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Enigmas (Puzzles) in Teaching and Learning of Physics

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Abstract

Teaching and learning of physics has been considered a challenge by both the teachers and students in India. The text books prescribed normally do not refer to these challenges which are mostly at conceptual level. An attempt has been made to recall some of the puzzles which are encountered by most of the students in learning physics. The historical origin of puzzles in particle physics has been brought into focus during discussion of pion-muon, tau-theeta and neutrino puzzles. The solution of these puzzles led to award of Nobel prizes in physics, with the 2015 prize awarded for solution of neutrino mass puzzle. A brief description of dual nature of matter and radiation puzzle is also given.

Keywords: *Newton's laws of motion, second law of thermodynamics, entropy, elementary particles, pi meson, mu meson, tau-theeta particles, neutrino, dual nature, parity*

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INTRODUCTION

Physics is one of the most exciting disciplines of science but it has many puzzles and enigmas which make it somewhat difficult to understand and comprehend at school, college and university levels. At high school level, one starts the study of physics with Newton's laws of motion. The first law states that a body remains in the state of rest or of uniform motion in a straight line unless an external force acts upon it. But contrary to its definition we observe in daily life that moving bodies always stop automatically when in motion. This enigma bothers all young minds as they do not realize that the external force acting on the body is friction. But how could Newton formulate his first law without any experimental proof in his times is what we call an act of genius. The other two laws of motion enunciated by Newton are not so difficult to comprehend by students.

Moving on to heat and thermodynamics, one is baffled by the second law of thermodynamics and its implications. It was a French engineer, Sadi Carnot, who established this law by his hypothesis that efficiency of an ideal heat engine cannot reach 100%. All other engines, both internal and external combustion types, have efficiency far below the Carnot's ideal engine which is fully reversible. Why is it so? Efficiency is typically less than 100% because friction and heat loss convert the energy into alternative forms but the real culprit is entropy which is the measure of the energy in system that can not be used to work. Second law of thermodynamics has been defined in term of entropy which states that entropy always increases with time. Entropy represents the degree of disorder or randomness in the system. Ultimately the entropy of our universe will reach its maximum value, no conversion of heat into work is possible as all temperatures will be equalized, and as a consequence, it will lead to heat death of the universe. In a way, entropy will play the role of Shiva, the destroyer of the universe.

PUZZLES IN PARTICLE PHYSICS

In the early years of 20th century, one could hardly count electrons, protons and neutrons as the building blocks of matter in the universe. However, with the advent of particle accelerators, the search for new elementary particles began on war footing. During my M.Sc. studies in early sixties of last century it was an assumption that a new particle or a resonance will be discovered almost every week. Some famous laboratories in Europe and America started working as factories for production of particles. As a consequence, most of the puzzles were created in the field of particle physics.

The Pion-Muon Puzzle

Hideki Yukawa predicted in 1935 pi meson as quanta of nuclear force and won the Nobel prize in 1949. The mass of particle was predicted in the range of 300 m_e (mass of electron) and it was predicted to be strongly interacting particle in matter. However, scientists discovered a new meson particle in cosmic ray experiments but its interactions were not as strong as predicted by Yukawa. More than a decade was to elapse before the true Yukawa particle was discovered again in the cosmic ray experiments carried out by C.F. Powell at Bristol in UK. The puzzle of true Yukawa particle was solved by naming it pi meson or pion and its counterpart discovered earlier as the mu meson or muon. The misadventure of pion-muon puzzle greatly encouraged the development of meson theory proposed by Yukawa and it boosted the search for elementary particles.

The Tau-Theeta Puzzle

Just after resolution of pion-muon puzzle, another strange phenomenon was discovered in the early 1950s in cosmic ray experiments known as Tau-Theeta puzzle. It was observed that two particles called tau and theta appeared to be identical in every respect; same mass, spin, charge, etc. however, they exhibited different decay modes: Tau decaying into three pi mesons and theeta into two pi mesons as shown below:

Tau (τ^+)$\rightarrow\pi^+ + \pi^- + \pi^+$,

Theeta (θ^+)$\rightarrow\pi^+ + \pi^0$

Tau-theeta puzzle was solved by two Chinese origin scientists, Lee and Yang, by proposing that tau and theeta have different parities (-1 and +1), depending upon their behavior under the operation of mirror inversion. The parity conservation was a sacred symmetry of nature and found to be conserved in all strong, electromagnetic and gravitational processes occurring in nature. However, parity violation occurs in weak processes as in tau-theeta and β-decay. Lee and Yang prediction of parity violation was confirmed experimentally by another Chinese madam C.S. Wu, who made it possible for Lee and Yang to win Nobel prize in 1957. Why she was not awarded Nobel prize along with her compatriots who predicted this phenomenon is a great mystery?

Neutrino Puzzle and Award of Nobel Prize in Physics (2015)

Neutrino is known as an elusive particle which defied detection for several decades after its prediction by Wolfgang Pauli in 1930. Enrico Fermi called it neutrino (small neutron in Italy) in 1933, when he proposed his Fermi theory of β-decay. This elusive particle was detected by Reines and Cowan, much later in 1956, for which Reines was awarded the Nobel prize in 1995.

Many puzzles were solved by prediction of neutrino but the particle itself remained a big puzzle. The β-spectrum in β-decay was an enigma for physicists as it challenged the fundamental laws of physics, namely, laws of conservation of energy and of spin. Neutrino prediction solved this enigma as it does not allow the violation of laws of conservation of energy and spin in β-decay as follows:

$n\rightarrow p+e^- +\bar{\upsilon}$ (anti-neutrino)

According to standard model of particle physics, both neutrino and anti-neutrino have been assigned zero mass. This assumption has been challenged in neutrino oscillation experiments which were carried out in Japan and Canada. These experiments established that neutrinos come in three flavors and have a very small mass, which is responsible for neutrino oscillations. The big puzzle was not mass but the detection of mixed flavors in pure neutrino beams when travelling between the source and detector.

In Super-Kamiokande experiment conducted in Japan, it was observed that solar electron neutrinos changed into muon and tau neutrinos due to influence of neutrino oscillations. In T2K (Tokai to Kamioka) experiment started in 2009, the reciprocal phenomenon was observed in 2013, which established that muon neutrinos travelling from Tokai proton synchrotron transformed into electron neutrinos on reaching Kamioka detector.

In 2015, Nobel prize for physics has been shared between Takaaki Kajita (Super-Kamiokande) and Arthur McDonald (Sudbury neutrino observatory) for detection of neutrino flavor oscillations, as a consequence of neutrino mass; hence putting a question mark on the validity of standard model.

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From their pioneering work, the neutrino field has boomed across the world, with experiments in every continent. Now that we know neutrinos have mass, we need new theories to explain how they acquire it. If new fundamental particles are responsible for neutrino masses, one of them could account for dark matter, a mysterious substance that makes up the vast majority of the matter in the universe. Work is ongoing in this area and exciting discoveries may be just around the corner.

DUAL NATURE OF MATTER AND RADIATION

The biggest enigma in physics is the concept of dual nature of matter and radiation. It is well known that all matter is composed of elementary particles, mainly protons, neutrons and electrons. The motion of material particles is governed by Newtonian mechanics but when we deal with microscopic world of elementary particles, the motion is governed by relativistic laws of motion which fall under Einstein's theory of relativity. The boundary line between classical Newtonian regime and the relativistic regime is not very well marked, rather both overlap depending upon the velocity of the particle. For example, when a cricket ball is thrown at a high speed towards the wickets, its motion is governed by Newtonian mechanics and relativistic effects are blurred or negligible in this velocity range.

On the contrary, when an electron or proton beam is emitted from an accelerator source, the motion is governed by relativistic laws of Einstein and Newtonian effects are blurred or invisible at high velocity ranges. Relativity theory and quantum mechanics have revolutionized our thinking about the phenomena we encounter in our daily life. Light travels in the form of a wave motion in a medium, is a well established fact of life but Max Planck introduced the concept of quanta or photon, as established by photoelectric effect, for light transmission. It means radiation has dual nature, which is a great puzzle for students and teachers both.

Following the analogy of dual nature of radiation, Louis de Broglie proposed the concept of dual nature of matter in 1924 in his doctoral thesis submitted to Paris university of Sorbonne. He proposed that all elementary particles exhibit wave nature when they are in motion. But which nature is predominant, depends upon the conditions of experiment undertaken to study its behavior. Using Broglie's ideas, Erwin Schrodinger developed wave mechanics, the theory which explains the phenomena in the microscopic world. Let me end this article with the remark that even quantum/wave mechanics is not free of puzzles; just think of EPR paradox proposed by Einstein, Podolsky and Rosen in 1935 and Copenhagen interpretation of Neils Bohr in defense of quantum mechanics.

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