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Sound: The Vehicle for Speech and Music

V V Raman

A thousand trills and quivering sounds
In airy circles o'er us fly...

– Joseph Addison

Sound: ***Its variety.***

There is the serene chant of worship which lifts up the soul, and the magic of the mantra with its occult significance. There is the melody of music which fills us with delight and the hearty laughter which reflects a happy feeling. There is the cooing of the birds and the gurgling of the stream in rustic nature. There is the shriek of the frightened, the moan of the dejected, and the wail of the bereaved. There is the noise of the machine and the roar of the thunder. There is the secret of whisper and the knock on the door. There is the chime of the bell and the bleating of the goat. There is the call of a familiar voice and the vigorous beat of the drum. One can go on and on with the wondrous variety of sounds that fill our world of perceived reality.

Every sound enriches our life in a different way, and connects us invisibly to our surroundings. Some sounds evoke thoughts, some incite feelings. Some create emotions and others only jerky responses. Some give us delight, others cause pity. Some convey information, others nothing at all. We rarely pause to consider the countless ways in which we are affected by the myriad sounds that impinge upon us. Yet, though seldom dramatic in its manifestation, sound is an extraordinary feature of our lived world which adds depth and meaning to our experiences in a hundred ways. Its rhythmic forms in poetry and prayer seem to put us in touch with some higher realm of reality, and its magnificent expressions as music have been regarded as divine since time immemorial. Ancient Hindu visionaries recognized the spiritual power of sound[1] and keen Hindu philosophers recognized its role in the acquisition of knowledge[2].

The Nature of Sound: ***Sound consists of vibrations in an elastic medium.***

So what is this ding-dong of the bell that we hear? What is this sound that we experience, rejoice

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[1] In classical Hinduism the notion of *shabda* is central in Hindu spirituality, metaphysics, and in epistemology, with esoteric meanings. Its passing aspect is *dhvani*. In Sikhism, *shabad* corresponds to mantra: a hymn in the *Guru Granth Sahib*.

[2] In the Nyáya Vaishehsika School, *shabda* refers to the authoritative utterance of one who has attained enlightenment.

in and respond to? There are, of course, two aspects to this question: First, we may wish to inquire into what there is in the external world that is responsible for what strikes us as sound. Second, we could ask about what is happening in the internal world underneath the skull that produces this sensation. It is the recognition of this distinction between actual and perceived reality that distinguishes modern from ancient science.

Physics is concerned with the reality aspect, and the physiologist with the perception aspect. There is a correspondence between the two that creates the world of perceived reality.

There is nothing substantial that one can feel or see when one hears sound. Sound results from vibrations in the air surrounding us. These vibrations are simply longitudinal pressure waves, incredibly subtle, and not causing undue turbulence in the air. The vibrations may be set up by any vibrating body: a drum or a string, a bell or the vocal cord or whatever. So what we perceive as sound consists of waves: in air, in water, or in solids, but waves in a material medium, for there is something that vibrates and causes the waves[3].

Air is always disturbed to one degree or another by the motions occurring in it. By simply swinging a rope or a baton in air we can set up vibrations in it. But we do not hear every swing because our sensory mechanisms respond to frequencies only within a certain range. But elephants hear low frequency vibrations. No human hand can shake a cane at twenty or more cycles a second, for that is the minimum frequency for vibrations to become audible. On the other hand, a mosquito can flap its wings this fast: which is why we hear the annoying hum of the beastie as it hovers in our vicinity. Nor do we hear the much faster vibrations of the atoms in a solid, for there is also an upper limit to audible frequencies: about 20,000 hertz. Mice can hear very high frequency waves.

The Speed of Sound: ***Sound travels with a finite speed.***

There is a Tamil proverb which says that the elephant comes after we hear the bell on its neck. This is very true, but it would be wrong to conclude from this that sound travels faster than light. We have all noticed that the clap of thunder reaches our ears only a few seconds after the flash of lightning blinds our eyes: from which follows the truth that sound travels slower than light. When we talk to a person, even at the far end of a room, unlike the thunder from the distant sky, the hearer sees the lip motion and hears the sound simultaneously. This suggests that sound must be traveling quite fast. So the question that arises is: How fast does sound travel? More interesting still is the question, how does one come to know how fast sound travels?

[3] In technical terms, the waves are longitudinal and the medium must be elastic.

In the first half of the seventeenth century, Marin Mersenne and Pierre Gassendi made an experimental determination of the speed of sound[4]. Other experiments followed, like the one that William Derham did in 1708: He fired a cannon at one place and recorded how long it took for the sound to reach a point some twelve and a half miles away. His result yielded a value of 1142 feet per second[5]. In 1738 the French Academy of Sciences arranged to have cannons fired from Montmartres in Paris at half hour intervals, recording the sounds at Montlhéry about eighteen miles away. Their determination gave a speed of 336 meters per second. These are not very different from the currently accepted value.

Now think of what would happen if sound traveled at a much slower pace, say a few millimeters a second. Then when the professor is lecturing, students in the back rows will be hearing her much later: maybe a few minutes later than those in the front rows! The thud of thunder would be heard perhaps an hour after the flash of lightning. Both theory and experiments reveal that the speed of sound depends on the temperature and pressure the air (of gas), and considerably so on when the medium itself is solid or liquid.

In 1827 a bell was immersed at a point in Lake Geneva in Switzerland. When it was struck gunpowder was flashed above ground more than thirteen kilometers away. Under the lake a huge ear-trumpet with a membrane was immersed to which a tube was fixed that rose above water. From the observed time difference between the instants the flash was observed and when the bell was heard at this distant point, Jean-Daniel Collandon and Charles-François Sturm estimated the speed of sound in water to be about 1235 meters per second[6]. J B Biot's experiments gave the speed of sound in iron pipes.

One of the remarkable experimental methods in this context was the use of air columns for determining sound velocity. This experiment is still performed by students in laboratories. What is impressive here is that within the confines of a small room, indeed on a table top, using just a tuning fork and a hollow tube of adjustable length one can determine the speed of sound. Firing cannon balls is not needed any more, nor observations at points miles apart by different individuals[7].

These are not the sorts of things we take note of in our histories. They are not wars and

[4] See, for example, Allan D Pierce, *Acoustics: an introduction to its physical principles and applications*, Acoustical Society of America, 1989.

[5] Manja Smolenaars, "*Derham, William (1657–1735)*", Oxford Dictionary of National Biography, Oxford University Press, 2004.

[6] *Encyclopedia Britannica* (Eleventh ed.), Cambridge University Press, 1911.

[7] Credit for this goes to Galileo.

imperialist aggressions, nor political events, nor social upheavals, but they surely are adventures of the human spirit, conquests of the mind that enrich our understanding of the world.

Pitch and Frequency: ***The pitch we experience is related to the frequency of the sound wave.***

When we hear a singer practice her scales we recognize that it is an effort to produce as pure and clear a note as possible. A musical sound of a single pitch is referred to as a note. It is not easy to produce sound of a single pitch. We have devices which can do this.

What we experience as the pitch of a sound corresponds to the frequency of the sound wave. In other words, the pitch is the experiential dimension of how many times the wave oscillations occur in a given unit of time. Most of the sound that we normally hear is a complex of waves of different frequencies. In other words we seldom hear a pure note by itself. All the talk and noise, even the notes we hear on a musical instrument, are made up of several sound waves with different frequencies, perhaps not all in the same amounts. By the phenomenon of interference these different waves combine to form a single wave: at any rate we experience the combined effects of waves of various frequencies.

It was only during the 17th century that the correspondence between pitch and frequency was established[7]. Many experiments were performed in this context. Taking the length of a string fixed at both ends as representing half a wavelength, the frequency of the sound was fixed. And the puzzling thing was, how could a string of a definite length produce different frequencies? It was Joseph Sauveur who first realized that a string could vibrate in various modes which he called harmonics. His work contributed much to the launching of the field of acoustics[8].

During the eighteenth century, the vibration of strings was theoretically analyzed by a number of mathematical physicists, leading to many interesting results. At the same time the experimental study of sound vibrations on drums were also studied, where Ernst Chadlni played in important role[9].

In the 19th century a man named Karl Rudolph Koenig came to Paris after his education in Prussia. He worked for a violin maker, and began to design musical instruments himself. Living in an apartment in Île St. Louis in the heart of Paris, he investigated the nature of sound. Among the devices he constructed for this was a clock tuning fork with which he could determine the

[8] See in this context, V V Raman, 'Joseph Sauveur, the forgotten founder of acoustics,' *Physics Teacher*, Vol. 11, pp.161–163, 1973.

[9] See in this context, T D Rossing, 'Chladni's Law for Vibrating Plates', *American Journal of Physics*, Vol.50, pp.271–274, 1982.

absolute frequency of sound[10].

Loudness and Energy: ***Loudness corresponds to the amplitude of the sound wave.***

The sweet whisper of a beloved one and the firm order of an army commander are both sounds. The soft rustling of leaves in breeze and the roaring noise of a jet plane are sounds too. But there are differences: especially in their loudness. Loudness is a feature of sound that strikes us most. Up to a point it is necessary for sound to be audible. Beyond that, to an extent, it may be necessary for clarity. After that loudness is no longer necessary and may become a downright nuisance.

Recall that sound is a wave, and that a wave transports energy. From the perspective of physics the loudness of a sound is merely a reflection of the amount of energy a wave carries: the louder a sound, the greater the amount of energy it transports. Compared to the energy amounts which are involved in some other common contexts, the energy carried by sound waves is pitifully small. It is good that this is so, for the marvel of our ear can detect energy stimuli that are as low as a tenth of a quadrillionth of a joule per second. If, therefore, sound waves carried much larger amounts of energy, they would cause intolerable loudness, pain, and even deafness.

Physicists measure loudness on what is called the decibel scale (dB)[11]. The faintest audible loudness is taken as zero dB. On this scale the loudness of a city thoroughfare may be about 60 dB, of a speeding train about 80 dB, and of an aircraft propeller about 120 dB. What is interesting is that the loudest sounds to which we are exposed carry a trillion times more power than the faintest. But such magnification in power does not create loudness explosions by similar factors.

The energy carried by any wave depends on its amplitude; in fact, it is proportional to the square of the amplitude. If the swings are greater, the louder becomes the sound generated. In the case of sound waves the amplitudes are unimaginably small. In fact they are of the order of the billionth of a centimeter. This says something about the sensitivity of our sound-perceiving apparatus. Thus, in energy terms, the world of sound is only modest in production and sensitivity. We expend only infinitesimal amounts of energy when we speak or shout. The physicist George Gamow once made an interesting calculation as to how much energy a

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[10] The role that musicians played in the context of physics is nicely narrated in Myles W Jackson, *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century Germany,* MIT Press, Cambridge, 2006.

[11] The decibel is not part of the ST system, but is still commonly used. It is named after Alexander Graham Bell (1847–1922), the inventor of the telephone. Other standard loudness units are the *phon* and the *sone*.

professor spends when he delivers a one hour lecture[12]. It is of the order of a tenth of a joule. This much electricity would cost less than a millionth part of a rupee! The moral we can draw from this is that it is not for the energy spent in producing the sound that we pay professors, but rather for the meaning and message in the sounds they produce.

Wavelengths of Sound: ***The wavelengths of sound are of the order of everyday things.***

All this is possible only because the wavelengths of sound are not way too small. When we hear a baby crying in another room, sound has turned around the walls and reached us. In the language of physics sound waves diffracted around obstacles. One may conclude from this that the lengths of the sound waves are of the order of magnitude as the doors and the walls.

Indeed they are. When we strike the middle C note on a piano we generate a sound whose frequency is 262 Hz. Recalling the relationship between wavelength and frequency, this corresponds to a wavelength of about 4.3 feet. The same note five octaves higher has a frequency of 8384 Hz, hence a wavelength of only 1.7 inches.

It is good that sound waves have wavelengths of a few inches and feet. Imagine for a moment that the wavelength of sound was of the order of a few millionth part of a millimeter. Then, we would not be able to hear a person calling us from right behind us, let alone the dog barking in the kennel or the prowler's stealthy steps, for the waves will not bend around to reach our ears.

This is a good example of how certain quantitative features of physical phenomena make us perceive the world the way we perceive it. It is not simply the physical laws that create the impressions we receive, but equally the numerical values of their measurable aspects.

This recognition has provoked in the minds of some that the world was created such as it is for our benefit. The architect of the world designed sound waves commensurate with our dimensions so that we might be able to hear the cry of the baby in the next room, for if not wouldn't the child die of starvation? Leaving aside the fact that microbes manage to survive for generations without this benefit - they do not even hear, let alone listen to the music played in the neighbor's apartment – this argument is as valid as the view that our noses were made with bridges so that we might be able to rest our eye-glasses on them.

Resonance: ***Systems with the same natural frequencies respond to one another.***

When we hear certain kinds of music we begin to nod or tap out foot almost instinctively. There

[12] George Gamow and John M Cleveland, *Physics: Foundations and Frontiers*, Princeton University Press, Princeton, 1960.

is something that prompts us to respond with sympathy. There is a physical phenomenon very similar to this, and it is known as *resonance*[13].

Every system that can oscillate has a *natural frequency* (period) of oscillation. The pendulum is the simplest example of this. When made to swing, a pendulum of a given length oscillates with its natural frequency (period). So does the child's swing in the yard. The swing can be kept in motion only by being pushed now and again, or else will come to a slow stop. Now, if the swing is given a periodic push at periods precisely equal to its natural period, the swing begins to oscillate with great energy: it is made to resonate. Resonance occurs when an oscillating system experiences a periodic force whose period is equal to the natural period of the system.

The effect of an applied periodic force maybe either to oppose or to contribute to the natural mode of oscillation of the system, depending on how well the force's own variation changes rhythmically with the natural modes of the oscillating system. If the applied force changes in a manner quite different from the natural frequency of the system, the most it can do is to force the system to oscillate like itself. If, however, the applied force varies in a manner very similar to the natural mode of the system, its effect will be to reinforce the oscillations, creating the resonance effect.

Resonance effects are quite common in physical structures. Particular attention must be paid to the aerodynamic stability in bridge construction. Architects take into consideration possible resonant effects due to winds when they design tall structures. In 1952 several light fixtures vibrated violently in a newly built office in Los Angeles because their pendulum-like suspensions were set into resonant oscillations by earth tremors. The transmission and reception of electrical oscillations through resonance are basic to the functioning of radio and television. When we tune a radio we are making the circuit in our set resonate with one of the incoming oscillations. The periodic steps of a rhythmic march of soldiers could cause forced oscillations of a bridge; hence a standard order for soldiers is to break step before crossing a bridge.

When a string fixed at both ends is plucked, it vibrates with its natural frequency. Waves may be set up in a cavity with air in it. The cavity will have its own natural frequencies. That is to say, waves of well-defined frequencies can be generated in it with greater ease than other waves. Such a cavity then becomes a resonator. Resonators are attached to most musical instruments. The vibrations set up by strings on the violin are picked up and reinforced in the resonating cavity, creating the melodious sound we hear.

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[13] For the role of resonance in philosophy and culture, see Veit Erlmann, *Reason and Resonance: A History of Modern Aurality*, Zone Books, 2010.

Echoes: ***Sound waves can be reflected and heard again.***

Sometimes in the open where there is a distant obstacle whence sound can be reflected one may make a loud noise and hear the echo. We can hear a single cannon fire more than once when there are hills around. Echo is the sound that is reflected back from a sufficiently far surface that is heard after the original one has died away[14]. For whenever we generate sound the waves are reflected: from the ground, from the walls of the room, from the ceiling, and so on. But these reflected waves reach our ears far too soon to be heard separately.

But when they bounce back from afar, they strike us as another wave altogether, an eerie repetition of what we had sent out. It sounds like a voice in the wilderness from a disembodied source, as it were. For us, this is simply another interesting phenomenon, a mere consequence of the reflection of waves. We can lead quite a happy life without hearing an echo. But there are creatures for which echoes are essential for their very survival. Lazzaro Spallanzani was a prolific scientific investigator of the eighteenth century. In 1794, when he was a sexagenarian, he did some experiments with bats[15]. He blinded the poor animals and found, much to his surprise, that this did not bother them in the least in their flights! He jumped to the conclusion that the creatures had a sixth sense which enabled them to detect obstacles on their way. Others found that the bats did not fare all that well when their ears were sealed. The suspicion arose that the ability of bats to locate obstacles had something to do with their hearing. But it took almost a century and a half before the matter was fully exposed. Donald Griffin and Robert Galambos discovered that bats emit high frequency pulses whose echoes make them aware of obstacles on the way[16].

Porpoises are able to spot obstacles even in muddied waters thanks to the echoes they receive of the very high frequency sounds they emit. In early decades of the twentieth century Paul Lengevin tried to utilize echoes from ultrasonic waves to locate submarines[17].

Applied to electromagnetic waves, this becomes radar: yet another device of 20th century technology which serves a wide range of purposes: from spotting speeding cars to detecting clouds and hurricanes, useful in weather prediction. Even the surface of Venus has been studied

[14] The word *echo* is the name of a nymph in Greek mythology who was excessively fond of her own voice, and with whom Zeus was fond of dallying. She fell in love with Narcissus who fell in love with his own reflection in a pool.

[15] Lazzaro Spallazani (1729–1799) published his results in *Giornale de letterati,* Vol.13, 1794.

[16] See in this context, K Richarz and A Limbruner, *The World of Bats,* TFH Publications, Neptune City, 1993.

[17] It was the Titanic disaster when it crashed on an iceberg that prompted Langevin to devise something that would detect objects under water. He and others invented a high frequency ultrasound sonar called the hydrophone during World War I. It was used in detecting a German U-boat.

with the help of radar. The simple phenomenon of echoes: But once we know the root of this perceived reality, look how much can flow out of it!

Music and Noise: ***The spacing of frequencies makes all the difference.***

At the experiential level the difference between music and noise is clear: We enjoy one and find the other to be not so pleasant. Both musical sound and noise are composites of waves, with this difference: musical sounds consist of discrete frequencies, whereas noise is made up of a continuous set of waves. It is somewhat like the difference between a can of pebbles and a can of flour. In the one case we can separate out the components, literally count them as so many; in the other case, it is one continuous pack of practically touching and indistinguishable parts. In a musical sound, well-defined frequencies are present. In noise, practically all frequencies are present.

A spectrogram displays the component frequencies in a given sound. The spectrogram of a musical sound would reveal straight lines corresponding to the frequencies that are present, whereas in the case of noise, we will find a whole continuous patch.

Now consider a certain tone, say the middle A corresponding to 440 Hz. Corresponding to this fundamental frequency there are higher harmonics as well. When this note is sounded in a given musical instrument, the higher harmonics are also present to some degree. The relative amounts of the various higher harmonics present when the note is sounded will depend on the instrument in question, because this is a function of the shape, size, material, mode, etc. of the resonating cavity. As a result, the same note sounds very different when played on a violin or a veena, a flute or a nádásvaram. This is sometimes called the sound quality.

This is equally true of the voice box or of any source of non-musical sound also. That is the reason why there are distinctive differences between the voices of different people. Indeed, each individual has his or her own characteristic voice spectrum. Like the fingerprint which is unique to the individual, we have our own voice prints as well: a vocal signature of our individuality, a uniqueness that has been used in forensics.

It is remarkable that these differences can have such varying effects on our perceptions. Music is soothing and pleasing; noise is not. At the tactile level, the situation is the opposite: it is the smooth continuity of surface that causes the pleasing sensation of soft velvet. Discontinuities on a surface with peaks and sharp protrusions, as in a bed of nails, are unpleasant to touch.

One of the pioneers in India in the field of music and acoustics was Sir C V Raman[18].

[18] In recognition of his work and for further research in the field, Jadavpur University in Kolata has established a Sir C V RAMAN Centre for Physics and Music.

Auditory System, The Ear: *There is a reason for the external ear.*

The magic occurs when the waves reach our ears. The surface area of the normal ear-drum is barely a centimeter square, smaller than a thumbnail. When slight sound waves strike the drum, it begins to vibrate. Then through the wiring made up of neurons (nerve cells), assisted by fluids and bone-structure, the stimuli reach the brain where the physical processes get transformed into the experiential mode. We *hear* the sound.

Ears add grace and balance to the face, or so we have been conditioned in our aesthetic responses, for a human face without ears would look odd and incomplete. The fan-like external protrusions, which anatomists call the *auricle*, do more than serve an aesthetic function: they collect sound waves and ease them into the interior through a narrow dark passage, called the *external auditory canal*. This tiny tunnel, equipped with hair and wax to trap dust and other unwanted intrusions, leads to the eardrum (*tympanic membrane*) which covers a cavity (the inner ear) where three auditory ossicles (tiny bones), called malleus (hammer), incus (anvil), and stapes (stirrup), lead the sound waves into the inner ear. In order for the eardrum not to burst from the external air pressure exerted on it, we need air from the inside to balance this pressure. This is provided through the nose. Yes, part of the air we take in through the nose goes into the ear through the auditory tube, and is meant for keeping the eardrum from cracking.

The ossicles conduct the vibrations to the snail-shaped cochlea which contains a fluid. The fluid is agitated, and this stimulates the thousands of nerve fibers – about 24,000 of them. The neurons transmit the impulses to the brain. The rest, we must say, is mystery: for we do not know how electrical impulses get transformed into music and endearing calls.

In brief, then, mechanical vibrations set up in air are first transmitted to the eardrum. These in turn are transduced into electrical signals in the cochlea. When these reach the brain, the experience of sound is brought about[19].

To the inner ear are attached three little tubes, one horizontal and two vertical, containing some fluid. These are known as semi-circular canals. Hair cells from these are connected to a nerve (the vestibular nerve) which is wired to the brain. When movements of the body affect ever so slightly the fluids in the canals, the brain is alerted right away, and instructions are sent to various muscles in the body, from neck to toe, to do the needful to keep the body in equilibrium[20]. Too much alcohol can interfere with the normal functioning of the semicircular

[19] This puzzle, recognized by many thinkers over the ages, was called the *hard problem of consciousness* by David Chalmers in 1995.

[20] See, in this context, Scott McCredie, *Balance: In search of the lost sense*, Little, Brown and Company, New York, 2007.

canals: then stable walking becomes a challenge.

Thus the ear which we regard as the hearing device we carry around also plays a role, through an internal appendage, in feeding data to the brain for not losing our balance. It has also been suggested that the semicircular canals may be responsible for our confinement – even psychologically – to a three dimensional space.

Voice Box: ***Muscles play a role in voice and speaking.***

In the course of our daily life we talk and we sing, we whisper and we shout. What makes it all possible is a little instrument in our throat, whose presence is indicated by the so-called Adam's apple. This little gadget is the marvel that enables us to communicate orally. It is the powerhouse whence emanate caring words of kindness and compassion, inspiring words of wisdom and ennobling pravachans, and yes, all the music, melodious and magnificent ragas that great vocalists are capable of.

It is right there at the entrance to the respiratory tract, and in it are the muscle tissues we call the vocal cords, attached on three sides. The crevice between the vocal cords is called the glottis. The vocal cords are subject to various tensions, thanks to a great many small muscles that control them. When air is forced out of the lungs, they are made to vibrate by the command of the brain. These vibrations create air puffs which resonate in the cavity of the mouth and the nose, generating all the wonderful sounds of the human voice that have rung in this world since the dawn of our emergence on the planet.

Tiny muscles, set in vibration, causing air-puffs that resonate in the little cavities of the mouth and the nose: This is the root of every sound we produce. But of a sustained note. What about the intricate speech, the creation of vowel and consonant sounds, the nasal and the guttural and the labial, their mixtures in words, and their continuity as sentences? What about long narrations and repetitions? The tongue and the nose and the lips, all play complex roles here. We recognize these organs primarily for their role in taste, smell and osculation, but they are essential for speech. We learn to manipulate them almost unconsciously when we learn to speak.

This sort of knowledge and insight we can never obtain without subdividing and analyzing. No cosmic contemplation about the nature of ultimate reality can reveal these intricate wonders of reality. Holism surely helps us to reflect upon, but reductionism is abundantly informational.

Our sensory organs receive physical inputs from the external world, and the brain, by what can only be described on the basis of current knowledge (or lack thereof) as a magical process, transforms these into a whole world of experience. The organs within the body serve the body's various vital function, but there is one unique organ that proclaims our connection with the external world: it is the voice box we all possess. Unlike the sensory organs which merely receive, or the vital organs which work silently and involuntarily, the voice box is a source and it is activated at our command.

The study of the mechanism of the human voice has been investigated for a long time. One of the earliest treatises on the subject of the voice and hearing along with its history was published by Giulio Casseri [21]. In this work, Casseri compared the human voice system with those of other animals. It was not until the beginning of the eighteenth century that the role of the glottis in the production of voice and tones was recognized.

Ultrasonics: *There are sounds beyond our auditory reach.*

We are grateful for our faculties of sight and hearing, of touch, smell, and taste. However, these natural capabilities make us aware of only a small proportions of the multifaceted physical world. Indeed, more often than not, our faculties are even slightly deceptive in how they portray whatever there is. But for instruments which human ingenuity has devised, and imagination which is an extrasensory faculty of the human brain, there is no way we can go beyond recognizing whatever is within our direct perceptual modes.

There certainly are a great many things not directly accessible to our sensory perceptions. There are, for example, pressure waves of frequencies much greater than 20,000 Hz and much lower than 2000 Hz which human ears do not detect. We call the higher frequency ultrasonic waves: sound waves which are beyond the audible frequencies.

The trick is to cause something to vibrate very fast. Disks made of quartz when electrically charged do this, generating ultrasound. The device is the ultrasonic transducer. Conversely, ultrasound may be reconverted into electricity, activating computers which can interpret the data.

Already in the 1940s sophisticated sonars came to be used for detecting submarines. Since the 1980s ultrasound has been used to study the development of fetuses. Ultrasonic waves have found application in a variety of unexpected contexts: like cleaning teeth and watches, mixing chemicals, even in welding, not to mention in the annihilation of kidney stones and brain tumors.

If light waves can be used for optical microscopes, why not construct an acoustic microscope using high frequency sound waves? When these are directed at tissues within the body, they

[21] *The New Dictionary of Scientific Biography,* Charles Scribner's Sons, New York, 2007.

bounce back as echoes. From an analysis of these echoes (with the aid of computers) one can gather a good deal of information about the objects studied: which could be anything from cells to microbes and viruses, and some day perhaps the very genes that print out life patterns.

In 1994 it was reported that by injecting ultrasound into water containing certain toxic chlorinated compounds, the latter were broken down. This technique has been developed considerably since then[22]. What this means is that one can use ultrasonic waves to clean up certain pollutants from our waters.

Unearthing the roots of the perceived reality of sound has opened up possibilities never before dreamed of. If someone of an earlier century had been told that the sex of an unborn child can be accurately told without so much as touching the expectant mother's body, or that the precise location of an underwater ship could be determined without the use of light, it would have sounded like pure fantasy. If we had added that such things could be done by a form of inaudible sound, the statement would have been taken even less seriously. Such are the unexpected turns in human knowledge when the spirit of the scientific quest is kept alive.

Music of the Spheres: *There are vibrations in the cosmic arena.*

The idea is ancient: that associated with the planets that move in harmony in high heavens is a cosmic music that fills the universe. Even as strings plucked in proper proportions produce the various octaves on the scale, planetary motions in conformity with celestial arithmetic must create a divine music: so went the reasoning. Hindu thinkers visualized it as the sacred *aum* that pervades the universe, while Pythagoreans thought of it as the music of the spheres.

The Hindu imagery was profound: That the universe is permeated by a serene vibration, not unlike the idea in modern physics that the constituents of the world are different modes of vibration (*string theory*). Indic thinkers also imagined the universe to be pervaded by mantras: poetry with spiritual prosody and esoteric significance. These nuggets of wisdom were revealed to the rishis of ancient India as the Vedas: the scriptural treasures of the Hindu religion.

The Pythagorean idea is beautiful: The spheres were heavenly wheels on each of which stood a sweet siren (an alluring nymph) who created a musical note. It is the combination of these notes that merged to form the music of the spheres. These became the Muses after Plato's school was formed, and Christian mythology transformed these into angels and other ethereal beings who formed the celestial orchestra. Aristotle who believed the heavenly bodies to be perfect crystalline material feared the delicate perfection of cosmic crystals would be shattered by such

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loud notes in heaven. The notion of the music of the spheres was taken quite literally even by Kepler in the seventeenth century. In this vision, when Moses heard the Commandments and the Prophet of Islam heard the Holy Koran, they too were privy to the this cosmic music.

Underneath the poetry of these ideas there is the insight that as music is intrinsically linked to mathematics, so is our understanding of the universe at large. As scriptural wisdom is the key to an understanding of the nature of the universe in the religious mode, so is astronomy in the scientific context.

From current perspectives, it is difficult to imagine music in stellar space if only because we need an elastic material medium for sound. No one can sing on the moon, and even if one beats a drum with full force no sound will be created where there is no atmosphere (elastic medium). So music in the heavens, poetic though it be, is really not physics such as we understand it.

And yet, in a strange sort of way, the idea has modern analogy. For in 1966 astronomers discovered a microwave radiation that is cosmic in scope and that has been there every since the birth of the universe[23]. This surely is not sound, nor music in the usual sense, but there is an all pervading vibration in the heavens: a notion that would have seemed strange and unacceptable to the physicists of the eighteenth and nineteenth centuries. One never knows what the future holds.

[23] For details, see P J E Peebles, *Principles of Physical Cosmology,* Princeton University Press, Princeton, 1993.

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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.

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