Darshana Jolts

Waves

V V Raman

What are wild waves saying,
Sister, the whole day long,
That ever amid our playing,
I hear but their low, lone song?

– Joseph Edwards Carpenter

Waves: *They are repetitive periodic motions.*

When you stand close to the waters on a sandy beach and face the vast blue ocean, you can see the waves surging incessantly. Those majestic waves lash out on the shoreline, only to subside into foamy bubbles. The noisy waves, splashing on and on with never-ending persistence, have been doing this day and night, summer and winter, since time immemorial: long before humanity emerged on earth. We have also seen small ripples in a lake or a pool, sometimes provoked by the mere fling of a stone. Aside from the water waves with which we are familiar, there are waves in the air, and in the void of space also.

What strikes one most about waves is their periodicity, routine repetition to and fro. Those waves at the beach come from some place in the sea, and are transported across the body of water, starting somewhere, reaching somewhere. They are motions *in* the ocean, not *of* the ocean. This too is important to note. In essence, a wave is the propagation of a periodic disturbance from one region of space to another. This disturbance is the motion. Motion implies energy. So we may look upon waves as a mechanism for the transport of energy from one point or region to another distant point or region. In fact, this is an important function that waves serve: the carrying of energy from place to place, often faster and more efficiently than other modes.

Though humanity has been seeing water waves since time immemorial, the serious and systematic study of waves did not start until quite recently in human history. Today the average educated person knows about them: sound waves and light waves, ultraviolet and infrared, microwaves and X-rays and such, and one learns about them in schools and colleges. It is not always realized that all this knowledge was acquired only in the past two or three centuries. They were *darshana* jolts to more ancient views of how waves occur in the physical world.

Parameters: ***Numbers can be associated with waves.***

If we wish to play the game of fruitful physics, we need to measure, we need quantitative descriptions. The first century C E Roman poet Marcus Valerius Martialis wrote in one of his Epigrammmes *You bid me to number the waves in the ocean*[1]. Physics has done more than that. It has ascribed several numbers to a wave. One full sigh of up and down is called a complete *cycle* of the wave. We can talk of how long it takes for a wave to make one full cycle. This is known as the *period* of the wave. A wave that takes two seconds for a rise and fall has a period of two seconds. We may count the number of cycles in a second. We call this the *frequency* of the wave, and measure it in units called hertz[2] (Hz). If the wave takes two seconds per cycle, it makes only half a cycle each second. Its frequency is one half Hz. The distance the wave travels during one full oscillation is known as its *wavelength*. We measure how high the wave rises and call this its *amplitude*. If the wave rises to a maximum of two meters, this is its amplitude. We reckon how far the wave disturbance travels in a second. This is the *velocity of propagation* of the wave. If the wave travels 3 meters in a second, its velocity of propagation is 3 meters per second, 180 meters per minute or 10.8 kilometers per hour. This is the core language of physics when one deals with waves. We speak of a wave's period and frequency, wavelength, amplitude and velocity. These provide useful quantitative descriptions of any wave we may be interested in. Numbers are not just for the tagging; they often mean a good deal more.

There are a good many more numbers and formulas associated with waves. There is one mathematical aspect of waves that deserves mention. It is what one calls the *wave equation* in technical jargon[3]. The wave equation is an expression in the compact symbolism of mathematics of how the various measurable elements of a wave are interconnected. It is a powerful mantra in the esoteric language of mathematical physics. If one knows the wave equation, and is skilled in manipulating it, one can not only draw useful information and interesting insights, but also predict the course and constraints of a wave.

Types of Waves: ***There are two types of waves*: *longitudinal and transverse*.**

Take a long slinky, and place it on a smooth floor. Press it gently at one end, and the compression will slowly travel to the other. A disturbance has been propagated from one region of space (in the spring) to another: we have a wave. Here the oscillations are *along* the axis of

[1] *Oceani fluctus me numerare jubes* (*Book* Vi, 23.) (vi.34).

[2] Named after Heinrich Hertz (1857–1894) who first experimentally established in 1886–87 the existence of the electromagnetic waves discovered theoretically by James Clerk Maxwell. See in this context, Heinrich Hertz, *Electric Waves*, New York Ed. 1962.

[3] The wave equation had its genesis in a work (1747) by Jean le Rond D'Alembert (1717–1783), explored further by Leonhard Euler (1707–1783),

the spring, and so is the *direction of propagation* of the wave. Such a wave is described as *longitudinal*, because its expression is entirely along a length.

Or again, consider a long row of pendulums on strings of equal lengths, all hanging parallel from a long horizontal rod. Swing the first one gently, and when it hits the proximate one, this too will begin to swing, and on and on the disturbance travels along the line of oscillation. This too is a longitudinal wave. The disturbances are not unlike what happens when a hundred matchboxes are kept standing side by side and the first one is tipped towards the next. One by one they all fall down: longitudinal propagation of a disturbance again.

Longitudinal waves tend to arise in media where the elements are not in direct contact with one another, as in air, for example. Sound, which we shall look in another essay, consists of longitudinal compressional waves. Parts of earthquake disturbances consists of longitudinal waves also: the rocks are forced to vibrate in the direction of propagation of the wave.

In waves on water, the motions of the medium are up and down while the wave itself is propagating horizontally. In other words, the lines of oscillation and of propagation are mutually perpendicular. This is an example of what are called *transverse* waves.

Consider transverse waves on a rope. We may make the rope oscillate up and down at one end, and the wave propagates along the rope. Transverse wave again. But we could also make it oscillate right and left. Indeed, the oscillation may be along any line perpendicular to the rope. If, however, the rope were to pass through a narrow slit, then the line of oscillation is restricted. In such case we say that the transverse wave is *polarized*[4].

Waves on water had been observed before, and oscillations on springs also. But it was long before one recognized the two kinds of waves. The transverse nature of light waves was recognized only in the 1820s[5].

Complex Waves: ***Most commonly observed waves are made up of several simple waves.***

We talked about the frequency and period of waves. A wave with a single frequency and period is a pure wave, a simple one such as we can only picture, a Platonic ideal as it were. In the crass world of physical reality, things are seldom so simple: not on our scale of experience at least. Here we only observe overall effects, the jumbling up of a myriad factors to make interesting

4 The term polarization of light was coined by Étienne Louis Malus (1775–1812) on the mistaken notion that the two rays of light emerging as a result of double refraction were aspects of two poles (like magnets) that light had. Jean Baptiste Biot (1774–1862) who did not accept the wave theory of light, did considerable work on the polarization of tight.

5 Augustin Jean Fresnel (1788–1827) established decisively the transverse nature of light waves.

and beautiful blobs. That is what makes complexity the central theme when it comes to studying matters of interest or importance to us.

Most waves in the world are complex: that is to say, mixtures or *superpositions* of a great many waves of different frequencies. They all add up as per an innate law of wave-addition and become one overall effect. In the observed experience, it may in no wise be clear that what appears is a combination. It is somewhat analogous to a fruit punch: sweet and flavorful, a single homogeneous satisfying beverage, but made up of a variety of juices of different tastes and concentrations. So we see white light, for example, which in truth is a combination of light of all the rainbow hues. We hear a sound, a shrill call or a sustained tune: it is one complete sound, or so we perceive it. In fact, it is made up of a great many sound waves of a great many frequencies.

The world of waves is always that way: never pure and simple, always complex and combined. This in itself is a significant recognition. But what is equally remarkable is that we have developed means and methods for analyzing complex waves into their component parts. For this we use instruments like spectroscopes. They are like machines into which you shove a heap of coins and out come equivalent pieces of lower denominations, all neatly sorted out.

Complex waves can also be analyzed through elaborate mathematical techniques known as Fourier analysis[6]. Such analysis is essential in a great many contexts, as in the construction of filters for our sound systems.

It is sometimes said by holists that reductionism is misdirected and narrow. Some in the postmodern world decry classical physics as misguided in its enthusiasm for the analytical mode. They object to the vivisection of Nature which obstructs our grasp of Nature's totality. The point is, holism and reductionism are both important modes in our interpretations of the natural world. We need the holistic approach for uncovering certain aspects of perceived reality, especially the significance of its totality. But one needs to be absolutely analytical, and adopt a reductionist approach to know that white light is made up of primary colors or that gross matter is made up of quarks and leptons. Reductionism gives us profound insights about the roots of perceived reality, as does holism; just as food gives us great satisfaction as does a knowledge of vitamins and proteins.

Reflection: ***Waves are reflected from appropriate obstacles.***

Stand in an open field and clap your hands. There is no one to hear you, none to respond. Let it be a region where a hill stands tall, and you will hear the clapping of your hands again. This

[6] Named after Jean Baptiste Joseph Fourier (1768–1830) who developed this in 1807.

echo is a prompt return of the sound to where it came from. Mysterious and magical it might seem[7]. Horace Smith described an echo as "the shadow of a sound – a voice without a mouth, and words without a tongue." The echo is the reflection of a wave; all waves reflect back when they encounter an obstacle. It is a simple property which causes richness in our experience. It is the reflection of light from a polished mirror that enables us to see ourselves. If there were no reflections, we could never know how we look unless we relied on photographs of ourselves.

When waves reflect, they follow precise and mathematical laws. Sometimes the reflections cause peculiar effects: like mirages on hot sandy deserts which make us see images of palm trees below them at a distance, creating the illusion of a calm pool over there. The laws of reflection also trap light inside some crystals like diamond and then release it with such sparkle that it has become a symbol for eternal love. It is thanks to the reflection of radio waves from the upper sheets of the atmosphere that our radio sets pick up broadcasts from distant lands, and satellites reflect microwaves, making intercontinental TV and communication possible. There are myriad situations, emerging in nature and in human devises, where reflections of waves create scenes and spectacles that otherwise would never be there in the world.

Attenuation: ***Waves lose their intensity* (*amplitude*) *as they move farther away.***

Stand in the open and call someone you see walking away at a distance. She does not even turn her head. What happened to the sound you made? It got dissipated slowly as it traveled the distance. The energy of a wave diminishes little by little: we say the wave attenuates: its amplitude gets less and less along its course.

When we call someone in the open ineffectively we recognize the disadvantage of attenuation. But attenuation is also helpful. If sound waves do not attenuate, every secret whisper would be heard miles away, every conversation in a room would become public. And there would be so much noise in the world we wouldn't hear anything, but suffer the pain of garbled loudness.

So sound dies off with distance, as do all waves that travel through a medium. It is attenuation that causes water ripples to die off when we cast a stone in a pond. Attenuation is like the gradual slowing down of an oscillating pendulum which ultimately ceases oscillating when all its energy is lost to the medium.

There is no material medium between us and the stars, so their lights travel light-years of distance, unattenuated all the way. If there was some matter in the interstellar separations that

[7] In Greek mythology Echo was the name of a nymph who loved herself, but fell in love with Narcissus who also loved himself. Once Narcissus heard the footsteps and exclaimed, "Who is there?" to which Echo replied, "Who is there?"

absorbed a little of the light passing through them, as some gasses do, then very quickly stellar radiations would die away, and there would be but pitch darkness in the night sky. Then astronomy would be impossible, we would never have known of the splendor and extent of the universe. Perhaps we would have formulated a very different physics and cosmology.

Interference: ***Waves add up in interesting ways, and produce a variety of phenomena.*** Two cars from different directions happen to collide at a point of intersection. That is their end as moving entities. No more car beyond the point of the encounter. This is the nature of material entities: being arrested abruptly if they run into one another.

But this is not so with waves. When a wave disturbance propagates, 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 the paths of the waves happen to cross at some point in the medium. The two waves will then *interfere*, unlike the unhappy collision of the cars just considered. What this means is that at the point of intersection, the elements of the medium will be agitated by the combined effect of the two waves. Now what is remarkable is that beyond the point of interference the waves will continue as if nothing had happened, i.e., as if they had not been struck in their paths by another wave! In the words[8] of Thomas Young (1773–1829) the discoverer of light wave interference, "When two Undulations, from different Origins, coincide either perfectly or very nearly in Direction, their joint effect is a Combination of the Motions belonging to each."

This property of waves plays an important role in our perception of physical reality. If light waves did not behave this way, we would be unable to distinguish objects as separate entities, because the light from them would all be jumbled up. Without this property we would not be able to hear the sounds produced by single individuals because when the waves encounter other sound waves, they would be destroyed. All the light from the countless stars, like all sounds from different sources, would mingle and become one diffuse chaotic whole.

Then again, when two masses are combined, the result is a body whose mass is equal to the sum of the combining masses. However, when two waves of equal amplitude interfere, because of their changing effects on the elements of the medium, their combined effect could be either double the amplitude of either or simply nil, depending on the relative aspects of the waves when they meet at the point. What this implies, for example, is that it is possible for two light waves to interfere, and it is possible that at some points the result is total darkness; or when two sound waves interfere, at some points the effect could be total silence. These would have been unthinkable and deemed impossible before the discovery of interference of waves.

[8] Quoted in Encycl. Brit. Vol XIV, Cambridge University Press.

Thomas Young used pinholes and sunlight and the simplest of arrangements to unravel a most significant root of perceived reality. An arrangement by which he demonstrated the phenomenon of light interference, known as the *double-slit experiment*, has become a classic, and is repeated to this day by countless students of physics in laboratories all the over the world. The quantitative side of Young's experiment enables one to determine the wavelength of light[9]. Here was yet another instance of the older (classical) physics when some of the most significant roots of perceived reality were uncovered by very modest experimental set-ups which cost next to nothing.

The property of interference of waves gives rise to a variety of phenomena in the physical world. The multicolored patterns we see when oil spills on the floor as well as the colorful soap bubbles are due to the interference of light waves. In fact, by measuring the spacing of the colored patterns it is possible to determine the thickness of the oil spill. Films thinner than a billionth part of a meter have been measured by using interference techniques. At the other extreme, the diameter of stars have been measured by exploiting interference also. Through this method, the diameter of Betelgeuse in the constellation Orion has been estimated to be about 36 million kilometers.

Diffraction: ***Waves can bend around obstacles and continue their course.***

Throw a clay pot at a pole, it breaks upon reaching the obstacle. Hold a stick in the path of a ripple in a pond; the ripple bends around and continues. The ability of waves to bend around obstacles on their way is referred to as *diffraction*[10].

The diffraction of sound waves is easily recognized. You may call someone on the other side of a wall. Sound waves diffract and reach the person. The diffraction of light waves is not as obvious. You can't see the individual on the other side of the wall. The reason for this is that waves can only diffract around obstacles whose sizes are comparable to their wavelengths. Light waves have very short wavelengths. The walls are way too large for them.

It is somewhat like our ability to jump over hurdles. Everyone can do it, but if the hurdle is too large compared to our dimensions, we cannot put into evidence this human potential. After all, who can jump over a lake or a hill?

Diffraction of light can be observed under appropriate conditions. Consider, for example, a small hole through which a narrow beam of light is made to pass. Were it not for diffraction, all

[9] Remembering that the wavelength of light ranges from 390 to 750 nm, it is an extraordinary feat to measure them. Because the method for doing this has become commonplace, this is not recognized as such.

[10] The credit for the discovery of the bending of light around an obstacle, and for coining the term diffraction, is usually attributed to the Italian Jesuit Francesco Maria Grimaldi (1618–1663).

one would see would be a bright spot on the screen behind. But what one actually observes is a series of bright and dark circles, resulting from the interference of the diffracted waves.

This is why when a point source of light is observed through an optical instrument (the eye or the telescope, say) the resulting image is never a bright point. Because of diffraction, we see a small circular spot around which there are dimmer bands. As a result, if two bright spots which are very close to each other are viewed, the images overlap into a single blur. That is the reason we cannot distinguish with the naked eye between planets and their satellites, or double stars. The degree to which an optical instrument can distinguish between two close point sources is measured by its resolving power.

Waves on Strings: ***Musical sounds are created by the vibration of strings.***

Music is a major source of our aesthetic delights. Many musical instruments are string based. The veena and the sitar are good examples. The waves that can be set up in strings fixed at both ends are at the root of the music that can be generated in them. Musical sound arises from the superposition of one or more waves of discrete frequencies. This is possible with strings of finite lengths fixed at both ends.

Musical vibrations on strings result from the interference of waves generated on them, reflected back and forth from the fixed ends. The wavelengths depend on the lengths of the strings, and the frequency depends on the tension with which the string is plucked as well as on the mass density of the string. This means that we may use strings of different thicknesses to produce different notes. Here we recognize a most interesting root of perceived reality: the beautiful music we hear played on the sitar or the veena is all the consequence of the variety of waves (vibrations) that may be set up in fixed strings! We may note here that though C V Raman is best known for his work on light scattering, it is not as widely known that he was the first to analyze the role of the black patch in the *mridangam* in the production of harmonics[11].

The mathematical analysis of string vibrations, initiated in the eighteenth century, was a high point in the history of science. It led to the formulation of the so-called wave equation mentioned earlier. Explorations of this resulted in the development of important fields of mathematics.

Equally remarkable is the fact that we ourselves carry such fixed strings in a little cartilaginous tuner called the larynx. This vocal box protrudes slightly as the Adam's apple. It is also the entry to the lungs. The air from the lungs is extremely important, even as in any stringed instrument we need resonant air to vibrate sympathetically for the sound to be produced. So we have the

[11] C V Raman and S Kumar, Musical Drums with Harmonic Overtones, *Nature,* Vol.104, p.2620, pp.500–500, 1920.

oral cavity which gets the air puffs from the vibration of the cords. By controlling the air puffs in different ways we can produce a dull and unimpressive noise or the most sophisticated *aláp* or rága. Women's voices tend to be more shrill because the mass of a woman's vocal cord is usually less smaller than that of a man.

Seismic Waves: *Earthquakes involve waves.*

Earthquakes are unwelcome jolts to the stability of lands. They cause damage to dwellings and harm to lives. Over the ages innumerable earthquakes have occurred in practically all parts of the world. It has been estimated that during the past four thousand years more than ten million human beings have perished as a result of these cruel and unexpected intrusions into the daily lives of people.

When Norway was hit by a bad earthquake in 1657 (April 24) a panic ensued, whereupon a wise and scientifically inclined theologian by the name of Millel Oedersön Escholt wrote a scientific analysis of the earth[12]. In 1755 there was a terrible earthquake in Lisbon. Voltaire wrote a moving poem on the disaster. In the 1770s Nicolas Desmarest (1725–1815) wrote one of the first essays on volcanic eruptions and earth tremors[13]. In the early 1880s a group of natural scientists began a systematic study of earthquakes that included mathematical techniques for analyzing the day. In 1889 when the region of Andalusia was shaken scientific investigators rushed to the place to study the tremors. They measured the velocity of shock waves in different soils[14]. By investigating the travel times of seismic waves one can probe into the bowels of the earth, locate the epicenters of earthquakes, and generate data which help us understand the motions of the earth's crusts. A mathematical analysis of the modes of oscillation in an elastic sphere, undertaken by Horace Lamb (1849–1934), initiated the serious subject of seismology[15].

When the string of a musical instrument is elevated from its normal position, and suddenly let go, oscillations result. So it is with the rocks in the crust, kept under tension for too long, and then released at some instant. Tremors follow, and seismic waves are generated. Armed with instruments scientists have been collecting considerable amounts of data on earthquakes. From these we have come to know that there are seismic waves of different kinds. There are slow moving surface waves which, like waves on sea, move along the crust. Then there are the much

---

[12] His book, entitled *Geologia norvegica*, introduced the word geology in scientific literature. Nils Spjeldnaes, in DSB, Vol.IV, p.406.

[13] Hugh Chisholm, Ed., *Encycl. Brita*. Vol VI, 1911.

[14] Lamb's paper, Propagation of Tremors over the Surface of an Elastic Solid in the *Phil. Trans. Roy.Soc*., Series Vol.A 203, 1904, was a major step forward in the mathematical analysis of seismic waves.

[15] For details, see Charles Davison, *A Study of Recent Earthquakes*, The Walter Scott Publ. Co., 1905.

faster moving ones, called primary (P) and secondary (S). Of these again, the P waves move even faster, penetrating into the depths of our globe. These are compressional (longitudinal) waves. On the other hand the relatively slower S waves are transverse in nature, attenuating rapidly when they enter a liquid medium.

Seismographs record and measure even very slight seismic waves[16]. By analyzing these data geologists can determine with precision when and where a particular earth tremor originated. These instruments have been compared to X-ray machines because with their aid one can see what is going on inside a volcano.

Gravitational Waves: ***The oscillations of massive bodies generate gravitational waves*****.**

In 1916 Albert Einstein presented a paper to the Royal Prussian Academy of Sciences. Here he showed that when the equations of general relativity are solved (even approximately), gravitation travels from one body to another in the form of waves[17]. Two years later, in another paper, Einstein discussed the effect of gravitational waves on mechanical systems. Some even suggested that gravitational waves interfered with light waves to produce effects like the red-shift of galaxies. Then in 1922 Arthur Eddington showed that gravitational waves must travel with the same velocity as light. These discussions instigated considerable theory-building, and engaged a great many mathematically inclined physicists for at least three decades.

Gravitational waves could arise from two kinds of sources: periodic and catastrophic. Periodic sources include any body, say a rod, spinning around at a regular speed. Another example could be a spinning star. By an (astronomically) catastrophic event we mean occurrences like the explosion of a supernova. Such events also cause the generation of gravitational waves. In any case, gravitational waves are extremely subtle, and cannot be detected easily. They are very poor carriers of energy.

Experimental work on the detection of gravitational waves did not begin until the 1960s. This involved sophisticated instruments. By the close of the decade, reports began to come in to the effect that detectors placed a thousand kilometers apart[18] revealed coincidences attributable to gravitational waves. This instigated similar efforts in many parts of the world.

[16] The India Meteorological Department, in its various stations, monitors seismic activities. It was established in 1898 in Calcutta.

[17] For technical details, see E Amaldi and G Pizzella, 'Search for Gravitational Waves,' in Francesco de Finis (Ed.), *Relativity, Quanta, Cosmology*: *In the Development of the Scientific Thought of Albert Einstein*, Vol.I, Ch.1, New York, 1979.

[18] One detector was placed at the University of Maryland and another at the Argonne National Laboratory.

In 1974, astronomers discovered a pair of neutron stars orbiting around each other. In principle such a system must be emitting gravity waves. As a result they should be losing energy, which means that they should be getting closer to each other as they orbit. This in turn should speed them up, and decrease their period of revolution. Careful measurements carried out for more than fifteen years showed that this was indeed happening. This is taken as an indirect evidence of gravitational waves.

Efforts to detect gravitational waves is one of the finest instances of the utterly disinterested spirit of the scientific quest. At this point, at any rate, it is very unlikely that the putting into evidence of the existence of these waves will be of any practical value. But that does not concern the probing scientists. Their only interest is to reveal yet another root of perceived reality.

Matter Waves: ***Waves are associated with all matter.***

We look upon matter as chunks of mass, stationary or moving, localized in space and time. 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.

But this is not exactly so. This is yet another surprise at the root of perceived reality. In the early 1920s Louis de Broglie (1892–1987) proposed from theoretical considerations that with every material particle must be associated an intrinsic undular aspect: matter waves, as it were[19]. They are not recognizable, of course, in the case of moving cars and footballs, 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 bullet here below, but a tiny entity with an associated periodicity, crudely analogous to a creature with a heart-beat.

De Broglie's hypothesis was no empty speculation. He derived in mathematical and verifiable terms what the wavelength of such an associated matter wave would be, should such an entity exist. The wavelength would depend on the mass and speed of the particle in question, he stated,

[19] De Broglie presented his famous hypothesis in his doctoral dissertation in 1923. He reasoned this from the symmetry in nature. Radiant energy had been revealed to have both a wave (Maxwell) and a particle (Planck) aspect. So matter too should have both these aspects. In a publication many years later (1970) he wrote, "When I conceived the first basic ideas of wave mechanics in 1923–24, I was guided by the aim to perform a real physical synthesis, valid for all particles, of the coexistence of the wave and of the corpuscular aspects that Einstein had introduced for photons in his theory of light quanta in 1905."

and in a very precise way[20]. 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. If there are electron waves, they too must interfere like waves, not collide like cars. Not long after De Broglie's thesis was propounded, the interference of electrons was experimentally observed[21]. From careful measurements, the associated wavelengths were determined. Lo and behold, they turned out to be exactly what De Broglie's hypothesis had predicted.

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 on undular ups and downs. Because matter specks and 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 is a whole different level of reality.

Brain Waves: ***Waves are generated in our brains.***

Our world of experience is dependent upon the normal functioning of the brain. That functioning involves complex electrical activities. These in turn generate subtle waves which were first noticed and studied by Hans Berger (1873–1942)[22]. These 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.

When brain waves are analyzed it is found that there are at least four varieties of them. First there are the *alpha waves* which are a sort of background pattern common to all normally functioning brains. These fast-moving waves with not too great amplitudes are very apparent when a person is fast asleep or just relaxing with eyes closed. These have been recognized[23] as "sinusoidal resonance pulses in idle motor neurons". But when one is under stress or agitated or intoxicated another type of waves, called *beta waves*, arises. These waves have still smaller amplitudes, and they travel much faster. Then there are the slowest waves, known as *delta*, which are clearly recognizable in the EEG when a person is in deep sleep. Finally we have the *theta waves* which

---

[20] This is the famous formula connecting the wavelength λ of a moving particle with its mass m and velocity v: $\lambda = h/mv$, (where h is Planck's constant) which is as fundamental as $E = mc^2$ in modern physics.

[21] The experimental confirmation of the De Broglie hypothesis came from Clinton Davisson and Lester Germer in 1927 while they were working in Bell Labs.

[22] It is said that one day a young Hans Berger was in a near fatal accident while he was training in the Swiss cavalry. His sister, many miles away, had an instantaneous awareness of his predicament. When he discovered this he was convinced this was telepathy, and he decided to study medicine and psychology which eventually led to the discovery of brain waves.

[23] W John White (ed.) *Frontiers of Consciousness: The Meeting between Inner and Outer Reality*, p.96, New York, 1976.

come about when the brain is affected in some abnormal way, through direct physical damage or psychological shifts in personality.

Knowledge of these waves has proved to be useful in fathoming the mysteries of mind and thoughts. The patterns of brain waves in practitioners of meditation and in scientists have been studied. As a result of yogic exercises Swami Rama of Rishikesh produced all four brain waves simultaneously: a remarkable feat indeed[24]. Aside from recognizing meditative practices as more than mere exotic modes, scientific exploration of this kind exposes the physical basis of meditation techniques.

Thus, waves are at the very core of our existence. There is much rhythm in this world of ours, not just in music and in drumbeats, but in pulsating stars, in heartbeats and yes, in cerebral modes as well which are at the very roots of our consciousness.

---

[24] Albert Rosenfeld (Ed.), *Mind and Supermind*, p.49, New York, 1977.

***

Previous Parts:
The World Above: Vol.15, No.10, pp.954–964; No.11, pp.1021–1030, 2010;
The Physical World: Vol.15, No.12, pp.1132–1141, 2010; Vol.16, No.1, pp.76–87, 2011;
On the Nature of Heat: Vol.16, No.2, pp.190–199, 2011;
Sound: The Vehicle for Speech and Music, No.3, pp.278–292, 2011;
Light: The Revealer of Chromatic Splendor, No.4, pp.359–371, 2011;
More on Light, No.5, pp.468–479, 2011;
Matter: The Stuff the World is Made of, No.7, pp.670–681, 2011;
More on Matter, No.8, pp.784–793, 2011; No.10, pp.987–998, 2011; No.11, pp.1061–1070, 2011;
More on Force: Vol.17, No.1, pp.83–91, 2012.

V V Raman is Emeritus Professor of Physics and Humanities at the Rochester Institute of Technology, Rochester, New York 14623, USA. He is available for giving Skype lectures in Indian universities. Email: vvrsps@rit.edu
http://en.wikipedia.org/wiki/Varadaraja_V. _Raman