mathematics and scientific instruments for a full and fruitful interpretation of physical reality.

Varieties of Motion: ***Motion may be uniform or non-uniform.***

The motion of bodies is one of the most ubiquitous features of the world around us. True, when we take a walk we see fixed trees, stationary buildings, and parked cars; but there are also many things in movement: not just birds and beasts, but also raindrops, winds, water waves, and more. René Descartes concisely described the entirety of the physical world in a single phrase: *matter and motion*.

It is not surprising that inquiring minds have always reflected on the nature and causes of motion[4]. Many views were expressed on this question, based on common observations and intuitive thinking[5]. Some of these persist to this day in the minds of many people.

Scientific thinkers in the 17th century analyzed and argued about the nature and properties of motion. Galileo tracked down some of its secrets by observing, experimenting, and measuring moving bodies. Thanks to such efforts, we now classify motion as *uniform*: that is to say, without changing speed or direction; and *non-uniform*: that is, with change in speed and/or

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[3] This is one reason why physics becomes 'difficult' to most people, and why popularizations of the subject seldom convey the full significance of what is being explained.

[4] Many keen minds of the ancient world, such as Chinese, Hindu, Greek, and medieval European, studied motion and offered various explanations for it.

[5] In everyday observations only animals move by themselves. Other objects move only when pushed or pulled by direct contact.

direction. A car moving with unchanging speed along a given direction is in uniform motion, whereas a ball hurled in the air is in non-uniform motion. Parachutes may descend in uniform motion; a free-falling stone has non-uniform motion. We rarely see uniform motion occurring in nature around us: moving bodies often change speed or direction or stop. This prompted the ancients to imagine that the orderly circular motion in the heavens is inherently different from the random and unsystematic motions one observes here below[6].

Then again, it is natural to think that if two bodies of unequal weights are dropped from a height, the heavier one will reach the ground first[7]. This is not so, unless the effect of air becomes significant, as when one of the bodies is a leaf. This fact was first uncovered by Galileo, much to the dismay and displeasure of some of his contemporaries who had been taught otherwise by the scientific sage of antiquity, Aristotle[8].

There are also motions which are rhythmic and regular, unchanging and deceptively uniform: the oscillation of a pendulum, the ups and downs of a wave, and the swing of the planets around the sun. In spite of their repetitious regularity, these are instances of non-uniform motion, because in such cases there is change in direction of motion. The recognition that uniform circular motion is not uniform motion is one of the important insights of modern science.

These results hinge on our understanding of three key concepts: *speed*, i.e., how fast or slow a body is moving; *velocity*, i.e., speed and direction of motion; and *acceleration*, which is a measure of rate of change of velocity. These are essential and fundamental notions in the quantitative description of the phenomenal world.

The systematic quantitative analysis of the properties of motion came to be called *kinematics*[9]. It is at the very foundation of any serious investigation of the physical world. The ancients studied the motions of planets in terms of geometrical figures and time intervals of reappearance. But they did not explore the notion of speed or acceleration, which are basic from the modern perspective[10].

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6 In Aristotelian physics, all celestial motion was permanent and perfectly circular; terrestrial motions abrupt and impermanent.

7 Everyday experience and intuitive thinking seem to suggest that heavier bodies must fall faster than lighter ones.

8 See in this context, V V Raman, The Leaning Tower of Pisa Experiment, *The Physics Teacher*, Vol.10, No.4, pp.196–198, April 1972.

9 Among the many who initiated experimental and quantitative kinematics must be mentioned Niccolò Tartaglia of Italy and Simon Stevin of the Netherlands.

10 There have been exceptions. For example, Subash Kak has shown that an interpretation of the commentator Sayana would suggest that Vedic thinkers were aware of the (currently accepted) speed of light from the motion of the sun. Subhash Kak, Sayana's Astronomy, *Indian Journal of History of Science*, Vol.33, pp.31–36, 1998.

Force and Change: ***Force does not cause motion, but change in motion.***

Since ancient times scientific thinkers have wondered about the causes of motion. It is clear from everyday experience that bodies at rest begin to move when they are pushed or pulled. Pushes and pulls are what we call *forces*. From this fact of common observation one was tempted to conclude that force is what causes motion. This is not a great discovery, but a fundamental error of perception, to which most normal people are subject, as may be verified by asking anybody what a force does.

A corollary from this is that we need a force to keep a body moving. This too is often observed in the world of everyday experience where the only 'observed' forces are direct pushes and pulls. But then we also see planets moving in the sky. Who is exerting a force on them to keep them moving? Thus arose the angel-hypothesis: invisible angels do the pushing[11].

Then again, when a projectile is thrown in the air, it is seen to be in motion without the assistance of any push. To explain this phenomenon, some ancients proposed the notion of an impetus which, once given to a body, can persist for some time, enabling it to be moving[12]. The impetus notion continues in the minds of those who have not been touched by the *darshana* jolt in mechanics which occurred in the 17th century.

During that century, thanks largely to the work of Galileo, Descartes, Huygens, Leibniz, and Newton, it was recognized that force causes, not motion, but changes in it; in other words, force causes acceleration[13]. When a force acts on a body, the body could speed up or slow down, and/or change direction. Likewise, as long as no external force comes into play, a body will remain at rest or continue in its state of *uniform motion* indefinitely. This is the principle of inertia[14]. What this means is that when we observe a body to be at rest or in uniform motion we may conclude that the net external force acting on it is zero. This is a very simple idea, but a profound

[11] This idea, strange as it may sound to modern ears, even of those who argue on behalf of ancient physics, was taken quite seriously at one time. Even Johannes Kepler toyed with the medieval European theory that angels were propelling the planets in the skies. But few modern thinkers in the West come to his defense in this context.

[12] The impetus theory was formulated and discussed first by Jean Buridan in the 14th century, and it remained quite popular for a long time.

[13] Unfortunately, Aristotle stated this in his writings and therefore his name is associated with this error. But the Aristotelian view is alive and well in the minds of most people who believe to this day that the effect of a force on a body is to make it move, i.e., to cause speed. See, in this context, V V Raman, The Second Law of Motion and Newton's Equations, *The Physics Teacher,* Vol.10, p.136, 1972.

[14] One of the earliest formulations of this principle was by Giambattista Benedetti in the 17th century when he wrote, that a body "which moves by itself when an impetus has been impressed on it by any external motive force has a natural tendency to move on a rectilinear, not a curved, path." I E Drabkin, *Mechanics in Sixteenth Century Italy,* University of Wisconsin Press, p.156, 1969.

revelation that distinguishes ancient from modern science. By understanding the effects of forces, we can discover the existence and variety of forces in the physical world.

Universal Gravitation: *Everything attracts everything else.*

The effects of celestial bodies on things terrestrial had been suspected since very ancient times. Effects there sure are, but not of the kind imagined by planetary fortune tellers. The *law of universal gravitation* states that every mass in the universe attracts (pulls towards itself) every other mass with a force. This was the deep insight of Isaac Newton[15]. In one grand sweep Newtonian gravitation accounted for Kepler's laws of planetary motion; it is also applicable to distant stars and planetary systems.

The quantitative aspects of gravitation gave rise to many problems demanding complex calculations[16]. Some of the best mathematical minds tackled these problems long before computers came, when calculations meant hard work and ingenuity. The grand subject of *celestial mechanics* arose in our efforts to explore and apply the gravitational thesis.

Aside from the fact that it is only due to gravitational pull that we manage to stay on our planet, the relevance of gravitation lies largely at the astronomical level. It is mind-boggling to think that Pluto, billions of miles away, moves with mathematical precision in orbits and with periods dictated by the gravitational sway of the sun. No less wondrous is the fact that the sun, like a billion other stars, is hurtling around the galactic core, trillion and quadrillion kilometers away, only due to gravitation . Gravitation keeps astronomical systems stable over long stretches of time. But for it, masses from the primordial Big Bang would have splintered helter-skelter along divergent paths, receding away independently for as long as time will tick.

Stellar Origins: *Stars were born and they die due to gravitation*.

Nor would the sun and stars be possible without gravitation. For these are gradual but massive accumulations of matter, enticed together through the gravitational force which compressed matter of mammoth magnitudes and thereby generated temperatures high enough to induce the nuclear fusion which set the stars aglow. The sun and the stars could not have been formed without gravitation, the weakest known fundamental force in the universe.

Ironically, it is again gravitation that decimates stars in their old age. With relentless pressure gravitation smashes matter at its skeletal void, transforming stars of ageless shining into white

15 For more on the history of this see V V Raman, A Background to Gravitation, *The Physics Teacher*, Vol.10, No.8, pp.439–442, 1972.

16 These problems included lunar precession, the three-body problem, the erratic orbit of Uranus, and the motion of Mercury's perihelion.

dwarfs and pulsars and more. When conditions become appropriate, gravitation can act with frightening fury and cause a gravitational collapse resulting in the monstrosity called the black hole. Within black holes space and time are mutilated, and the very laws of physics cry out for re-definitions[17].

Airy Ocean: ***We live submerged at the bottom of an ocean.***

More significant than the existence of vacuum was the conclusion from Torricelli's experiment that the atmosphere has weight. But if weight it has, and the atmosphere rises indefinitely, then wouldn't we all be crushed by it? Clearly, the atmosphere must extend to only a finite height. How can this be checked? By doing Torricelli's experiment up on a mountain, of course. There the column of mercury in the tube would rise to a lesser height. This is what young Blaise Pascal did in 1648, along with his sister's husband, comparing mercury heights in Torricellian tubes at Clermont-Ferrand and on top of Puy de Dôme[18]. Sure enough, the column was shorter higher up, proving that the atmosphere gradually attenuates. There is indeed an immense void beyond. Common knowledge today, but arrived at only through tortuous routes.

The unraveling of the roots of perceived reality is a slow process, and depends on hard work, experimentation, and reasoning, and less on speculation. It requires ingenuity and intelligent observation. In retrospect, though, it all seems very simple. A man and his brother-in-law carried troughs of mercury and thick glass tubes: one was at the bottom and the other climbed up a hill. The mercury level in the tube slipped down atop the mountain. That was all there was to it. *Voilà*, we came to know that the air surrounding us does not extend indefinitely!

At about the same time, Otto von Guericke – lawyer, engineer, politician, and mayor of Magdeburg – invented an air pump. He used it to evacuate most of the air from a huge sphere made up of two tight-fitting hemispheres which could not be pulled apart even by the strengths of sturdy steeds because of the might of the atmosphere outside[19]. Let us reflect on this a little: Though we move breezily through the earth's gaseous mantle, in fact it exerts considerable pressure on us: to the tune of one kilogram on each square centimeter or fourteen and a half pounds on every square inch. This is equivalent to carrying a considerable load on our heads all the time. Perceived reality is bearable because of evolutionarily adjusted physiology.

There is more to vacuum than what is perceived. In the course of time vacuum came to be used

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[17] For more details, see Cliff Pickover, *The Stars of Heaven*, Oxford University Press, 2001.

[18] For more on this, see Knowles W E Middleton, *The History of the Barometer,* Johns Hopkins Press, Baltimore, 2002.

[19] For more on Guericke's work see Fritz Krafft, 'Guericke (Dericke), Otto Von' in *Dictionary of Scientific Biography*, Charles Scribners' Sons, New York, Vol. V, pp.574–576, 1972.

in refrigeration, in light bulbs, in cathode ray tubes, as well as in the manufacture of countless things, including thin films. Many scientific experiments require high vacuum, which is one reason why some day they may be conducted on the moon or in space because here on earth it is not easy to produce complete vacuum.

We are voyaging with the earth in the vacuous void of space, but within an airy film we call our planet's atmosphere. Transparent and unrecognized except when we reflect on it, invisible air is what sustains us as breathing beings. The gaseous sheath that encloses our globe is among the countless factors that make life possible on our planet.

Yes, as Galileo said, "we live submerged at the bottom of an ocean of air". We see aquatic creatures and we can imagine plants and animals at the bottom of the ocean. But it does not occur to us that we ourselves are under a similar sea: not of water but of air.

Waves: *There are perpetual rhythms that rule the world.*

Since the most ancient times countless human beings must have stood firmly on the wet sandy beach and faced the vast blue ocean, whence surge incessantly majestic waves that lash on the shoreline, like a furious army charging at a defiant enemy, but only to die away into foamy puddles that meekly recede back into the ocean. Humans must have wondered what they were, those noisy waves, splashing on and on with never-ending persistence, during day and night, summer and winter.

What strikes one most about waves is their periodicity, routine repetitions to and fro. They are motion *in* the ocean, not *of* the ocean. A wave is the propagation of a periodic disturbance from one region of space to another. It is a mechanism for the transport of energy from point to point. This is another major discovery of modern science. Moreover, though the most visible form of waves are the ones we see in the seas or as ripples in ponds, there are waves in air that strike us as sound[20]. Light, the most ubiquitous feature of the physical world that makes us aware of the presence of things around us, and of their shapes and colors, has intrigued the human mind since time immemorial[21]. Modern science has revealed that it is also a form of wave[22]. Indeed, the

[20] See in this context, V V Raman, Sauveur, The Forgotten Founder of Acoustics, *The Physics Teacher*, Vol.11, p.161, 1973.

[21] The history of theories about light is a long and fascinating one. In the ancient Indian context, the *Samkhya* philosophical system (6–5th century BCE), light was recognized as the insubstantial source (*tanmàtra*) from which the material world emerges: a fascinating insight into the ultimate origin of the world. The *Vaisheshika* system links light to *àkàshà* or the fifth element ether. We may also recall that in the *Adi Parva* of the *Mahabharata* we read the interesting statement: "Mixing three colors, you have produced all the objects of sight." (Section II, p.37 in Kisari Mohan Ganguli's translation.)

[22] The wave nature of light was first proposed by Robert Hooke and Christian Huygens in the latter half of the seventeenth century.

entire universe is pervaded by a subtle form of wave which we have recognized as electromagnetic in nature[23].

Consider two cars coming from different directions which happen to collide at a point of intersection. That would be their end as moving entities. No more car beyond the point of encounter. This is the nature of material entities: being arrested abruptly if they run into another. But this is not so with waves. When a wave disturbance propagates through a medium it is disturbing every element of the medium along which it travels. Now suppose that another wave is passing through the same medium along a different path, and their paths happen to cross at some point in the medium. The two waves will then *interfere* at the point of intersection: the elements of the medium will be agitated by the combined effect of the two waves. Beyond the point of interference the waves will continue as if nothing had happened[24]. This property of waves plays an important role in our perception of physical reality.

Our world of experience is dependent upon the functioning of the brain. That functioning involves complex electrical activities. These in turn generate subtle waves which are essentially electrical rhythms in the brain which, when recorded by means of instruments (called electroencephalograms or EEG) on a roll of paper, appear as complex wave forms.

Thus, waves are at the very core of our conscious existence. We are immersed in a rhythm in this world of ours, not just in music and in drum beats, but in pulsating stars, in heartbeats and in cerebral modes too.

Matter Waves: *Bits of matter also undulate.*

We look upon matter as blobs of mass, stationary or moving, localized at any instant at some point in space. Waves, on the other hand, are spread out entities, unconfined and insubstantial oscillations. There is matter and there are waves, two distinct and different entities, or so it seems to be.

But no, for there is yet another surprise at the root of perceived reality. In 1924 Louis de Broglie proposed from theoretical considerations that with every material particle must be associated an intrinsic undular aspect: matter waves, as it were [25]. They are not recognizable, of course, with

[23] The discovery that light is ultimately a form of electromagnetic wave is one of the greatest triumphs of modern science. It was made essentially from theoretical/mathematical reasoning by James Clerk Maxwell. This result was published in 1873 in his classic work, *A Treatise on Electricity and Magnetism*.

[24] The phenomenon of light interference was firmly established through the experiments of Thomas Young in 1800, confirming the wave nature of light.

[25] Louis de Broglie presented the hypothesis of matter waves in his doctoral thesis in 1924.

moving cars and balls, or with anything at all on our scale of experience. But with the imperceptibly minute denizens of the microcosm – like electrons and protons – the wave aspect of mute matter becomes more than apparent in effect and significance.

Thus, as an electron travels from place it place, it is not simply a speck of matter that zooms in the invisible world of fundamental particles like a planet in the sky or a football here below, but as a tiny entity with an associated periodicity, analogous to a creature with a heartbeat.

De Broglie's hypothesis was no empty speculation. He derived what the wavelength of such an associated matter wave would be, should such an entity exist. It would depend on the mass and speed of the particle in question, he stated, and in a very precise way. These matter waves are not mere mathematical fictions: they can be observed through their effects. For one thing, an intrinsic characteristic of waves is interference. And if there are electron waves, they too must interfere. Not long after De Broglie's thesis was propounded, the interference of electrons was experimentally observed. From careful measurements, the associated wavelengths were determined too. Lo and behold, they turned out to be exactly what de Broglie had calculated.

So there are waves of matter too. At the deepest levels of the material world, there is a vast sea of subtle surges, an invisible ocean, as it were, in which the particles would be like ships heaving up and down. Because the matter specks and the waves are one and the same, there is no distinguishing between one electron and another: there are only overlapping clouds. Due to the wave aspect of matter, the microcosm ia a whole different level of reality.

These ideas and results were way beyond the framework of ancient science. Again and again, we need to respect and admire the intellectual and scientific achievements of the ancients. It is no irreverence to our ancestors to recognize that with the passage of times new results and insights have arisen. These are what constitute modern science.

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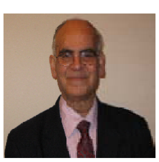

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