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Beauty and Truth in Science

Satyam Shivam Sundaram -Ancient Indian motto

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*Footnotes regarding eminent persons cited with superscript numbers in this article are provided in the end under **Notes**.*

What is Beauty?

'A thing of beauty is a joy forever' wrote British romantic poet John Keats[1]. A similar view is echoed by the French mathematician Henri Poincare[2] who says, 'The scientist does not study Nature because it is useful to do so. He studies it because he takes pleasure in it; and he takes pleasure in it because it is beautiful. If Nature were not beautiful, it would not be worth knowing and life would not be worth living'. Clearly, Poincare's basic premise is that Nature is beautiful not from sensory viewpoint but by its manifestations in terms of order and consistency associated with it. Man's aesthetic sense is influenced by what he sees, hears, touches, feels and thinks. Aesthetics, in so far as common understanding is concerned, refers to three types, namely, first, the visual senses owing to the sensory experience; second, the emotional experience being evoked by objects and people, and third, it refers to spiritual dimension. We appreciate beautiful paintings, mathematical equations, music, dance, human, anatomy, birds, animal species, mountains, rivers and flowers. We also say the mind is beautiful.

John Keats

Henri Poincare

Anyone can hardly remain unmoved by the ancient temples' magnificent architecture in India: they are not only feast to the eyes, also their form, pattern and aesthetics are mesmerizing. 'Beauty', an adage says, lies in the eyes of the beholder', yet it is arguably the underlying element of aesthetics in Nature and in many cultures. It is seen in natural objects, in processes and even in celestial events in the sky. It is real as much as it is transcendental. Laws governing natural phenomena as seen through the lens of science entail order and pattern, something being similar in Art.

Francis Bacon

Werner Heisenberg

The diverse natural phenomena manifest some degree of order, pattern and conformity of the parts to the whole. Nature, being characterized by these three aspects, is deservedly deemed beautiful. Yet we need to define beauty before we examine how it can be searched in science. Here are two complementary definitions: (i) One due to Francis Bacon[3] who said: *There is no excellent beauty that hath not some strangeness in the proportion;* (ii) Warner Heisenberg[4] says: *Beauty is the* *proper conformity of the parts to one another and to the whole*. Bacon's *strangeness* means high degree of conformity that is so striking that there is no beauty without it. It is not just the parts which make up the whole; it's their proper conformity to one another. These two statements may be regarded as the definitions of beauty.

The Scientist's Motivations: Nature is a vast expanse and is understood in terms of what it manifests by way of events in space and time. Our knowledge of the external world is derived from our observations of the natural phenomena, be it physical, chemical, biological or astronomical events. In our understanding of the microscopic world, we have discovered that atoms and molecules are the basic constituents that determine the properties of all forms of matter – gases, liquids and solids. This knowledge of the unknown microscopic world is derived from analogies of what we see in the macroscopic world which surrounds us. For example, the motion of atoms as a model propounded by Niels Bohr[5] in Physics and Chemistry has a strong similarity with the Solar System with the Sun being at the common center of the circles in which respective planets including Earth revolve it. The tiny 'planetary electrons' like planets, also revolve around their nucleus assumed to be in the center of the atom. The model is very successful in understanding various properties of atoms which are the constituents of all chemical elements, namely, hydrogen, helium, carbon, oxygen, nitrogen, copper, silver, gold, and so on. This analogy between the Atomic Model and the Solar System shows that Nature is similar at different levels from the microscopic to macroscopic world. The power of analogy concerning the two models is indeed remarkable, because both models are in agreement with our experience in the first stage of approximation. However, these two models again need to be replaced by more refined models is another topic for discussion. Here is some kind of self-consistency in what we see in diverse phenomena. It is this aspect of Nature which makes it beautiful and inspires scientific enquiry. When the natural phenomena fit into a coherent scheme showing logical consistency, a 'beautiful' theoretical scheme is born. Is this beautiful scheme true? In other words, does this beautiful scheme agree with observations? It's worth quoting John Keats again:

Beauty is truth,

Truth beauty -That's all
Ye know on earth,
And all ye need to know.

A scientific scheme or model as above is true if it is beautiful, though, the true model is not necessarily beautiful. Scientists have every reason to believe that what John Keats says holds good at the fundamental level in science. What motivates eminent scientists to appreciate beauty and seek truth in scientific pursuits is apparent in some life instances. What attracted Sir C.V. Raman[6] to a career in science by giving up a lucrative government job?

Sir C. V. Raman

Hermann von Helmholtz

Lord Buddha

Three books deeply influenced Raman while he was student at Presidency College, Madras. Raman read the book *The Light of Asia* by Edwin Arnold[7]. It is about prince Siddarth who later became Lord Buddha[8] by renouncing his kingdom and family to attain the Enlightenment. This supreme sacrifice in search of truth "is the very essence of human greatness", says Raman, though, the *search* is by no means easy path. Other two books which influenced him include *Elements* of Euclid[9] dealing with geometry and Hermann von Helmholtz's[10] classic book *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, which deals with study of music and musical instruments. Notwithstanding Raman's dislike of *Euclid's* detailed formalism, he came "to perceive the fascination and beauty of the subject". This is the reason why Raman saw beauty in crystals and gems which he copiously collected all his life. Helmholtz's classic book, in the words of Raman himself, "profoundly influenced my intellectual outlook". The book also taught Raman how scientific research is

THE SPRING CHRONICLE
We share knowledge

undertaken and provided him with many scientific problems for later study. Second example is about the thoughts of Richard Feynman[11] on "The Beauty of a Flower" which he has expressed in his book *The Pleasure of Finding Things Out*. Feynman quotes an artist friend who holds up a flower and says 'Look, How Beautiful it is'. Further, the friend adds 'you as a scientist, oh, take this all apart and it becomes a dull thing." Feynman writes that what his artist friend sees is available to all, including himself. He goes on to add that as a scientist he sees much more in the flower than his artist friend.

Richard Feynman

Srinivasa Ramanujan

Hermann Weyl

He can imagine the cells in the flower with complicated actions inside which also have beauty; there is beauty not only at the dimension of one centimeter but also there is beauty at smaller dimensions (i.e. inner structure). Feynman is, further, fascinated by the color of the flower which attracts insects to pollinate it. He poses the question whether aesthetic sense exists in the lower forms of life, say, at the level of insects? He concludes that scientific knowledge of the flower as a whole only adds, not subtracts, to the excitement, mystery and the awe. Science can be beautiful much like Art. This is the kind of motivation for scientists like Feynman. What one can say about the numbers, formulas and functions which mathematician Srinivasa Ramanujan[12] invented? He was a *Svaymbhu* – self-born, self-willed, self-directed and self-made. Ramanujan's formulas, says mathematician G.N.Watson, convey a strong sense of austere beauty similar to what is seen in Michelangelo's grand sepulchers in an Italian mausoleum *Sagrestia Nuova*. As for Ramanujan himself, what he wanted more than anything was freedom to do more mathematics by being in complete solitary environment where he was free to think, to dream, to seek 'truth' and 'beauty' in the theorems he invented. He attributed his fantastic originality and productivity to produce theorems, identities and formulas to the divine diktat from the family deity, *Namagiri Thayar*. To say the least, Ramanujan's mathematics has the beauty of 'the divine hand'.

Symmetry as a measure of Beauty:

Symmetry, being an attribute of objects, has played an important role in the scientific understanding of Nature and its influence in human creative efforts. Even the layman is struck by the symmetrical patterns on flowers, butterfly and plants; in crystals, animals, human body; similarly, of pyramids, ancient exquisite temples, churches, and mosques. No one can deny the instant appeal and splendid architecture of the ancient temples and monuments, being not just a stamp of piety but rather, showcasing man's exalted creativity that is transformative to the and stones and marbles. The term "symmetry" is the Greek word for "proportionality": the similarity in arrangement and parts. Objects differ from one another in their degree of symmetry: the sphere is more symmetrical than the cube. The sphere looks the same when rotated arbitrarily about any axis passing through its center. The cube, however, looks the same only if rotated through ninety degrees about the axis passing through its center. Hermann Weyl[13] defines symmetry, in a simple way, as 'an object is called symmetrical if it can be changed somehow to obtain the same object'. To put it simply, the unchangeability of an object after it is subject to some change because the object being symmetrical. Further he says that through symmetry man always tries to perceive and create beauty, order and perfection. Symmetry aspect is embedded in the laws of physics, chemistry, biology, mathematics, engineering, architecture, and sculpture. However, in the realm of poetry, painting, music and so on, its presence is rather ethereal.

Symmetry in the Physical Laws: It was Emmy Noether[14] who discovered that symmetry associated with the motions of a body or system leads to the conservation laws: i.e. if the linear momentum of the body is the same at different places, it is conserved or remains *invariant*; likewise, the angular momentum about any direction remains the same or *invariant* even if the system is rotated. The symmetry, as delineated above, can also be applied to physical laws – 'The laws governing natural events are independent of the state of motions of the reference frame in which these events occur if the frame travels without acceleration'- said Albert Einstein[15].

Emmy Noether

In other words, the laws of physics remain the same regardless of whether we are at rest or are moving in such a fashion that the motion covers equal distances in equal intervals of time. In technical terms, the symmetry of the laws of physics means that the laws are *invariant* under translation as well as rotation. It was Eugene Wigner[16] and Hermann Weyl who introduced symmetry into Quantum Physics, and Wigner has this to say: 'In Nature, two miracles exist: First one is that the "*Laws of Nature exist"* and the second one is *"The ability of the Human Mind to Divine them*". We, at this stage, wish to point out that at the deepest level of fundamental physical world the atomic particles influence each other via electromagnetic field, weak field, strong field and gravitational field with the involvement and breaking of symmetries connecting the particles and fields in a complex way.

Mathematics as Satyam Shivam Sundaram: Mathematics, in so far as its origin, logical structure and beauty are concerned, stands on its own. In India's ancient scriptures, the succinct motto says: *Satyam Shivam Sundaram,* meaning Truth, Goodness and Beauty. We may take the liberty to describe *Mathematics as Satyam Shivam Sundaram.*

An artistic representation of Satyam Shivam Sundaram (credit: amazon.in)

Our understanding of form, structure and beauty in Nature are amenable to formulation in a certain logical way and it is at this stage mathematics enters. Once mathematics takes over, Nature looks like a pure splendid architectural landscape where the paths to beauty and truth are laid out before us. Mathematics is both an art and a science; its pursuit is a study by 'meditation'; it is infallible. To quote Betrand Russell[17]: *Mathematics possesses not only TRUTH, but supreme beauty – a beauty, cold and austere like a sculpture, without appeal to any part of our weaker nature, sublimely pure, and capable of stern perfection such as only the greatest art can show*. Mathematicians are honored for their breakthroughs by the *Fields Medal*[18] on which it is engraved: *Rise above oneself and grasp the world*. Some scientists deeply believed in the mathematical beauty as the basis of truth. Hermann Weyl who, while developing theories, always tried to unite the 'true' with the 'beautiful'. While choosing one or the other, he chose the beautiful. We may therefore say that, mathematics lends credence to the search for truth and beauty.

Bertrand Russell

Albert Einstein

Paul Dirac

S. Chandrasekhar

For example, Weyl's gauge theory of gravitation which he regarded as mathematically beautiful was ignored until later it was found true. How this comes about is nicely answered by Subramanyam Chandrasekhar[19] who says 'what the human mind, at its deepest and profound, perceives as beautiful finds its realization in external Nature': '*What is intelligible is also beautiful*'. Scientists strongly believe that if their theories are formulated satisfactorily in terms of rigorous mathematical basis, the theories would be beautiful and as a result, they would also be true. Einstein's General Theory of Relativity, proposed in 1915, is regarded as an extremely beautiful theory just like a work of art. Dirac[20] says, 'What makes the theory so acceptable to physicists, in spite of its going against the principle of simplicity, is its great mathematical beauty'. Einstein himself said, 'Anyone who fully comprehends this theory cannot escape its magic'. Subramanyam Chandrasekhar, who studied the theory, says, 'the magic of the theory is in the harmonious coherence of its mathematical structure'. In 1917, very firmly sure of the trueness of the theory, Einstein proceeded to apply it for understanding the Universe, its physical character, size and so on. The theory predicted a model of the Universe which was evolving in time, referred to as an expanding Universe. He thought that this model contradicted the experimental evidence which, he believed, was in favor of a static Universe and his result was called Einstein's static universe. To get the static Universe he introduced 'a cosmological constant' in the theory to reverse the result for expanding Universe and finally deduced a model of the static Universe. However, later, new experimental evidences emerged in favor of the expanding Universe. Upon hearing this news, Einstein seems to have remarked about the unnecessary cosmological constant he introduced was his 'biggest blunder'. Scientists said Einstein unnecessarily introduced the cosmological constant in his General Theory of Relativity; if he had not done that, the theory might have predicted an expanding Universe in a natural way because of its mathematical beauty and its versatile scope for application to any problem. Dirac formulated a new Relativistic Quantum Theory of the Electron which is mathematically very beautiful and it also successfully explained the Hydrogen spectra. Its principal feature is prediction of a new atomic particle called 'positron' carrying the same amount of electric charge and mass as the electron but it is positively charged. Soon the positron was discovered in the laboratory. The negative energy associated with the positron comes out as one of the two solutions to the Dirac's Relativistic Wave Equation, a pure mathematical result that turned out to be experimentally true! These two examples illustrate that a mathematically beautiful theory with solid physical conceptual base would be a successful one, both from the point of view of symmetry criteria and the need to agree with experiment.

Mathematics as Pattern Creator: Mathematicians and scholars through the centuries realized the connection between numbers and their relations with patterns in Nature. Indian mathematician-cum-grammarian *Pingala*[21] and Western mathematician *Fibonacci*[22] discovered the following sequence:

1, 1, 2, 3, 5, 8, 13, 21,.......

The sequence can be generated with 1 and 1 to start, the remaining numbers are generated by adding the previous two numbers: 2=1+1; 3=1+2; 5=2+3; .... This kind of sequence of numbers seems to dictate the number of spirals on the snail shell to the geometry of the sun flower. The sequence has one more following property: if the ratio of a sum of two numbers (one succeeding larger number, say, *q* and its preceding smaller number, say *p*) *p*+*q* to the larger of the two numbers, *p,* equals the ratio of the same larger number, *p,* to the same smaller number, *q,* then it gives rise to *Golden Ratio* (see Table below).

Acharya Pingala

Fibonacci

3/2	5/3	8/5	......	34/21	55/34
1.500	1.333	1.600		1.619	1.617

The sequence converges to 1.618033988 and is expressible exactly as:

$$p+q/p = p/q = \Phi = [1 + \sqrt{5}]/2 = 1.618033988.$$

This *Golden Ratio*, Φ, has a very important role in mathematics as are the fundamental constants π (which refers to the ratio of the circumference to the diameter of a circle) and *e* (which refers to Euler's number and also is the base of the natural logarithm). The Greeks apparently used Φ in art and architecture without being aware of it. Likewise, the sequence or called *F-numbers* is used in Egypt's pyramids, in Leonardo da Vinci's *Mona Lisa* painting and in many areas of art, music, grammar (as a grammarian, *Pingala* is believed to have discovered the sequence), in today's technologies including cryptography and machine learning. Certain organisms being 'beautiful' owe it to the *Golden Ratio* embedded in their morphology.

***Beauty in Wabi-Sabi*:**

In Japanese culture, in contrast to other cultures, beauty is perceived from different aesthetic view-point. Beauty, its philosophy says, is to be found in *Imperfection*, *Impermanence* and in the natural *Growth-Decay* cycle. The cardinal point is to divorce the idea of perceiving Nature as beautiful nor is there a state of perfection having the high degree of conformity to the parts because everything is transient. It may thus be said that, symmetrical objects are transitioned to unsymmetrical ones as a natural process. There is no need for creating a perfect world than the one being *Imperfect*, *Impermanent* and subject to *Growth-Decay* process in which man should find peace and contentment. In so far as our discussion is concerned here, the element of *Imperfection* is to be found in the natural laws as a deviation from perfection. We may say skewed beauty corresponds to a new truth. As a first step, the scientist abstracts from Nature pure laws guided by his perception of their beauty. In the second step, when his experience demands that the laws need correction, he is thus bound to acknowledge the skewed side of the beautiful world. In so doing, he learns more and more about Nature which he continues to deem it beautiful. Symmetry as an ideal attribute lies at the heart of everything in Nature and the idea of beauty is its best descriptor, being inherent in all the spheres of human understanding. If Science is comparable in some measure to Art, it is because of the element of beauty being common to them. It is no surprising that in ancient Indian wisdom, the motto: *Satyam Shivam Sundaram* which broadly means Truth, Goodness and Beauty, recognizes these values as the essence of the highest form of life. Likewise, *the scientist's grand vision of science is driven by the search for beauty, by the search for truth*.

Notes

1. John Keats (1795-1821) is an English romantic poet. His poems are known for "sensualities" which bring out man's perspectives on beauty and pursuance.
2. Henri Poincare′ (1854 – 1912): He is a renowned French mathematician and theoretical physicist as well as philosopher. In fact, he is described as a polymath. Among his major contributions to physics and mathematics include Einstein's special theory of relativity and Group Theory. Poincare′ had almost been closer to inventing theory of relativity yet he missed it since he failed to treat the problem of ether being a non-actor in determining kinematics as Einstein did.
3. Francis Bacon (1561 – 1626) is an English philosopher and statesman. He served, among others, as Lord Chancellor of England under King James I. He believed in scientific method which he advocated for spreading science. It is said that his views on science influenced later centuries for creating awareness about scientific culture.
4. Werner Heisenberg (1901- 1976) is one of the most prominent German theoretical physicists who discovered Matrix Mechanics (also called Quantum Mechanics). He was awarded a Nobel Prize in physics in 1932 for inventing Quantum Mechanics.
5. Niels Bohr (1885 – 1962) is a Danish theoretical physicist and philosopher. His atomic model successfully explained the spectra of hydrogen and hydrogen-like elements, paving the way for more refined models and developments in physics. He was awarded a Nobel Prize in physics in
6. Sir C.V.Raman (1888 – 1970): Raman is an Indian experimental scientist who discovered incoherent scattering of light known after him as Raman

Effect. He was awarded a Nobel Prize in 1930 in physics becoming the first Asian Nobel Laureate. He derived inspiration for the discovery when he was struck by the blue color of the sea waters during his sea travel to the West. Raman also made several studies in sound, optics and magnetism while he was still government employee in Calcutta (now Kolkata) during 1907 – 21 and earned an international recognition, becoming a Fellow of the Royal Society (FRS), London. The manner in which he toiled during these years without a mentor, material support and without any visits to the Western universities nor labs is exemplary and inspirational.

7. Sir Edwin Arnold (1832 – 1904): Edwin Arnold is an English poet and journalist. His book The Light of Asia published 1879 was the first to introduce the life and work of Lord Buddha to the Western world. Highly acclaimed for its popularization of Buddhism, the book has been translated into many languages.
8. Lord Buddha ($6^{th}/5^{th}$ century BC): Lord Buddha was an ascetic who founded Bhuddism, one of the world's great religions. Born as a prince named Siddhartha Gautama, he renounced palace life for attaining enlightenment as a way of detaching himself from the worldly life. While Buddhism remained as a great influence over centuries, it eventually declined in India while it spread to the South Asian countries. Among its cardinal principles, the principle of ahimsa or non-violence inspired Mahatma Gandhi as his chief instrument of freedom struggle against British Rule in India.
9. Euclid (~300 BC): Euclid is one of the eminent Greek mathematicians known for his work on geometry and his book Elements provides the principles of geometry as we are taught it in schools.
10. Hermann von Helmholtz (1821 – 1894): He is a 19^{th} century German scientist who contributed richly to many fields including physics, physiology and philosophy of science. His classic book On the Sensations of Tone as a Physiological Basis for the Theory of Music is regarded as one of the best works of Helmholtz. The book's style, exposition, clarity of expression and above all its scientific method influenced young Raman.

11. Richard Feynman (1918 – 1988): He is an eminent American theoretical physicist who won the Nobel Prize in physics (1965) for his fundamental contribution to the field of quantum electrodynamics. He was professor at California Institute of Technology (popularly known as Caltech), USA. Feynman was an excellent teacher and his lectures to undergraduates at Caltech during 1961-64 were subsequently published under the title The Feynman Lectures on Physics (Vol I, II, III) and have since become popular course material for students and teachers all over the world.
12. Srinivasa Ramanujan (1887 – 1920): An Indian mathematician whose genius is comparable to world's most renowned mathematicians like David Hilbert, J.E.Littlewood, G.H.Hardy. His most important contributions to fields include mathematical analysis, number theory, infinite series, and continued fractions. He is the youngest Fellow of the Royal Society of London. His discoveries of several theorems and conjectures have kept mathematicians busy even to this day.
13. Hermann Weyl (1885 – 1955): One of the most influential German mathematician and theoretical physicist of the 20th century. He was very influential with his fundamental discoveries both in mathematics and theoretical physics. After Einstein's general theory of relativity, he proposed alongside Einstein and others a unified theory of general relativity and electromagnetism. Weyl emphasized that a theory must necessarily be 'beautiful' from the mathematical view-point regardless of its agreement with experiment. He also made contributions to the foundations and philosophy of mathematics.
14. Emmy Noether (1882 – 1935): A German woman mathematician who made many contributions to modern algebra. There are theorems in her name, notably the one connecting law of conservation of physical quantities (i.e. energy, momentum, etc) and symmetry of a system. Her premature death left the world of mathematics in shock and Einstein paid tribute to her saying "Noether was the most significant creative mathematical genius thus far produced since the higher education of women began."

15. Albert Einstein (1879 – 1955): He is the most eminent physicist in history since Sir Isaac Newton. Einstein single-handedly invented fundamental theories as landmarks which paved way for new sciences. His two theories, among others, Special (1905) and General Theory of Relativity (1915), have revolutionized our conceptual understanding of space, time, matter, energy and gravity. His most famous formula between mass and energy, $E = mc^2$, is the basis of the atomic bomb. Einstein was honored with a Nobel Prize in physics in the year 1921. Following the United Nations declaration, the year 2005, being called miracle year, was celebrated throughout the world in more than one way to mark Einstein's greatest science since Newton's.
16. Eugene Wigner (1902 – 1995) is a Hungarian-American physicist who introduced symmetry principles into quantum physics and nuclear physics at the fundamental level providing a deeper understanding of the atomic nucleus. As a result, he was awarded a Nobel Prize in physics in 1963. He and Hermann Weyl introduced the Theory of Groups into Quantum Physics. Wigner made a number of fundamental discoveries not only in quantum mechanics, atomic and molecular spectroscopy, nuclear physics but also in mathematics.
17. Bertrand Rusell (1872 – 1970): The most well-known British mathematician, philosopher, logician, free thinker and writer of the 20th century. His books among numerous others and essays include Principia Mathematica, The Principles of Mathematics and History of Western Philosophy that are widely acclaimed. He was awarded the Nobel Prize for literature in 1950. Russell spent his final years in opposing atomic bomb programs pursued by the developed countries. The famous Russell-Einstein manifesto is the result of such campaign which alerted the governments about the perils of nuclear wars and its threat to the humanity.
18. The Fields Medal in mathematics is equivalent of the Nobel Prize. It is named after the Canadian mathematician John C Fields. It is awarded to, once in four years, a single or up to four persons under 40 years of age for

making breakthroughs in mathematics. The motto on the Fields Medal reads: Rise above oneself and grasp the world.

19. Subramanyam Chandrasekhar (1910 – 1995): He is an Indian-American theoretical astrophysicist. His wide-ranging contributions include stellar structure and evolution, black holes, hydrodynamics, white dwarfs, quantum theory, general relativity and others. He discovered that there is a maximum limit of the mass of white dwarf star and above this limit the star starts to shrink, a state of collapse into a black hole. The limit is called the Chandrasekhar Limit. He was awarded the Nobel Prize physics in 1983 for his theoretical studies associated with structure and evolution of stars. His seven lectures on aesthetics, motivations and patterns of creativity have been published under the title Truth and Beauty: Aesthetics and Motivations in Science, providing the essence of how scientists pursue their passions guided by certain motives. Being himself, a scientist endowed with extra-ordinary math talent, analytical bent of mind and unwavering passion for aesthetics, Chandrasekhar demonstrates how the great men think and create science.
20. Paul Dirac (1902 – 1984) is a British physicist who founded quantum mechanics based on his own mathematical formalism. He also created the Relativistic Quantum Mechanics by combining Einstein's Theory of Relativity and Heisenberg's and Schrodinger's Quantum Mechanics. As a result, he was awarded the Nobel Prize in physics with Schrodinger in 1933. His PhD thesis was the first one on Quantum Mechanics at St John's College, the University of Cambridge, the UK. Dirac's book entitled The Principles of Quantum Mechanics is regarded as one of the best books on the subject. His contributions to the advancement of theoretical physics in all directions has been immense. Dirac is compared to Einstein both for his fundamental discoveries and influence.
21. Acharya Pingala (3rd/2nd BCE): Acharya Pingala belongs to the galaxy of the most eminent ancient Indian mathematicians, grammarians and poets. His treatise Chandahśāstra, a Sanskrit prosody, is about the combinations of

short and long syllables being equivalent of strings of varying durations in the rendition of poems. The discoveries in prosodies led him to invent a mathematical sequence in which each number is the sum of the two preceding ones (0, 1, 1, 2, 3, 5, 8, 13, 21……), popularly known in the world of modern mathematics, the Fibonacci sequence. The sequence is now also referred to as the Pingala sequence, a credit Acharya Pingala deserves. Not only he is credited with this invention, Acharya Pingala, says history, also applied mathematics to analyze the components of poetry, a rare multi-disciplinary approach given the divergent scope of mathematics and literature.

22. Leonardo Fibonacci (1170 -1240/50 AD): Fibonacci is an Italian mathematician who lived in the Middle Ages. He independently invented the Pingala sequence known after him Fibonacci sequence and mentioned it in his book of theory of numbers, Liber Abaci. The book included Indo-Arabic numeral system to which the Europe was introduced. It is said he did refer to the Golden Ratio in his book though it is related to the Fibonacci sequence.

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