Darshana Jolts

Atoms and Molecules: Beneath the Tangible World

V V Raman

To see a world in a grain of sand….

William Blake

Introduction: ***Underneath it all matter is very different.***

Much of perceived reality is like actors on a stage: all nicely dressed up and saying so many interesting things, but each one of them is in reality very different as a person. The costumes and the make-up, the gesturing and the motions, the laughing and the crying, are all just to entertain us. Only those who get behind the stage and get to talk to them truly realize how different they are in actuality. This is not unlike what some ancient philosophers of India surmised: that the world of reality is very different from the world of appearance which they described as *máyá*. So it is indeed with the phenomenal world, with the world of perceived reality.

This is brought home to us most dramatically when we probe into the ultimate nature of the tangible substantial world. Up until the twentieth century no one could have imagined that in its ultimate roots matter is so richly complex. As physicists delved deeper into the secrets of tangible matter with their microscopes, both mental and material, they uncovered an utterly different level of material existence, more surprising and marvelous than the fantastic world of microorganisms which too remained hidden from human understanding for millennia. It is this totally different world, the world of atoms and molecules which we will be reflecting upon in the next few essays.

Penetrating imagination had also taken thinkers of ancient times into the substratum of matter. It brought to their vision tiny indivisible entities of all shapes and qualities, moving about perpetually. These were believed to be causing smell and taste and life itself. These were the atoms of yore, and in varied forms they were imagined and described by Hindu, Greek, Chinese, and other thinkers in centuries past. They bore a parallel to our own views in only so far as they were considered invisibly small and at the root of the material world[1]. Beyond this, there is very

[1] Atomic theories were elaborated especially by the *Nyáyá* and the *Vaisesiká* schools in India. In this context, it is important to recall Kanada of ancient India as much as Democritus of ancient Greece. For more on this, Dick Teresi, *Lost Discoveries: The Ancient Roots of Modern Science*, Simon & Schuster, 2003.

little in common between what we understand by atoms today and what the ancients imagined, or 19th century chemists believed atoms to be. Since matter itself is solid for the most part, it was once thought with logical consistency that the ultimate bricks of gross matter should also be rigid and unbreakable, even as the bricks making up a sturdy building are firm and strong. So Kanada called them *anu* and Democritus called them *atomos.*

In the first decade of the 19th century, the word was revived by John Dalton (1766 –1844) in the context of his studies of weather phenomena and also when he wrote on the chemical combinations of gases[2]. Like all new ideas in science, Dalton's notion of chemical atoms was not enthusiastically embraced right away. But by the later part of the century, it had become part of scientific discourse at least as a useful concept, though many still seriously doubted if such ultimate entities actually existed. A good many scientists wondered whether as empirical scientists one had even the right to talk about things that were apparently beyond our reach anyway.

Atoms are very close to us: they are in everything we see around us and in our physical bodies; and yet they are so remote: way beyond our direct perceptual faculties. They are at the deepest roots of perceived reality while we go about our business at scales way above, unaware of their very existence.

Elements and Compounds: ***The countless substances in the world are made up of a finite number of simple substances.***

Let us briefly review what we noted earlier regarding elements and compounds. Quite a few elements have been known since ancient times, like copper, carbon, sulfur and mercury. Chemical industry is one of the earliest experimental enterprises.

The conceptual classification of matter into elements and compounds did not come about until the 18th century. It was Antoine Lavoisier, we recall, who published the first list of elements in 1789. Eighty years later, Dmitri Mendeleev (1834–1907) from Russia did something more: he produced a systematic table, rather than a list, of elements, and classified them according to their common and repeating chemical properties. One recognized patterns in the plethora of matter[3].

In Mendeleev's careful categorization, some absences were gaping: places where, if Nature behaved consistently, there should be some elements. Mendeleev was bold enough to declare that those elements did exist, with properties his table demanded, but that they had not yet come

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2 Frank Greenaway, *John Dalton and the Atom*, Cornell University Press, Ithaca, New York, 2001.

3 Paul Strathern, *Mendeleyev's Dream: The Quest For the Elements*, St Martins Press, New York, 2001.

within the sweep of human knowledge[4]. Some chemists thought the Russian was going too far, magic-mongering perhaps. But they were wrong in their assessment. Barely five years later de Boisbaudran proved Mendeleev right by discovering gallium, and five more years later, samarium. Next germanium was recognized, then scandium, then dysprosium, and so on. During the remaining decades of the century scrupulous investigators kept discovering one by one a whole range of new elements, giving them exotic names. The power to predict is an aspect of modern scientific methodology that is not there in ancient scientific visions. Mendeleev's was the first instance of the prediction of new kinds of matter.

Composite Nature of Atoms: ***Atoms are not unbreakable as the ancients had pictured.***

We also recall that at the core of matter there are pure electric charges: positive as well as negative. The positive ones are the more massive, and are called protons. They are almost two thousand times as massive as the negatively charged ones which are the punctilious electrons. In each atom the protons are crowded together as a massive central focus called the nucleus. Within the nucleus there is another type of ultimate particle, but this is without any electric charge, and is therefore called the neutron. Though its existence had been suspected since the 1920s, it was experimentally identified only in 1932[5]. Thus, in one sweep, we introduce four different terms in the description of atomic structure: a central *nucleus* made up of positively charged *protons* and electrically neutral *neutrons* around which swirl negatively charged orbiting *electrons*. Every element is characterized by the total number of protons it bears in its nucleus.

What the poet Blake had expressed poetically, physicists accomplished experimentally, for they saw the world in a grain of atom. By the early 1920s it was well established that in their structure at the deepest levels, those minute atoms are strikingly similar to what we see up there in the sky: miniature planetary systems, as it were, where smaller entities whirl around larger ones.

The electrons are swung around, not by the gravitational force that mass exerts, but by the electromagnetic field arising from electric charges. There are other important differences too. In principle, planets in a solar system could revolve at arbitrary distances from the central star. Those distances from the sun arose from the accidents of their initial formation. On the other hand, within atoms, electronic orbits are well-defined: electrons can move only along certain orbits. When given sufficient energy, an electron may jump from one allowed orbit (or energy level) to another. Such transitions call for absorption or emission of energy.

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4 Eric R Scerri and John Worrall, Prediction and the Periodic Table, *Studies in History and Philosophy of Science*, Vol.32, pp.407–452, 2001.

5 James Chadwick, Possible Existence of a Neutron, *Nature*, Vol.129, 1932.

If such a structure suggested itself from the data of experiments, the precise distances of the orbits from the nuclei, their shapes and specifications, etc., were precisely calculated by the use of mathematics. It is important to take note of this, for it reminds us once again of the power of theoretical conceptualization and mathematical analysis in our exploration of the physical world. The uncovering of atomic and subatomic constitution and structure by physicists may be likened to the accomplishment of a group of blind people who, by their faculty of touch alone, feel their way through the entrails of a complex clock and find out how it works.

As mentioned before, atoms are unimaginably small. They are not in millimeters, but way, way smaller: of the order of 10^{-12} cm. More striking still, the atom as a whole is empty in the same way that the solar system is empty. The system is grandiose compared to the dimensions of the regions occupied by the material concentrations in it. An alien spaceship from a distant orb can zoom right through our solar system without touching a planet or a satellite. Likewise, assuming no other interaction, a minute entity of subatomic size can go right through an atom, as if through empty space.

This could well be seen as Nature's humor for so large a universe to be built up of such minute entities. Things are stretched a bit too far along both directions, as if to baffle the human mind. If anyone asks, "Could we have had a universe of more modest size with atoms somewhat larger to cope with?" the answer would be, "Perhaps, but it would be nothing like the one we know."

The Spinning Particles: ***The principal constituents of the atom are perpetually spinning.***

Whether they are parts of atoms or free, whether they are speeding past atoms or parts of molecules, whether they are speeding in a wire as current, or are somewhere solitary in empty space, aside from the precise amount of electric charge they carry, electrons always preserve a definite amount of a property called spin[6]. The precise value of the spin – i.e., a measure of how fast they are rotating – is the same for every electron in the universe, and it does not change, no matter what happens to the electron or what it does. Physicists have a unit for measuring this spin. On this scale the electron spin has a value of one half. A spinning electron may be going around in a clockwise or in a counter-clockwise direction with respect to a given direction. To distinguish between the two possibilities, we say that the electron spin may be +1/2 or –1/2.

The same is true for the proton and the neutron. They too keep spinning like a top, but never slow down or stop. Their spin value is the same as of the electron: ±1/2, which they maintain since

[6] Though we use the word spin, it is a far more complex property than the spin of a top. The history of the discovery of the electron spin, generally attributed to George Uhlenbeck and S A Goudsmit, is fascinating. Goudsmit's account of it, translated from Dutch into English by J H van der Waals, is available on the internet: http://www.lorentz.leidenuniv.nl/history/spin/goudsmit.html.

the moment they are created. It is as if Nature had put this spell on these fundamental particles. We are reminded of the poet Tennyson's words in another context: " Let the great world spin for ever down the ringing grooves of change!"

The unerring precision with which these basic units of the material world preserve their mass, charge, and spin is among the marvels of Nature. Matter on our scale may swell or diminish in size, change mass and speed, alter and change phase. But these little bricks at the core of the material world preserve their basic traits for ever. Electrons and positrons may collide and may even be transformed. But for as long as they are electrons and positrons, their mass, charge and spin remain the same, no matter what or where or when. They never become defective, losing a little charge here, or slowing down their spin for a while, etc. Matter, at the basic level, is like what the ancients had imagined heavenly substances to be: unchanging.

It is this invariant characteristic of the constituents of the world that keeps the world such as it is for eons. Yet, the laws are so designed that they also allow for transformation and newer configurations, for variety and evolution at grander scales.

Some Technical Terms: ***Science cannot progress without precisely defined terms and concepts.***

Now let us introduce some technical terms in this context. We saw earlier that the electron in an atom can be in any one of several mathematically determined levels (orbits). This is somewhat like a person residing in any one of several buildings, numbered 1, 2, 3, etc. The orbits of the electron in an atom are numbered as 1 (lowest or orbit number 1), orbit number 2, etc. These numbers are known as its *principal quantum numbers*[7]. Thus, to say that the principal quantum number of an electron is 3, simply means that it happens to be in its third allowed level. When the principal quantum number is 1, the electron is said to be in its ground state.

It turns out that in any given level (depending on the level), the orbit may be either perfectly circular, or slightly elliptical. The number of allowed distortions depends on the level number in a specific way. The first level admits of only one circular path. In the second there can be two orbital forms: one circular and the other slightly elliptical. In the third, three forms are possible: a circular one, a slightly elliptical one, and one that is even more elliptical. And so on. A number is associated with each of these possible orbits: It is called the *orbital quantum number*. These are numbered 0, 1, 2, etc. Consider the following analogy. Suppose that there are buildings on a street numbered 1, 2, 3, etc. Let us suppose that the first building has only one floor, numbered 0, the second has two, numbered 0 and 1, the third has three: 0, 1 and 2, and so on.

[7] A quantum number refers to one of the permitted parameters that an entity in the microcosm can take.

Furthermore, in the first allowed orbit, there is one spatial orientation; in the second, there are three. In level three, i.e., for the third orbit, five different orientations are allowed. Numbers, called *magnetic moment quantum numbers* in the technical jargon, are given to these possible orientations. For reasons we need not go into, the convention is to number the magnetic moment quantum number from a negative integer to the corresponding positive integer. Thus, we will have (0), (– 1, 0, +1), (–2, –1, 0, +1, +2). etc. Going back to the buildings-analogy, it is as if the ground floor had only one room, the second floor has three rooms, the third has five rooms, etc., numbered as above.

Finally, recall the two spin possibilities for the electron: clockwise and counter clockwise. Each of these is referred to as a *spin quantum number*. In our analogy again, this is like saying that each room in the building has two beds[8].

Now we introduce an esoteric term of 20th century physics: the *quantum state* of the electron in the atom. This refers to the totality of the quantum numbers associated with a given electron in the atom. For example, if a physicist says that the quantum state of an electron is (2, 1, 0, –1/2) it simply means that the electron is in the second allowed level in a slightly elliptical orbit, spatially oriented in a specific way, spinning in a counter clockwise manner.

Finally, in any quantum state the electron in the atom has a certain amount of energy. This energy is in fact negative: it simply means that this amount of energy has to be furnished to the atom to wrench the electron out of it. The higher the level, the lower the energy. In other words, the outer electrons are more easily kicked off even as, if we have a pot full of sand, a slight breeze is enough to blow off the particles on top, while a vigorous scoop with a spoon is needed to get the sand particles in the bottom layers.

Thus the atom is more than just a nucleus with a bunch of electrons swirling around, any more than that a town consists of just a central square and people distributed at random all around it. Like a highly planned town with homes and rooms built in accordance with strict codes, electrons in atoms have mathematically specified states which they occupy.

The Pauli Principle: *Within an atom, not more than one electron can have a set of quantum numbers.*

From our everyday experience we know only too well that in a crowded train or bus no two people can occupy the same seat. A somewhat similar principle holds in the realm of atoms too, but far more stringently. The rule is simply this: No two electrons in an atom can be in the same

[8] For a detailed history of these, see Abraham Pais, Niels Bohr's Times, In *Physics*, *Philosophy*, and *Polity*, Clarendon Press, Oxford, 1991.

quantum state. Going back to the analogy of buildings and floors and rooms and beds, the statement is equivalent to saying that not more than one person can occupy a bed in any of the rooms on any floor in any building.

This is known as *Pauli's exclusion principle*, after the brilliant physicist Wolfgang Pauli (1900–1958) who reigned supreme for some four decades in the arena of international physics[9]. The Pauli principle is a fundamental criterion in the blueprint for the construction of matter. The world did not come about simply by the shuffling of electrons and protons in a grandiose container. There are laws to be obeyed, principles to be followed, numbers to be respected. That is how this enormously complex and smoothly functioning cosmos came to be. Tinker with any one of the ground rules, and the whole thing will collapse into chaos of the worst kind, though some may proclaim such occurrences as miracles.

The Pauli principle is a little like an usher in a concert hall, overseeing whether the available seats in the atom are appropriately occupied. Indeed, that is the terminology in atomic physics too: electrons *occupying* various quantum states in an atom.

It may sound far-fetched, but it is because of the Pauli principle that we can sit on a chair and stand on a floor, for otherwise, the atoms, like solar systems, can move right through because of the empty spaces between measly electrons and minute nuclei. But Pauli prevents this, since the quantum states are all occupied in the atoms, and intervening electrons are prohibited.

Again, it is the Pauli principle that stacks electrons in various orbits in the higher elements, accommodating no more than two in the first level, eight at most in the second, and so on. It also plays a role in the architecture of complex molecules, and thus serves as a cornerstone in chemistry. The poet Longfellow exclaimed,

> Ah, to build, to build!
> That is the noblest art of all the arts.

To build the universe, Nature follows a set of cosmic rules. The Pauli principle is one of them.

Molecules: *The variety of substances result from different molecules.*

Now let us look into the next more complex building block of matter: the molecule. No doubt, there is variety in ninety and odd elements. But this is too small a number for so vast a universe of such large duration, if interesting things are to happen. It is all very good to have rice and

[9] Wolfgang Pauli was one of the most brilliant physicists of the 20th century. See in this context Charles P Enz's book *No Time to be Brief, A Scientific Biography of Wolfgang Pauli*, Oxford University Press, 2002.

flower and sugar, salt and butter and a range of spices. But when they are combined in the right proportions under the right conditions, wondrous culinary creations emerge.

Likewise, there is a cosmic culinary complex, as it were: a fine art by which Nature, always in accordance with established principles, concocts an incredible variety of atomic combinations. These are the *molecules* of compounds[10]. They are at the root of perceived reality in the variety, quality, structure and the different properties of substances. Every substance we see around us and the multitude that we don't see are made up of molecules containing two or more atoms. Recall the lines of Alexander Pope in his poem *Essay on Man* (Epistle III), where he wrote in 1734, long before scientists thought of atoms and molecules:

See plastic Nature working to this end,
The single atoms each to the other tend,
Attract, attracted to, the next in place,
Form'd and impell'd its neighbour to embrace.

They may be just two or three, or the component atoms may number a few hundred in a molecule. We should not take lightly the phrase *just two or three*: the molecule of common salt is made up of just two different atoms, and the water molecule has no more than three, and we know how important and indispensable these are.

Like atoms, molecules too are imperceptibly small. A molecule of an ordinary substance barely stretches to a few millionths part of a millimeter. One of the intellectual achievements of 19th century science was to reckon how many molecules there are in, say, a teaspoon of water. This is of the order of a trillion trillion. No honest person will claim that he or she can grasp what this number is. Written out explicitly it is one followed by twenty four zeroes.

Drinking water and tasting salt in *sambar* are soothing and delightful, but they can never reveal this numerical wonder in the roots of perceived reality. That we could arrive at such a number from conceptual considerations is what we must recognize in this context: the power of the human mind when applied to modern scientific methodology. This number of molecules in a gram of hydrogen, probably the first number of such mind-boggling magnitude ever to be derived by the human mind in a non-speculative context, is known as Avogadro's number[11].

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10 Though the word molecule had been used even in the 17th century, it entered chemistry in a serious way only in the nineteenth after a good deal of confusion, debates, and skepticism. See J R Partington's classic *A Short History of Chemistry*. Dover Publications, Inc, 2009.

11 Though Avogadro stated his *hypothesis* in 1811 to the effect that a mole of every substance contains the same number of molecules, it was almost fifty years later that an approximate value of this number (6.03×10^{23}) was estimated. It is difficult to imagine that a spoonful of water contains more molecules than there are spoonfuls of water in the Indian ocean.

The correctness of this statement has been confirmed in a thousand contexts. Already in the 19th century, a simple and clever experiment enabled physicists to at least estimate how many molecules there are in a drop of oil. Such a drop, thrown in a tank of water, can fill an entire tank some thirty feet square. Taking the radius of the drop to be of the order of a millimeter, one can estimate the size of the molecules that spread as a single layer over this whole area.

Biological molecules? *Many molecules in organisms can be synthesized in the laboratory*.

For a long time it was believed that there are essentially two kinds of substances: Those that are found in non-living things and those that can be made only within living organisms. The former were called inorganic substances, and the latter were the so-called organic substances.

This idea was based on the notion that a vital force[12] was acting within living organisms, and was responsible for life. It was indispensable for making organic substances. But with the synthesis of urea (H_2NCONH) by Friedrich Wöhler in 1828, the distinction between organic and inorganic began to melt away.

This led to the systematic study of the chemistry of countless compounds which seem to be characteristic of living organisms, leading to the name *organic chemistry*. This branch of science deals essentially with the properties of thousands of carbon compounds and the structure of their molecules, and the chemical reactions in which they are involved. The experimental aspects of organic chemistry was instigated largely by industry: pharmaceutical, petroleum, and the like.

But its theoretical basis came from the discovery of the structure of carbon and of other molecules[13]. For example, there is the very interesting molecule made up of six carbon atoms and six hydrogen ones, forming what chemists describe as a ring. This is the molecule of benzene, a toxic liquid that can catch fire at the slightest provocation. What is interesting is that this microcosmic ring is the characteristic feature of countless more complex molecules which

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[12] The idea of the vital force was a reflection on the physical plane of the notion of the metaphysical soul. An assiciated idea was that living principles were not governed by the same rules as the material world.

[13] The credit for establishing this usually goes to J H Van't Hoff (1852–1911) and Joseph Le Bel (1847–1930) in 1875, but the idea of a tetrahedral structure had been proposed by August Kekulé (1829–1896) and others more than a decade earlier. See in this context, Patrick Coffey, *Cathedrals of Science: The Personalities and Rivalries That Made Modern Chemistry*, Oxford University Press, 2008.

affect the olfactory cells entrenched in mucous membranes in our noses. Put in plain language, we can smell them. So the benzene-based compounds are called *aromatic compounds*, though these are not the only ones with this property.

Here we come to another marvel in the physical world: the root of the perceived reality of smell is a bunch of molecules that lock in atoms of carbon and hydrogen for the most part in strongly linked rings!

Macromolecules: ***Many interesting properties of substances arise from their great size.***

The word *macromolecule* is an oxymoron of scientific coinage, because *macro* means big, and molecule means *small mass*. Macromolecules are so named because compared to the molecules of ordinary matter these ones are super-large: by more than a hundred times.

A single carriage serves a purpose, and many of them linked together becomes a train. Macromolecules are like trains, molecules linked to molecules, in chains or in more complex structures. Sometimes all the wagons in a train are the same. We get *addition polymers* this way: a whole series of identical molecules hooked together like beads in an open rosary. Polystyrene – the stuff of throw-away coffee cups and packing cushions – are made up of identical molecules. On the other hand, if the component units are not quite the same, we get *condensation polymers*. The polyester materials we see all around these days belong to this category. All plastic is polymer of prodigious variety.

In their own clever ways, human beings try to go a step beyond Nature's handiwork, often along different directions. Thus, for example, we have concocted *buckyballs*, molecules made up of sixty or more carbon atoms, discovered in the mid 80s[14]. These have the tremendously useful property that, in association with ions of thallium and rubidium, they become superconducting at reasonably high temperature. More formally known as *fullerene*, these molecules are finding their way into the world of useful science in a variety of ways: as in the fabrication of super strong fibers, and for medicinal purposes too. Fullerene tubes, fullerene layers and non-carbon fullerenes have all been synthesized.

Analyzing starlight with sensitive spectroscopes, astronomers recognized tell-tale signs of large aromatic molecules – the so-called polycyclic aromatic hydrocarbons (PAC) – out there: fragrance in the firmament, one might say, because these are made up of benzene rings. And they also found that buckyballs are also not unusual in the universe. This may have some impact on our understanding of biochemistry.

[14] Buckminsterfullerene (buckyballs) discovered by Richard E Smalley in 1985. See in this context Yasu Furukawa, *Inventing Polymer Science*, Chemical Heritage Foundation, 1998.

Molecular Biology and DNA: ***Our ultimate roots are macromolecules.***

While philosophers wonder about the mystery of existence, scientists investigate the material basis of life. They look into the chemistry of fundamental biological processes and the properties and structures of the molecules that cause the throb of life. These investigations form the subject matter of molecular biology. It turns out that the mother of all life-principles is a complex molecule known as the DNA: *deoxyribonucleic acid* which is one of the best known abbreviations of modern science. This is a stupendously large molecule, nearly a hundred and twenty million times as massive as a hydrogen atom[15]. With variations here and there, it is intertwined in pairs, twisting away in spiral forms, often with some five thousand turns, forming a characteristic structure which has come to be called the double helix[15]. These awesome complex spirals are the most precious entities in the whole universe, for in them are encoded every bit of information pertaining to the functioning and continuation of the life principle. It has been estimated that there are some twenty-five trillion cells in the human body, each with twenty five thousand DNA molecules. These embody all the information necessary for the maintenance and continuation of human life.

The discovery of DNA may be compared to that of the atomic nucleus in that it has opened up possibilities for humanity that can be enormously valuable, but also unexpectedly catastrophic. While the knowledge of DNA has taken us deeper into an understanding of life and even the mechanism of evolution, that knowledge may also be used to alter slightly or significantly the nature and properties of organisms. This has opened up an entirely manipulative field of genetic engineering which has had some remarkable positive applications but is also wrought with dangers of which we may as yet be quite unaware.

Aside from the artificially synthesised macromolecules like plastics, there are many macromolecules in the natural world also. Rubber and cellulose with their peculiar properties, are polymers *par excellence*. So there is a hint that polymers come into play in living matter. Indeed, proteins and the other supporting stuff which form the material basis for life are polymers. Some may complain, look what science has done: it has reduced us all to bunches of polymers! Though we know the structure and composition of many basic bio-molecules, their synthesis in a laboratory is not as easy. But it has been achieved. Synthesis of yeast tRNA (a gene) was achieved forty years ago by Har Gobind Khorana[16].

[15] First isolated in 1869 by a physician Friedrich Miescher and called nuclein, DNA has a long history which has a climax in the discovery of its double helix structure in 1953 by James Watson and Francis Crick. See in this context James D Watson, *DNA: The Secret of Life*, Random House, New York, 2004.

[16] While culture patriots still talk about Hindu knowledge and Western knowledge, it is good that creative Indian scientists are contributing to the furtherance of world knowledge for humanity at large. In this context see, U L Rajbhandary, Har Gobind Khorana (1922–2011). *Nature*, Vol.480, p.322, 2011.

Scientific knowledge is *exopotent*: it can be used to manipulate the external physical world in mild or substantial ways, for the good or for the bad. The knowledge we derive from other fields, such as history and art and religion are *endopotent*: they have an impact in our inner being, on how we feel about the world. The feelings and convictions that come from endopotent knowledge affects and values and behavior in significant ways[17].

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[17] For more on these terms see V V Raman, *Truth and Tension in Science and Religion*, Beech River Books, 2010.

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Previous Parts: The World Above: Vol.15, No.10, pp.954–964; No.11, pp.1021–1030, 2010;
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