CHAPTER 10

# Modern Perspective on the Physical World *

**B.V. Sreekantan**

National Institute of Advanced Studies, Bangalore 560 012

Einstein: *"The most incomprehensible thing is that the universe is comprehensible"*

COMPREHENSIBILITY (or the lack of it) is the power of human mind which has its own limitations. However science and technology have made it possible to expand the horizon of the knowable to a very large extent. But as John Wheeler has said, "as the island of our knowledge grows so does the shore of our ignorance". Thus it has happened that we do know a great deal about the physical world, but there is certainly very much more we do not know.

Let us first understand where we are in the scheme of the Universe. Each one of us is one among about six billion people on the earth. The earth itself is one among nine planets circling round the star called the Sun. The Sun is one among a hundred billion stars in the galaxy called the Milky Way and there are two hundred billion galaxies in the Universe.

The most fantastic achievement of modern science, developed over the past four hundred years, is to establish that the entire universe is the play of just three entities—matter, radiation and force. But these three by themselves are complex entities which we have to understand in detail before being able to form a modern perspective on the physical world.

## Matter and its Ramifications

The first thing that we recognize about matter around us is that it exists in three states—solid, liquid and gas and some of the substances like water exist in all three states depending on the environmental temperature. The chemists have been able to establish that the matter around us and as we shall see later, all the matter in the entire universe, is ultimately made out of ninety-two elements—hydrogen to uranium. Each element is reducible to its characteristic molecules and it is the combination of the different elements at the molecular level that leads to

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the formation of different substances. The molecule of each element in turn is made of atoms of that substance, which is the ultimate level up to which the identity of the element is retained. Each atom has a nucleus which is positively charged and is surrounded by a shell of electrons, which carry negative charge with the result that atom as a whole is always electrically neutral. The nucleus which is at least a thousand times smaller in radius compared to the atom, carries practically all the mass of the atom. The nucleus itself is composed of two types of fundamental particles called the Protons and Neutrons. They both have roughly the same mass, about 1800 times the mass of the electron. While the proton is positively charged the neutron is electrically neutral. The positive charge of the proton is identical in magnitude to the negative charge of the electron. Thus to make the atom neutral, the number of electrons in the atom has to be equal to the number of protons in the nucleus which is so. This number designated 'Z' is called the atomic charge number and is the same as the atomic number is in the Mendeleev Periodic Table of elements. The total number of protons and neutrons in the nucleus determines its atomic weight called the mass number and designated as A. If we denote the number of neutrons by n, then among the light elements n equals Z. But as we go to heavier elements the number of neutrons can be far in excess of the number of protons. Those that have the same nuclear charge but different number of neutrons are called isotopes, and those that have the same mass number but different nuclear charges are called isobars. While originally one started with only 92 elements found in nature, several transuranic elements have been produced at accelerators and have also been recognized in stellar explosions. These are extremely unstable. As of now there are about 300 stable and 1000 unstable (radioactive) isotopes. Stable isobars occur mostly in pairs. Fifty-nine isobaric pairs have been discovered and there are 5 isobaric triads.

Even though one cannot define an exact radius for the nucleus, the order of magnitude of this radius which has a weak dependence on the Atomic Number A is given by $R=R_0A^{1/3}$ where $R_0 \sim 1.3–1.7 \times 10^{-13}$ cms. One of the important parameters concerning the structure of a nucleus is "the binding energy" which is the difference between the energy of the protons and neutrons in the nucleus and their energy in the free state; and the magnitude of this binding energy determines its stability against disintegration into other elements. The protons and neutrons in the nuclei are held together by nuclear forces the nature of which we shall discuss later on.

Even before these structural details of nuclei were figured out, the spontaneous disintegration phenomena of elements like Uranium had been discovered towards the end of the 19$^{th}$ century, through the detection of the emission of three different kinds of radiations—α-particles, β-particles and ϒ-rays. It turned out that the α-particles were the nuclei of Helium, the β-particles were electrons and the ϒ-rays were high frequency electromagnetic waves. While Radioactivity itself was discovered by Becquerel, detailed investigations on the nature of these emitted particles and their identity were all established by Rutherford. The puzzling feature was that even though the α-particle inside the nucleus did not have sufficient energy to overcome the potential barrier of the nucleus, occasionally the particle did leak out. This particular feature was explainable only in terms of quantum mechanical theory, which we shall discuss later on.

The α-particles became an important tool in the hands of Rutherford in establishing the fact that inside the atom, there was the nucleus much smaller in size and carried all the mass of the atom.

**Radiations**

Heat and Light are the two most familiar radiations we encounter in everyday life. The idea of hot and cold and of temperature as a measure of these features and the expansion and the contraction of bodies as a function of temperature and the general explanations of these in terms of molecular structure and motion and vibrations of molecules, the varying specific heats of materials and conduction and convection of heat are all features that have all been well accounted for, quantitatively explained as part of thermodynamics and statistical mechanics. In these contexts certain very important principles followed rigorously by nature are recognized which form the foundations of physics—the law of conservation of energy, the natural direction of energy transformation (from mechanical to heat energy) as determined by entropy increase, entropy being a measure of disorder. These ideas have considerable influence on engineering designs of transport, locomotion, and the recognition of the impossibility of perpetual machines. The most important philosophical fall out is that the entropy of the universe as a whole is increasing—moving towards more and more disorder. This means that as we go backwards in time there was increasing order. The idea of heat energy being transferred by a third mode, namely radiation is also quite old. This is the mode by which heat energy comes to us from the Sun—from a distance of 93,000,000 miles across practically vacuum. All the substances that we are familiar on the earth turn into gaseous state at a temperature of 6000°C. Since the solar material is the same, all the matter in the sun is in a gaseous form.

**Light—Particle or Wave?**

Light is what enables us to see things around us and to admire those twinkling bright stars that fill the horizon of our view in the sky. Great names are associated with systematic study of light—Newton, Huygens, Fresnel, Young, Maxwell and Einstein. These great scientists and others made experimental studies and offered theoretical explanations for the most significant properties of light like rectilinear propagation, reflection, refraction, polarization, interference, diffraction and velocity of propagation in different media. Newton famous for his dynamics also made pioneering contributions in the field of optics. He believed, on the basis of the beautiful experiments he carried out, that light consists of swarms of particles emitted by a source, that move away at a very high speed. This corpuscular theory of light was opposed by his contemporary Christian Huygens the proponent of the wave theory of light. These two theories predicted exactly opposite results on the velocity of light in substances, and since during their time there was no capability for measuring such high velocities, the nature of light remained an open question. The phenomenon of interference and diffraction went in favour of the wave theory of light. However with the advent of quantum mechanics and the explanation of photoelectric effect in terms of the 'photon' theory of light by Einstein, the corpuscular theory was revived but in a very different sense as we shall see later.

An important development that goes back to the time of Newton himself is the Prism Spectroscope followed by the Spectrometers with Diffraction gratings. These opened up the whole field of Spectroscopy which provided much insight into our knowledge regarding the structure of atoms. Each chemical element emits a set of spectral lines characteristic of that particular element. Helium, was first discovered by the spectral analysis of the light from the Sun. The study of spectral lines characteristic of different elements led to the discovery of certain regularities in the emissions of light by the atoms and pointed to the possible mechanism behind these line emissions based on Bohr's theory of the atom which we will discuss after becoming familiar with the quantum hypothesis of Max Planck.

In the wave picture, light of different colours corresponds to different wave lengths of the associated wave. The shortest wave length visible to the eye is $4 \times 10^{-5}$ cms and is beyond the blue colour—namely violet shade. An important relation between the wave length of maximum intensity emitted by a hot body and its temperature is known as the Wien's Law which states that the wave length of maximum intensity is inversely proportional to the absolute temperature. Stefan and Boltzman came up with another important relation that the total intensity of the emitted radiation is proportional to the fourth power of the emitter's absolute temperature.

Beyond the range of human eye perception we have on the longer wave length side infrared radiation which is essentially the 'heat radiation' that we talked about earlier and on the shorter wave length side the ultraviolet radiation.

**The Quantum Hypothesis**

When James Jeans made an attempt to determine the distribution of energy between the different wave lengths on lines similar to what Maxwell had done to calculate the distribution of energy between different molecules of gas (the famous Maxwell-Boltzman distribution of velocities), he ended up with a paradoxical result which came to be known as the "ultraviolet catastrophe". The calculations showed that all the available energy will be redistributed in such a way that it will be all at the shortest wave length. This exposed the inadequacy of the classical theories present till then. Radically new ideas and concepts were required and this came in the form of quantum theory—which was a development on the quantum hypothesis made by Max Planck in the Christmas week of 1899.

Planck made the hypothesis that for each kind of radiation there corresponds a definite amount of energy which he called "the quantum". Light of different types carry different amounts of energy and the amount of energy in the corresponding "quantum" is inversely proportional to the wave length of light or directly proportional to the frequency. He wrote down $E=h\upsilon$ where E is the energy of the quantum and $\upsilon$ is the frequency of light. The proportionality constant, known as the Planck Constant has the value of $6.6 \times 10^{-27}$ erg seconds.

On the basis of this hypothesis Planck was able to rework the relation between wave length and energy distribution and showed that the problem of ultraviolet catastrophe had disappeared. Planck also derived the Wien and Stefan-Boltzman laws on the basis of his new hypothesis.

This new hypothesis of Planck, was soon very strongly supported by Albert Einstein which he adopted for explaining the photo-electric effect. It had been found that some materials like copper plates when irradiated with visible or ultraviolet light emit electrons—the particles responsible for conduction of electricity in metals. The anomaly that had remained unexplained before Einstein was, that the energy of the electron was not proportional to the intensity of light that shone on the substance.

Einstein explained the phenomenon on the basis of quantum hypothesis that the electron absorbs the entire energy of the quantum (which he called the photon) in one bite and not fraction of it, and the energy of the outgoing electron will depend on the energy of the photon incident in it. This explained why the number of electrons emitted depends on the intensity of light, but not the energy of the outgoing electron. These considerations led Arthur Compton to study the scattering of x-rays (photons of energy much higher than the optical photons) and establish that the photons did behave like particles in the collisions very similar to the collisions of billiard balls.

**The Bohr Atom**

Rutherford's experiments on the scattering of α-particles hitting metal targets, had clearly established the existence of nuclei inside atom, the nuclei carrying all the mass and being very much smaller in size (a factor of 1000 in radius) compared to the atoms. He came up with the planetary model of the atom in which the electrons revolved round the central nucleus in very much the same fashion as planets revolve round the sun. The problem however with this model was that in going round the nucleus, the electrons emit electromagnetic waves and lose energy and finally spiral into the nucleus and the atomic configuration will not be stable. Bohr, who had joined Rutherford as a student calculated that in a hundred-millionth of a second, the orbiting electron would lose all its energy. This was certainly against what had been observed in nature. Bohr came up with rather revolutionary ideas and made some bold assumptions. Bohr's postulates were:

(i) From all the mechanically possible circular and elliptical orbits of electrons around the atomic nucleus, only a few highly restricted orbits are "permitted" and selection of these "permitted orbits" is to be carried out according to specially established rules.

(ii) Circling along these orbits around the nucleus, the electrons are "prohibited" from emitting any electromagnetic waves, even though conventional electrodynamics says they should.

(iii) Electrons may "jump" from one orbit to another, in which case the energy difference between the two states of motion is emitted in the form of a single Planck-Einstein light quantum.

Clearly all these were arbitrary assumptions that were made just to fit the experimental observations. There were no logical arguments in favour of them. These hypotheses, however, did permit Bohr to interpret the regularities (the Balmer series), that had been observed in the analysis of spectral lines of hydrogen. In fact the constants in Bohr's theory were adjusted to fit the Balmer series. The success came with the verification of the predictions that were made for other atoms. While Bohr had assumed circular orbits, Sommerfeld added an elliptical orbit to Bohr's second orbit and two elliptical orbits to the third Bohr orbit and so on and these extensions helped in understanding the fine structure of spectral lines. Wolfgang Pauli came up with his famous principle that two electrons moving in the same orbit have to have opposite spins. This was an important development since it explained the periodic elements of the chemicals that had been arranged by Dmitri Mendeleev and also to fill the gaps in the elements that had been left out and which were discovered later.

**Matter Waves: Particle/Wave duality**

Bohr's hypotheses of stationary orbits of electrons in atoms, which did not radiate electromagnetic waves, led de Broglie to take a cue from the concept of standing waves in mechanical vibrations (violin strings, organ pipes etc.) and consider the possibility that the motion of electrons within an atomic orbit may be guided by some kind of waves which he called "pilot waves". Further de Broglie postulated that for stationary waves to be established, the wave length of the associated wave must be such that there are an integral multiple of them to fit exactly into the circumference of the orbit. De Broglie figured out that for the n[th] orbit, this relation would lead to

$$\lambda_n = \frac{nh^2}{2\pi m_e^2}$$

based upon Bohr's theory for the hydrogen atom that gave the relation

$$r_n = \frac{n^2h^2}{4\pi^2 m_e^2}$$

for the radius of the $n^{th}$ orbit, $h$ is the Planck constant, which had crept in from the restriction that Bohr had made that the angular momentum of the electron should be an integral multiple of $h/2\pi$, (Quantization rule assumed by Bohr). This gives for the velocity of the electron in the n[th] orbit the relation

$$\left(V = \frac{2\pi e^2}{nh}\right)$$

With these considerations, de Broglie deduced the relation $l = h/m_e v$ as the wave length of pilot wave associated with an electron of mass $m_e$ and velocity $v$ and generalized it to all particles of mass m by stating $\lambda = h/mv$.

Through a study of the scattering of electron beams in a crystal, Davisson and Germrer obtained a diffraction pattern of the electrons and established that electrons also behave like waves and the wave length corresponds to what de Broglie had calculated. Later Stern showed that Sodium atoms too behave in a similar manner.

This was another major revision of classical ideas of material particles and raised the question about what "reality" is? How can an entity be both—a particle and a wave?

In this context, Gamow and Cleveland say "Modern Physics extends its horizons far beyond everyday experience upon which all the "common sense" ideas of classical physics were based, and we are thus bound to find striking deviations from our conventional way of thinking and must be prepared to encounter facts that sound quite paradoxical to our ordinary common sense. In the case of the theory of relativity, the revolution of thought was brought about by the realization that Space and Time are not the independent entities they were always believed to be, but are the parts of a unified space-time continuum. In quantum theory we encounter a non-conventional concept of the minimum amount of energy, which although of no importance in the large scale phenomena of everyday life, leads to revolutionary changes in our basic ideas concerning motion of tiny atomic mechanisms".

## Elementary Particles and their Interactions

We have already talked about four elementary particles—the proton, the neutron, the electron and the photon. The protons and the electrons were discovered as elementary particles in the study of electrical discharge phenomena in gases. The analysis of the streams of particles that moved from the cathode to the anode, originally called Cathode rays, and the discovery that the individual particles carried the same charge as the hydrogen ions in electrolysis and that they had a mass about 1800 times smaller than the hydrogen atom, all led J.J. Thomson to conclude that these particles were the carriers of electricity everywhere and the name 'electron' was given to them. Around the same time in late 1890's, it was also discovered that there were also streams of particles of opposite charge in the discharge tubes which moved in the opposite directions from anode to cathode of discharge tubes. These were called Positive Rays. In 1898 Wien measured the charges and masses of these carriers by the method of electric and magnetic deflections. Each particle was found to carry a positive charge equivalent to the negative charge on the electron and had the mass of the hydrogen atom. Stripped of one electron the hydrogen atom had become a positive ion. The name 'Proton' was given by Rutherford much later in the early 1920's.

The second constituent of the nucleus, the neutron was discovered by Chadwick in 1932 at the Cavendish Laboratory. Bothe and Becker had observed in 1931, that when Beryllium was bombarded by a-particles, a highly penetrating radiation was produced. They had thought that this radiation comprised gamma rays. The very next year, Chadwick proved that this radiation emitted by beryllium consisted of material particles of the same mass as the hydrogen atom, and he gave the name neutron to these particles.

## Discovery of Mesons and Meson Theory

With the protons and the neutrons as the constituents of nuclei, the question arose as to how these are held together so closely despite the Coulomb repulsive force between the protons, compounded further by lack of any electrical force between protons and neutrons and neutrons and neutrons. In the early 1930's, Hideki

Yukawa of Japan proposed that the nuclear forces that held these particles in the nucleus were due to the exchange of heavy mass particles between them. These exchange particles were initially called Yukons and later the word Meson which meant a particle of mass intermediate between that of the proton and electron, became more popular and has stuck on.

Around the time Yukawa's theory was gaining ground, it so happened that a particle of mass intermediate between proton and electron was discovered in Cosmic rays in a cloud chamber by Carl Anderson, the discoverer of the 'positron' the anti-particle of the electron. Yukawa had persuaded in the light of his theory, his Japanese colleague Nishina to design an experiment to look for the Yukon. Despite being the second world war period, and facing acute shortage of electrical power for his magnet, Nishina did set up a cloud chamber experiment and recorded the existence of a particle of mass 200 $m_e$. By this time, the papers by Anderson and his collaborator Neddermayer and also by another group at Harvard, Street and Stevenson were published in the Physical Review.

Apart from the suggestion of Yukawa, the existence of a particle of intermediate mass had also been necessitated by the presence of a penetrating component in cosmic rays at mountain altitudes and sea level. From a systematic analysis of all cosmic ray data on the soft and penetrating components and from a critical assessment of quantum-electro-dynamics Homi Bhabha had in mid 1930's come to the conclusion that either quantum-electrodynamics breaks down at high energies or there should exist a particle of mass intermediate between proton and electron. The discovery of Anderson seemed to fit well with the requirement of Yukawa. However, the rather hasty identification of the Anderson meson with the Yukon created serious problems and confusion. It was found that the Anderson particle was very weakly interacting with nuclei, while Yukon had to be a strongly interacting particle. The spontaneous disintegration of the meson was theoretically predicted by Bhabha and others and the measured lifetime of the particle was about two micro seconds, however did not fit well with Yukawa's requirements of the nuclear force particle in terms of lifetime. The Yukon was to have a lifetime of the order of $10^{-8}$ seconds. These contradictions were resolved by the discovery by Powell and his collaborators of another meson heavier than what Anderson had discovered and which spontaneously decayed into the Anderson meson with a lifetime of $2 \times 10^{-8}$ seconds as required by Yukawa for the Yukon. It turned out that the meson of Powell was strongly interacting and agreed well the requirements of the particle responsible for nuclear forces. The heavier meson was called the 'pi-meson' and the lighter one the 'mu-meson'. Clearly the era of particle physics had begun. Very soon in cosmic rays several new types of mesons, and particles heavier than nucleon called hyperons were discovered. These were extremely short lived but they played an important role in focussing attention on the microworld of elementary particles and their interactions which, though not very much in the limelight of everyday experiences, have important controlling effects behind many natural phenomena. The list of elementary particles discovered in Cosmic rays is given in Table I. The particles discovered in cosmic rays range in their mass values from one electron mass to 2586 electron masses and the lifetimes of those which are unstable range from $2 \times 10^{-6}$ seconds to $10^{-17}$ seconds. They are all singly charged particles, some of them have half integral spin like the electron and the proton, and some '0' spin and some +1 and –1. The K-mesons which were the mesons to be discovered immediately after the Pi-meson, had a very strange property. They were always produced in association with another K-meson or a $\wedge$-particle which was a hyperon, a particle of mass higher than nucleon. This led Gell-Mann to postulate that there is a new conservation principle operating in the production of these particles and for this purpose he introduced a new parameter

TABLE I

Properties of elementary particles discovered in Cosmic Rays 1930-1955.
(Some of the properties listed—spin, lifetime, anti-particle, decay modes were determined later in accelerator experiments.)

| Name of Particle | Symbol | Strangeness no. | Anti-Particle Symbol | Anti-Particle Strangeness no. | Mass in terms of ($m_e$) | Spin | Charge | Lifetime in Seconds | Decay Modes |
|---|---|---|---|---|---|---|---|---|---|
| Positron | $e^+$ | 0 | $e^-$ | 0 | 1 | 1/2 | 1 | – | – |
| Muon | $\mu^-$ | 0 | $\mu^+$ | 0 | 207 | 1/2 | 1 | $2.2\times10^{-6}$ | $(e^- \nu_\mu \nu_e)$ |
| Pion | $\pi^-$ | 0 | $\pi^+$ | 0 | 273 | 0 | –1 | $2.6\times10^{-8}$ | $(\mu^- \nu_\mu)$ |
| | $\pi^0$ | 0 | $\pi^0$ | 0 | 264 | 0 | 0 | $8.0\times10^{-17}$ | $(\gamma \gamma)$ |
| Kaon | $K^+$ | +1 | $K^-$ | –1 | 966 | 0 | +1 | $1.2\times10^{-8}$ | $(\pi^+ \pi^o)$, $(\mu^+ \nu_\mu o)$, $(e^+ \pi^o \nu_e)$ |
| | $K^0$ | +1 | $\bar{K}_0$ | –1 | 974 | 0 | 0 | $K_S$: $9\times10^{-11}$<br>$K_L$: $5.4\times10^{-8}$ | $(\pi^+ \pi^-)$, $(\pi^0 \pi^0)$ $(\pi^0 \pi^0 \pi^0)$, $(\pi^0 \pi^+ \pi^-)$, $(\pi^- e^+ \nu_e)$ |
| Lambda Hyperon | $\lambda^0$ | –1 | $\wedge_0$ | +1 | 2183 | 1/2 | 0 | $2.5\times10^{-10}$ | $(P \pi^-)$, $(n \pi^0)$ |
| Sigma Hyperon | $\Sigma^+$ | –1 | $\bar{\Sigma}^+$ | +1 | 2328 | 1/2 | +1 | $8.0\times10^{-11}$ | $(P \pi^0)$, $(n \pi^+)$ |
| | $\Sigma^0$ | –1 | $\bar{\Sigma}^0$ | +1 | 2334 | 1/2 | 0 | $10^{-14}$ | $(\wedge^0 \gamma)$ |
| | $\Sigma^-$ | –1 | $\bar{\Sigma}^-$ | +1 | 2343 | 1/2 | –1 | $1.5\times10^{-10}$ | $(n \pi^-)$ |
| Cascade | $\equiv^0$ | –2 | $\equiv^0$ | +2 | 2573 | 1/2 | 0 | $3.0\times10^{-10}$ | $(\wedge^0_0 \pi^0)$ |
| | $\equiv^-$ | –2 | $\equiv^-$ | +2 | 2586 | 1/2 | –1 | $1.7\times10^{-10}$ | $(\wedge^0 \pi^-)$ |

called "strangeness quantum" number and as can be seen from the table excepting the electrons, μ-mesons and pions, all the others have strangeness quantum numbers associated with them. While the strangeness quantum number is conserved in production (in strong interaction) as can be seen from the table itself, this is not so in the case of spontaneous decay (weak interaction).

**Meson and Baryon Production**

The various particles discovered in cosmic rays were all produced in the nuclear collisions of the very high energy incoming cosmic rays (protons, α-particles and other nuclei) with the nuclei of air. Depending on the energy of the incoming cosmic ray, the number of secondaries produced could be anywhere from a few to several hundred in a single collision.

Among the secondaries produced the most abundant were the Pi-mesons. Next in abundance were the K-meson and hyperons. A new feature that was discovered was that in addition to the particles, their anti-particles (see the table) were also produced, but the strange aspect was that in these collisions electrons, Mu-mesons, and photons were not produced. Nucleon-Anti-nucleon pairs were produced in large numbers at higher energies. The lighter particles, the electrons and Mu-mesons were produced in the decay of the π-mesons and K-mesons. The decay of the neutral $\pi^0$ mesons gave rise to ϒ-rays. A very interesting development followed the observation of two types of decay of the K-meson. Sometimes the K-meson would decay into two particles and sometimes into three particles. This created complication for a feature known as parity conservation. The violation of this parity meant that the laws of physics were not the same when the observation was made in a mirrored system. This was a very strange result, and two Chinese-American theoretical physicists Lee and Young made the bold hypothesis that in weak interactions i.e., the spontaneous decay of particles, 'parity' is not conserved. The violation of parity was confirmed experimentally by a Chinese-American Scientist madam Wu at the Columbia University, New York.

**The Mysterious Neutrino**

The neutron, one of the constituents of all nuclei, when free decays into a proton and electron and another neutral particle. The existence of this neutral particle called the neutrino was proposed by Wolfgang Pauli to save the principle of Conservation of Energy in the decay of the neutron. The detailed theory of β-decay of the neutron based on Pauli's proposal was worked out by Fermi, who gave this neutral particle the name 'neutrino'. Apart from the fact that the particle had no charge, the neutrino had to have either 0 mass or a very small mass compared to the lightest of all material particles, the electron. Though the neutrino was predicted in the 1930's, it was only in the early 1950's, after the advent of nuclear reactors that the particle was experimentally detected, by Reines and Cowan. It turns out that the neutrinos like the μ-mesons are produced only in the decays of fundamental particles, as can be seen from the table. The neutrino which has half-integral spin, also serves the other important purpose of spin conservation. The neutrino has also, like all other particles, an anti-particle called the anti-neutrino, whose spin direction is always anti-parallel to the direction of motion. As we shall see later, accelerator experiments have revealed that there are three different types of neutrinos—the electron neutrino $\upsilon_e$, the muon neutrino $\upsilon_\mu$ and the Tau neutrino $\upsilon_\tau$ and corresponding anti-neutrinos. The $\upsilon_\mu$'s were produced in the decay in mu-mesons and $\upsilon_\tau$ in the decay of τ-mesons. Being the decay products of so many particles, the neutrinos are in abundance in cosmic rays. Since they are very weakly interacting, they can go through the earth without suffering any interaction and energy loss. The first detection of Cosmic ray muon neutrinos was done in India in the Kolar Gold Mines at a depth of 8000 ft. below ground in 1965 with a very large scale set up. The neutrinos have a great astrophysical significance too. The Sun is an abundant source of neutrinos produced in the fusion reaction—conversion of hydrogen to helium in the core of the sun. A serious anomaly has cropped up with regard to the recorded flux of solar neutrinos ($\upsilon_e$'s) on the earth. Measurements carried out in a mine in the US revealed that the observed flux is lower by a factor of 3 compound to the calculated flux. The solar physicists are quite confident that their calculations cannot be wrong. To resolve this discrepancy one of the proposals is that there could be an oscillation of one flavour of neutrino say the $\upsilon_e$ to another flavour $\upsilon_{\mu,\tau}$. Such an oscillation with favourable oscillation length would remove the discrepancy by a factor of 2. However, this would demand that one of the flavours has to have a finite mass. While there is some indication from some cosmic ray experiments carried out underground in Japan that such an oscillation is taking place, the question is not fully settled. There is another context in which the neutrino mass problem has become very crucial. This is in connection with the so called 'missing mass' problem of the universe which we will come to later on.

**Particle Physics at Accelerators**

The discovery of so many new particles in cosmic rays particularly during the period 1945-55 motivated the construction of higher and higher energy accelerators; this paid off rich dividends through the discovery of many more new particles and high energy processes and served to delve deep into the structure of matter at the most fundamental levels, and understand the nature of the forces operative at the subatomic levels and finally to formulate a grand theory of particle physics known as the Standard Model. This model has evolved out of the close collaboration between theoretical physicists and experimentalists.

A very large number of elementary particles, running into several hundreds have been discovered over the past fifty years. Many of them belonged to the class of mesons and many were baryons and the rest called "resonances", had all fundamental particle identities like mass, spin, change strangeness number etc, but decayed away into other particles in times of the order of $10^{-23}$ seconds or less. A vast majority of them belonged to the class of strongly interacting particles given the general name hadrons. With such large number of particles with varying properties, all qualifying to be fundamental, it became necessary to classify them in some order. We have seen that the first classification was according to whether their mass is higher or lower than the nucleons. The higher mass particle were called hyperons and those of lower mass mesons among strongly interacting particles—the hadrons. A parameter called isotopic spin was introduced by Heisenberg to distinguish between particles that had the same mass, but different charge-states like proton and neutron, $p^+$ , $p^0$ and $p^-$ etc. The number of charge states was 2I+1 where I was the Isotopic spin. The notation Z-component of I was introduced to distinguish between the different charge components. We have

TABLE II

Isotopic Spin, Z-component of Isotopic Spin and Strangeness number for Mesons and Baryons.

| Particles | Isotopic Spin | Z-component of Isotopic Spin | Strangeness |
|---|---|---|---|
| $\pi^+$, $\pi^0$ and $\pi^-$ | 1 | 1, 0, –1 | 0 |
| $K^+$, $K^-$ | ½ | ½, –½ | +1 |
| $K^+$, $K^0$ | ½ | –½, ½ | –1 |
| P, n | ½ | ½ –½ | 0 |
| P, ñ | ½ | –½, ½ | 0 |
| $\Lambda^0$ | 0 | 0 | +1 |
| $\Sigma^+$, $\Sigma^0$, $\Sigma^-$ | 1 | 1,0, –1 | –1 |
| $\Sigma^+$, $\Sigma^0$, $\Sigma^-$ | 1 | –1, 0, 1 | +1 |
| $\equiv^-$, $\equiv^+$ | ½ | –½, ½ | –2 |
| $\Xi^-$, $\Xi^+$ | ½ | ½, –½ | +2 |
| $\Omega^-$ | 0 | 0 | –3 |
| $\Omega^+$ | 0 | 0 | +3 |

already seen that some particles were always produced in pairs though they belonged to different category. The strangeness quantum number was introduced by Gell-Mann for this purpose and the Conservation of strangeness quantum number was strict in strong interactions i.e. production of particles, while it was not necessary in weak interactions.

Table II gives the values of these parameters for some of the mesons and baryons.

$\Omega^-$ was predicted by Gell-Mann and was discovered later at the accelerators in the interaction $K^- + P = \Omega^- + K^+ + K^0$ involving the production of three strange particles and requiring conservation of strangeness. Since $K^-$ has strangeness –1, and $K^+$ and $K^0$ have strangeness of $K^+$ is +1 and $K^0$ also +1, the $\Omega^-$ disintegrates in three stages as follows:-

$$K^- + P = \Omega^- + K^+ + K^0$$

$$\searrow \; \Xi^0 + \pi^-$$

$$\searrow \; L^o + \pi^0$$

$$\searrow \; P + \pi^-$$

The identification of $\Omega^-$ required this three cascade decay to be registered and was achieved.

## Quarks

One of the anomalies that had been noticed, particularly after the discovery of a large number of hadrons among the elementary particles, was the lack of proliferation of light weight particles called the Leptons. The only particles discovered among the non-interacting leptons were $e^-$, $e^+$, $\mu^+$, $\mu^-$, $\nu_{e,}$ $\nu_\mu$, $\nu_{e,}$ $\nu_\mu$,. To resolve this discrepancy, Gell-Mann put forward in 1964, the "quark hypothesis" which assumed that all hadrons consist of few elementary "building blocks" called quarks and the number of quarks should be equal to the number of leptons, thus ensuring quark-lepton symmetry.

In 1964, when the quark hypothesis was first proposed by Gell-Mann and Zweig, they had thought that three quarks (u, d, s) and three antiquarks (u, d, s) standing for up-quark, down-quark, and strange-quark and their corresponding anti-particles would be sufficient to build all the known particles and anti-particles among the hadrons. The quarks and antiquarks had to have special properties which are given in the following table.

TABLE III
Quarks and Anti-quarks.

| | | Electric Charge | Baryon Number | Z Component of Isospin | Strangeness |
|---|---|---|---|---|---|
| Quark | u | +2/3 | +1/3 | + 1/2 | 0 |
| | d | −1/3 | +1/3 | − 1/2 | 0 |
| | s | −1/3 | +1/3 | 0 | −1 |
| Anti-quark | $\bar{u}$ | −2/3 | −1/3 | − 1/2 | 0 |
| | $\bar{d}$ | +1/3 | −1/3 | + 1/2 | 0 |
| | $\bar{s}$ | +1/3 | −1/3 | 0 | +1 |

Quark Structure of Baryons and Mesons

| P | N | $\Lambda^o$ | $\Sigma^+$ | $\Sigma^o$ | $\Sigma^-$ | $\Xi^o$ | $\Xi^-$ | $\Omega^-$ | $\pi^+$ | $\pi^-$ | $K^+$ | $K^o$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| uud | udd | uds | uvs | uds | dds | uss | dss | sss | ud | ud | us | ds |

u = up-quark, d=down-quark, s=strange-quark

The interesting facts to note are that the quarks and antiquarks have fractional charges and fractional baryon numbers. There are also strange quarks and antiquarks. All the quarks are fermions with spin 1/2. The s-quark has strangeness quantum number −1.

Later experiments showed that there has to be a further elaboration of the quarks. Each quark (and antiquark) has attached with it another parameter that has been given the name colour—thus there is red u-quark, a yellow u-quark and a blue u-quark. Similarly the other d and s have the three colours. Each baryon is made of 3 quarks of different colours, the baryons by themselves having no colour attached to them. A surprising feature is that despite considerable effort, free individual quarks have not been recorded in any experiment so far. The signature of fractional change which they possess is one that makes detection of free quarks easy. While no free quarks were observed, scattering experiments with high energy electrons on nucleons somewhat reminiscent of the way Rutherford established the existence of nuclei with-in atoms, conclusively proved that there are three scattering centres in each nucleon as required in the quark theory. Confirmation also came from another direction—from the discovery of yet another type of new particles called "Charm Particles".

Towards the end of 1974, a new particle of mass about 6000 $m_e$ with a lifetime for decay of $10^{-20}$s was discovered almost simultaneously at two American accelerator centres, Brookhaven in the east coast and in Stanford in the west coast.

The east coast discoverers called it J and the west coast scientists called it $\psi$ for no particular reason. Hence the name J/$\Psi$ has stuck on. J/$\Psi$ is a neutral particle. To account for the properties of particles a new quark called Charm quark c had to be introduced in addition to the prevalent three quarks u, d and s. It was necessary also to assume that like parity and strangeness, charm also had to be conserved in particle production interactions, and also in electromagnetic interactions, but not in weak interactions. The electric charge of the new c-quark is +2/3. The quark structure of the J/$\Psi$ was $c\bar{c}$ and is naturally given the name Charmonium. Charmonium has higher level energy states called $\psi$, $\chi_0$, $\chi_1$, $\chi_2$ etc.

In 1976, another meson the $D^0$ meson was discovered with the quark structure (cu) and later in 1977 $F^{\pm}$ meson which had the quark structure (cs). A long time after the discovery of the three leptons electron, muon and neutrino, yet another called $\tau$-meson was discovered in 1975. It had a mass around 3500 $m_e$. Still it belongs to the class of leptons because of other properties. The assumption had to be made in the light of the existing theories that there must be a corresponding $\tau$-neutrino. Experimentally, $\tau_u$ has not been directly discovered yet.

Further experiments at accelerators have shown that there are two more very heavy mass quarks—one called the beauty quark (also called bottom quark) b and the other true quark (or top quark) called t. The beauty quark b has a mass ~10,000 $m_e$ and charge – 1/3, The $b\bar{b}$ meson has a mass of ~20,000 $m_e$.

## SPACE, TIME, MATTER AND FORCE UNDER THEORIES OF RELATIVITY

### (a) Special Theory of Relativity

In the previous sections, we have seen how the scientific efforts of the 19th and 20th centuries to understand the properties of the structure and properties of matter and radiation, gradually led to the discovery of the microworld of molecules, atoms and elementary particles as technological abilities enabled the probing of smaller and smaller entities. We also saw that this reductionistic drive led us finally to recognise that the ultimate concept of all matter are two species of particles quarks and leptons with specific well identified intrinsic properties like mass charge, spin and interaction characteristics. In dealing with these particles, we have accessed regions of space smaller than $10^{-16}$ cms and intervals of the order of $10^{-23}$ seconds. Four very different types of interactions have been identified which account for most of the phenomena which we encounter in everyday life and also in some of the specially created laboratory conditions and also many celestial phenomena. The four forces are Gravitational force, Electro-magnetic Force, Weak force and Strong force. Of these the gravitation and electro-magnetic forces are long range forces and the weak and strong forces are extremely short range. What is most interesting is that the very concept of force and the way it is mediated has totally changed over the past hundred years, especially with the advent of relativity and quantum mechanics and a closer link has been established with happenings in space and time.

While the concept of force is an anthropomorphic one, which probably arose with the muscular strain experienced while lifting a heavy weight or pushing a loaded cart, the scientific quantification concept of force was introduced by Newton through the two relations

(i) $F = ma$,

where $F$ is the force, $m$ the mass and $a$ is the acceleration of the particle

(ii) $F = G\frac{m_1 m_2}{r^2}$

where $m_1$ and $m_2$ are the masses of two particles and $r$ is the distance of separation and $G$ is the constant of proportionity. While Newton's gravitation equation stipulated the distance dependence of the force, there was no indication from his theory how this force was mediated between the two objects. In the case of the astronomical objects, say the Sun and the Earth held together by the gravitation force between them the distance will be as large as 89,280,000 miles.

Regarding this action at a distance and the mechanism of gravity, Newton's views have been stated by Sir Edward Whittaker in his book "From Euclid to Eddington", as follows: Newton's views as to the mechanism of gravity have been preserved in Query 21 of his "optics" and his letters to Bentley and Boyle.

Having postulated an ether pervading all bodies and all space, he proceeds: "Is not this Medium much rarer within the dense bodies of the *Sun, Stars, Planets, and Comets,* than in the empty celestial spaces between them? And in passing from them to great distances, doth it not grow denser and denser perpetually, and thereby cause the gravity of those Bodies towards one another and of their parts towards the Bodies; every Body endeavouring to go from denser parts of the Medium towards the rarer?" Whether this might be true explanation or not, at any rate he says, 'to suppose that one body must act on another at a distance through vacuum without the mediation of anything else ... is to me so great an absurdity, that I believe that no man who has in philosophical matters a competent faculty of thinking can ever fall into'.

Even in subsequent years no one succeeded in formulating a mechanical picture of action of gravity.

This mysterious Medium ether turned up again and again in several contexts. Leibnitz introduced the idea of Kinetic Energy, visvive the quantity obtained by multiplying the mass of the particle by the square of the velocity of the particle, followed by John Bernouli with the principle of conservation of energy (conservatio virium vivarum) and Rankine the concept of potential energy. The conservation principle was extended to the field of optics by Fresnel who had supposed that light consists of vibrations of 'aether', though the nature of aether itself was not clear. The vibrations of aether helped him to formulate equations similar to ordinary dynamics for the case of light rays, in dealing with reflection and refraction properties. While tackling the problem of the potential energy associated with electric and magnate charges, Thomson showed that the energy was not in the magnets or electrified bodies, but in the fields surrounding them and this led Maxwell to propose the electromagnetic theory of light. To explain the propagation of electromagnetic waves, Maxwell tried very hard to invoke the mechanical properties of aether—the elastic deformities, but was unsuccessful.

The concept of aether despite so many negative aspects was not given up since it had provided the possibility of a mechanical model for all physical phenomena and also served as a fixed frame of reference for all motion. It had not been possible, however, to provide experimental proof of its existence. A.A. Michelson and Morley carried out a classic experiment at Cleveland, USA, in the year 1881. The experiment was based on the sample principle; if all space is simply motionless aether, then the earth's motion through this aether should be measurable in the same way as one can determine the velocity of a ship sailing in water. The velocity of the earth in its orbit around the Sun is about 20 miles per second. If a light beam is sent against the aether stream, then its velocity would be reduced from 186,284 miles per second to 186,264 miles per second while a light beam sent with the aether stream would be 186,304 miles per second. Setting up a light interferometer with a system of mirrors, Michelson and Morley tried to measure the expected difference in the light velocities on this assumption of a stationary ether (for the source of light they used a distant star). The experimental results conclusively showed that the light beam travelled with the same velocity regardless of the directions.

The negative results could be interpreted on the basis of two alternatives. One was that the earth itself was stationery and did not move which was against the well established Copernican theory of the motion of planets and the other was to give up the aether theory.

The results also meant that light, as an electro magnetic wave had a peculiar feature; its velocity did not follow the theory of addition of velocities which had been the basis of Newtonian Dynamics.

It is in this context that Einstein formulated his special theory of relativity; completely transforming the concepts of space and time that had been prevalent till that time. Space and time are concepts that are drawn into the field of scientific explanation on the basis of everyday experience of phenomena occurring around us. In our minds, space is characterized by emptiness and is essentially regarded as plenum for matter to occupy. Time is an entirely different kind of experience and the flow of time is considered to be independent of us. In Newtonian Dynamics, space and time are independent of each other. Time is universal and rate of flow of time is the same everywhere, wherever we go in the universe. All these ideas had to be changed to account for just one observed fact that velocity of light is independent of the motion of the source or the observer as revealed by the Michelson and Morley experiment and those that followed.

Einstein said, "We can do away with the aether, velocity of light may be regarded as a constant of nature independent of the motion of the source or the observer. But, we have to give up our conventional ideas of space and time". According to Einstein "The laws of science should be the same for all freely moving observers no matter what their speed" Formulating the special theory of relativity, he stated:

(1) There is no absolute time; space and time have to be fused into four-dimensional space-time continuum.
(2) Space contracts and time dilates in a moving medium—the extent depends on the velocity.
(3) Idea of simultaneity has no longer any meaning.

These new ideas themselves were revolutionary and contrary to common sense and daily experience. However, they were all verified to be true by a set of beautiful experiments in the following years. They also led to other important consequences—Mass and Energy, though distinctly different concepts till then, were shown to be equivalent and the famous relation $E=mc^2$ was given by Einstein connecting these entities. As is well known, it is this equation that enabled the realization of the Atom Bomb and all the peaceful uses of atomic energy. This equivalence of mass and energy also meant that the two principles, conservation of mass and conservation of energy as two distinct and separate laws of nature, had to be combined into one principle of conservation of mass and energy.

This principle of equivalence of mass and energy and the possibility of transformation of one to the other gave an insight into the mechanism of stellar energies and to the physical possess going on in the interior of stars.

It is extremely interesting and instructive for us to familiarize ourselves with the novel methodology by which a concept like time dilation due to motion could be verified. We saw in the previous section that the penetrating charged component of cosmic radiation is a particle called the $\mu$-meson, which is the spontaneous decay product of the Pi-meson produced in high energy nuclear collisions of the primary cosmic rays with air nuclei. The m-meson itself is an unstable particle and decays into an electron and neutrino and an antineutrino. In its own rest system, the Mu-meson has a half-life of 2.2 microseconds. This can be measured by bringing the meson to rest in the laboratory in a medium like carbon. Even though its life time is 2.2 microseconds, it is found that in the atmosphere it is able to travel the entire length of more than 10 kms from the point of production to the point of decay, moving almost with the velocity of light the time taken is of the order of 33 microseconds. How does it do it? This happens because of relativistic time dilatation. It is shown in the theory of relativity that the dilatation factor is given by $E_\mu/m_\mu c^2$ where $E\mu$ is the energy of the μ-meson and $m_\mu$ is the rest mass of the m-meson. In the case we are considering, if the μ-meson has to live for more than 30 microseconds, then its energy must be more than 300 mev.

Another important consequence of relativity theory was that the mass of a particle increases with velocity and as velocity approaches the velocity of light, the mass becomes infinite. This fact ensures that no particle can travel with a velocity faster than that of light.

In the context of the finiteness of the velocity of light and its independence of the motion of the observer, the meaninglessness of simultaneity may be explained in the following way: Suppose you are standing in a railway platform and you notice with the help of a system of 45° inclined mirror right in front of you, two lightning flashes occurring at the same time, and you make a note of the exact time. Let us further suppose that the lightning flashes have occurred exactly on the railway lines and at the same distance from you. Next suppose there is another observer, perched on the top of a fast moving train and he crosses you at the same instant when you saw the two simultaneous flashes. The question is whether the moving observer on the train equipped with a similar mirror device will observe the flashes at the same instant as you. The answer is No, since the train is moving with a velocity it is moving away from one flash and towards the other. Naturally the meeting point of the lights from the two flashes for him will be closer to the point the train is approaching and away from the other.

The flashes meet for the moving observer at a different location and time. In the extreme case of the train moving with the velocity of light, the light from hind direction will never reach the observer on the train, and he will maintain that he saw only one flash the one from the front. For any other lower velocity of the train, the observer will say that the flash from the direction ahead of him struck first and the one from behind later. Consequently in relativity, we have the strange concept of 'relativity of simultaneity'!

If phenomena of nature have to be accounted for in terms of uniform and consistent laws, then according to the special theory of relativity, the measures of distance and time are variable quantities. The relations that connect these variable quantities are known as the Lorentz transformations, in which the unchanging quantity is the velocity of light c.

Table IV
Lorentz Transformation

| | |
|---|---|
| $x^1 = \dfrac{x - vt}{\sqrt{1 - v^2/c^2}}$<br>$y^1 = y$<br>$z^1 = z$ | $x^1y^1z^1,t^t$ coordinates in moving frame with a velocity v |
| $t^q = \dfrac{t - (v/c^2)}{\sqrt{1 - v^2/c^2}}$<br>$m^1 = m^0 \Big/ \sqrt{1 - v^2/c^2}$ | x,y,z,t coordinates in the system at rest.<br>c = velocity of light.<br>$m^1$ = mass at velocity v<br>$m^0$ = rest mass |

The Lorentz transformation equations show that when the velocity v is very small compared to the velocity of light, the transformation equations reduce to those earlier equations based on the principle of addition of velocities. On the other hand, when the velocity is comparable to that of c, radical transformations take place in the distance and time intervals.

Another interesting consequence of the theory of relativity is the variation of the mass of a particle with velocity. It can be seen that as the velocity approaches c, the mass become large and larger and at c, any particle with finite rest mass, becomes one with infinite mass. This naturally sets the limit to the velocity of any particle to the value c.

Interestingly this increased mass with velocity is what led Einstein to deduce the equation $E=mc^2$. The increased mass could only be attributed to the increase in energy at higher velocities.

All the consequence of the special theory of relativity have been beautifully confirmed by ingenious experiments. What this theory highlights is that the old Newtonian Dynamics based on ideas of absolute space and absolute time is not adequate to describe phenomena at high velocities which is necessarily the case in the atomic world and in the realm of elementary particles. The velocities of electrons in the atomic orbits and of the protons and neutrons inside the nuclei are very high and comparable to the velocity of light.

### (b) The General Theory of Relativity

While the special theory of relativity brought about radical transformation of our concepts of space, time and matter, established the equivalence of mass and energy and had profound relevance to phenomena associated with very high velocity particles, the general theory of relativity by Einstein completed by 1917, went deeper into the structure of space, time, matter and force and gave insights that had significant implications to the origin of the universe and the large scale phenomena in the universe filled with celestial objects and environments very different from those encountered in our daily experience, on earth and its immediate surroundings.

It is known from the time of Galileo and Newton that all objects fall to the earth when thrown up, at the same rate, regardless of their inertial mass. It is also known from Newton's second law that the force acting on a body is proportional to the mass. Since all the bodies fall at the same time and have therefore the same acceleration, it is obvious that Gravitation and Inertia are at perfect balance in the case of falling bodies. How can this be explained? For almost three hundred years this had remained a puzzle. Einstein did not believe that this coincidence was just an accident, nor did he like the idea of instantaneous gravitational interaction between bodies separated by such large distances as the Earth and the Sun. He developed a new ingenious theory of gravitation instead. Einstein did this again with recourse to a gedanken experiment—an imaginary experiment, as he did in the case of special theory.

Imagine that you are inside a completely closed, freely falling elevator which is coming down under the action of the earth's gravity. Now you start dropping things from your pocket—say a kerchief, a key bunch, a fountain pen, a coin, etc. You find that none of them would fall to the ground of the lift and stay wherever you released them. You feel that you have moved out into outer space, for away from domain of the gravitation of the earth. If you try to push things horizontally, then you find that they are obeying the usual Newton's laws in an inertial frame. What is a freely falling elevator under the action of gravity for an observer on the earth outside the lift, behaves exactly like an inertial system for the observer inside. The reverse situation can also be imagined. If in an outer space environment where there is no action of gravity, the same elevator with you inside is pulled up with an acceleration equal to the gravitation as acceleration of a freely falling body, you start feeling that gravity has appeared. Things start falling down, there is upward pressure on your feet, and so on.

From such simple considerations, Einstein demonstrated the equivalence of gravitation and inertia in the case of accelerating systems.

The gravitation force of Newton was based on the assumption that material bodies attract each other under the influence of this force. According to Einstein gravitation is not a force. The movement of material bodies stems from their inertia and their path is determined by the properties of space and time around the bodies—more appropriately of the space-time continuum. Unlike that of Newton the law of gravitation that Einstein formulated contains nothing about the force, but gives a quantitative description of the gravitational field at various locations, analogous to the magnetic and electric forces in the terms of the fields around magnets and electrically charged bodies. The characterisation of the field is nothing but the characterisation of the space in all these cases. According to the general theory of relativity, it is not that matter is housed in a space-time continuum which in turn is influenced by the matter itself in its surroundings. On the contrary, matter itself is regarded as equivalent to curvature of space—the substratum is space-time continuum. While curvature of space gives rise to matter, what about its effect on time? Einstein showed that the gravitation field has an effect on time too. He showed that the time interval also varies with the gravitational field. A terrestrial clock transported to the Sun runs at a slightly lower rhythm than on earth. This would also mean that the frequency of light emitted by an atom say of hydrogen, in the neighbourhood of the Sun would be lower than the frequency emitted by a hydrogen atom on the earth. This shift in frequency is quite small and may be difficult to measure. However, if you consider say the companion star of Sirus (the brightest star in the sky), then the gravitational red shift can be quite appreciable and measurable. This is because of the very high density of the star (white dwarf) which is as much as a ton per cubic centimetre, while its diameter is only three times that of the earth.

The concept of the universe as matter floating in the infinite sea of space had to be modified in the light of Einstein's general theory of relativity. Unlike his predecessors, Einstein did not believe that the universe was infinite and the geometry that defined space was Euclidean. He had shown that the geometry was not Euclidean in a gravitational field and the predicted bending of light in the gravitational field of the sum had been confirmed by experiments carried out at the time of solar eclipse. According to the new ideas of Einstein, the gravitating bodies like the earth, the Sun, the planets, the stars, the galaxies, determined the geometrical structure of space—the local irregularities in space-time—and this resulted in an overall curvature of space-time continuum. All this resulted in a curved universe of finite dimension. But the curved universe though finite is unbounded. The emerging picture of such a universe is described by Sir James Jeans as follows:

> A Soap-bubble with corrugations on its surface is perhaps the best representation, in terms of simple and familiar materials of the universe revealed to us by the theory of

> Relativity. The universe is not the interior of the soap bubble but its surface and we must remember that while the surface of a soap bubble has only two dimensions, the universe bubble has four- three dimensions of space and one of time. And the substance out of which this bubble is blown, the soap film, is empty space welded onto empty space.

It is extremely difficult, nay impossible to visualize this modern concept of space. However it can be represented mathematically and the consequences on natural physical phenomena in the universe tested. This situation is not different from the difficulty we have in envisaging the fundamental particles and their interactions. There also we can only observe their effects in large scale phenomena. We can never even imagine how they really are.

## The Dirac Vacuum—anti-particles

In the section on elementary particles, we have made a reference to antiparticles without considering in detail how they arise and in what way they are different from normal particles. Considerations on antiparticles is extremely important from the point of view of understanding the structure of empty space—the quantum mechanical vacuum.

In the late 1920's, Dirac formulated the quantum mechanical equation for relativistic electrons and found to his surprise that the solution of the equation gave both positive and negative energy states for the electrons. Without disposing off the negative energy states as unphysical and therefore not to be considered further, Dirac tried to find a meaning to these legitimate mathematical solutions. He made the bold assumption that what we regard as normal vacuum is not empty, but is filled with these negative energy electrons without any vacancy in the allowed states according to his equation and there could be infinite number of them. Normally they are not observable. They become observable only when a vacancy arises which can happen either by spontaneous fluctuation or by deposition of sufficient positive energy in an extremely small region of space. When a vacancy does arise by the removal of a negative energy electron to a positive energy state—to that of a normal electron, something very strange happens. The vacancy will behave like a positively charged particle with a positive energy and this should become detectable. Thus in this process a pair of electrons—one the normal negatively charged electron and the other a positively charged electron the 'hole' in the Dirac sea—the 'positron' as it came to be known later are produced. This is the phenomenon of pair creation. The positron as a positively charged equivalent of the electron and the phenomenon of pair creation were almost simultaneously observed in the studies on cosmic rays. It also became clear in subsequent years that corresponding to every known fundamental particle there is an antiparticle. So the Dirac Vacuum was filled with not only negative energy electrons, but also with the negative energy states of all the fundamental particles discovered so far. Further, with the concept of exchange of particles, the bosons namely the photons, the $W^{\pm}$ and the gluons as the mediators of the electromagnetic, weak and strong forces created as virtual particles in the vacuum between the particles on which the forces are acting, the material constituents of the universe and the forces all reduced to the activity of this substratum—the quantum mechanical vacuum—or empty space in the normal parlance. While the need for identifying the four-dimensional space-time continuum of relativity with the Dirac Sea of fundamental particles is obvious there are still some technical difficulties connected with quantization of gravity. Also experimental detection of gravitons , the particles that have been postulated to mediate gravitational force has not been feasible yet, though there are considerable international collaboration efforts towards this. The connection between elementary particles, quantum mechanics and gravitation will become obvious in the next section.

## THE FIRST MOMENTS OF THE UNIVERSE*

Does the Universe have a beginning? If so, When? And How did this happen?—are the questions that have engaged the consideration of mankind for thousands of years. The concept of the Universe itself has undergone radical changes with the passage of time, especially after discovery of telescope and the applications of spectroscopy for the analysis of the light received from different celestial objects. Developments in the field of Astronomy since the beginning of this century especially after the commissioning of the large telescopes, and the advent of radio and space astronomies, have made us realise the vast dimensions of the Universe and the existence of totally new environments very different from our experiences on the earth. The recent astronomical observations together with advances in the field of High energy and Elementary Particle Physics, have led to plausible theories on the origin of the Universe and its probable evolutionary course. The two most important astronomical discoveries of relevance in this context are:

(1) the discovery of the general expansion of the Universe, and

(2) the discovery of the Universal Microwave Radiation.

While the first led to the postulation of the Big Bang theory of origin, the second provided the strongest support for this theory. When we talk of the "the first moments of the Universe", it is with reference to the Big Bang.

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## *2. The Structure and Composition of the Universe*

Figure-1 summarizes in a way our current knowledge regarding the composition, the distance scale, and the relation between the size and mass of the different constituents of the Universe.

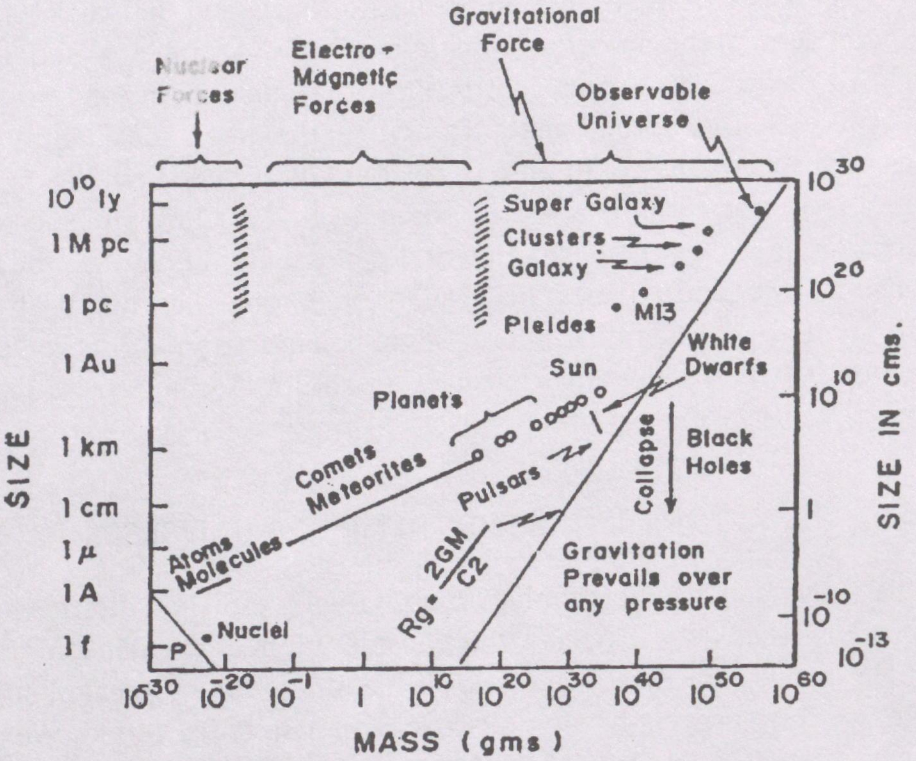



Fig. 1. Mass and size of the structural units of the universe (From Kleczek—*The Universe*).

The mass range of the structural units extends from $10^{-24}$ gms (mass of the nucleon) to $10^{56}$ gms, which is the total mass of the observable Universe. The corresponding size range is $10^{-13}$ to $10^{20}$ cms, with the hierarchy of celestial objects like Comets, Meteorites, Planets, Stars, Cluster of Stars, Galaxies and Cluster of Galaxies falling in between in terms of size and mass. It is also to be noted from the figure that majority of the objects populating the Universe satisfy the relation

$$Rg > \frac{2GM}{c^2}$$

It is only in recent years that the evidence has started accumulating on collapsed objects like Neutron Stars and Black Holes which fall in the category

$$Rg \leq \frac{2GM}{c^2}$$

The Universe in addition is also filled with photons, neutrinos, antineutrinos, electrons and positrons, which also play a major role in the history of the Universe.

### *3. The Expanding Universe*

Our current ideas on the origin of the Universe have arisen essentially out of parallel developments and the confluence of theoretical ideas stemming from the general theory of relativity and the astronomical observations made with the giant optical telescopes during the period 1917-1930.

Einstein had realised the implications of his general theory of relativity to the Cosmological problem and since at that time, the Universe was believed to be unchanging and static, had introduced the idea of a Cosmological repulsive force effective at very large distances, to overcome the attractive forces of gravity—Einstein had exchanged his ideas on this subject with de Sitter who came to the conclusion that Einstein's equations lead to an unstable exponentially expanding Universe. The Soviet scientist Alexander Friedman found a flaw in Einstein's solution (which Einstein conceded later) and was the first to emphasise that the Universe is expanding and is associated with a hyperbolic velocity space. In 1925, Lemaitre traced this expansion back in time to the explosion of a "superdense atom"—the first germ of an idea of the Big Bang creation. In 1928 Robertson drew attention to the Cosmological Red Shift that would result from such an Universal expansion.

Around the same period , the 60" and 100" telescopes in California were being used by Slipher and Hubble to explore and understand the structure of the bright patches in the sky—the Nebulae. They arrived at the unexpected and fascinating result that these are discrete galaxies composed of large number of Stars, similar to our own galaxy. Their observations led to another fundamental aspect of the Universe that these galaxies are receding from us—the greater the distance of a galaxy from us, the greater is its velocity of recession as revealed by the red shift of the spectral lines $\nabla \lambda/\lambda = Z = kr$.. Assuming that the observed red shift is due to Doppler effect, Hubble deduced the famous relation v=Hr where H is the Hubble's constant and v is the velocity of recession.

Figure-2 shows the current status of this relation between the red shift and the distance of the galaxy expressed in terms of brightness magnitude. Hubble's original data corresponded to a very small range of distances. The Validity of Hubble's relations is now established over a wide range of distances by Sandage.

It is most important to realise that this general expansion of the Universe is discernible only over distance scales of 100 to 300 megaparsecs (1 megaparsec ~ $10^{24}$ cms). On this scale the number of Stars, and Galaxies is the same, in any

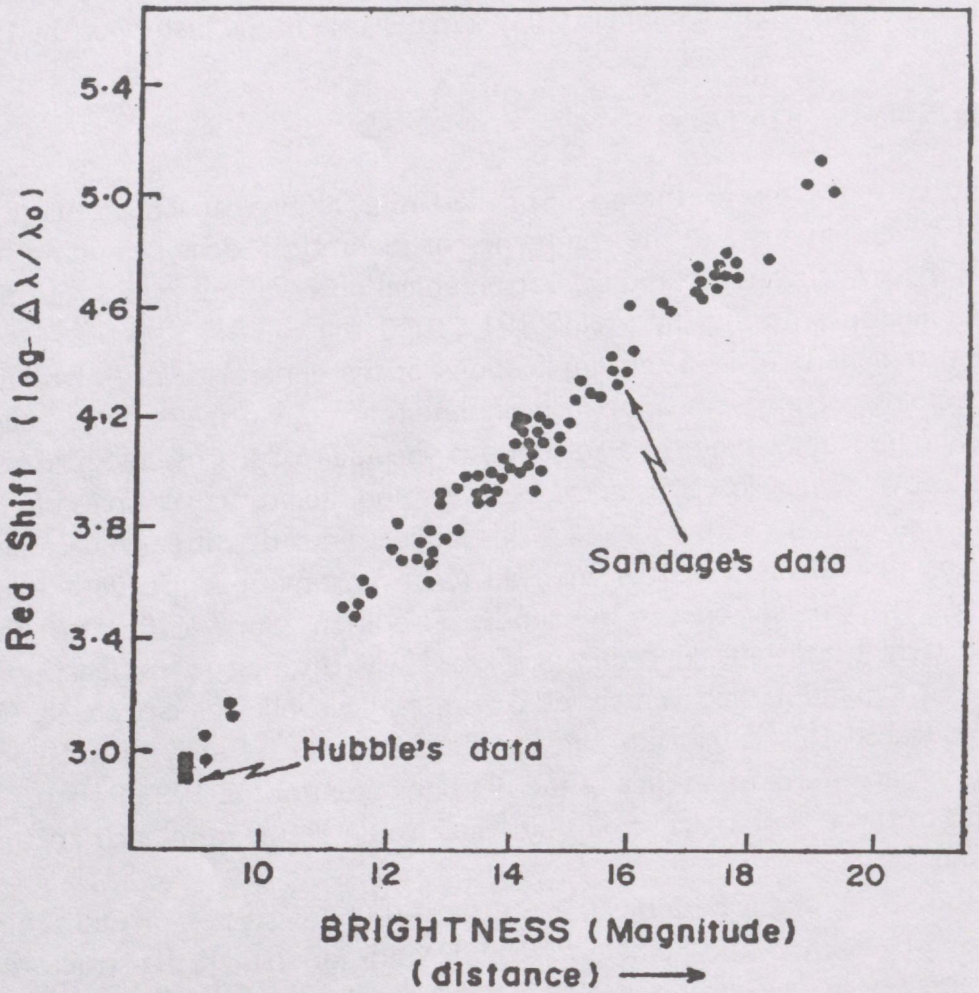



Fig. 2. Expansion of the universe.

region of space and on these scales we can talk about an average density of the Universe and also of homogeneity of the Universe.

The implications of such a universal expansion for Cosmology were first realised by Abbe Georges Lemaire. Such a picture meant that as we go back in time any region of the Universe would have been in a highly squeezed state with much higher density, and this density would continuously go up as the Universe contracts more and more and will ultimately result in infinite density and therefore in a singularity. Thus the universe starts with the Big Bang singularity, and as some scientists believe, "time" also started with this Big Bang explosion. The laws of Physics as are familiar to us, will not determine the initial state of this singularity. We can only use the physical laws to work out the evolution after the lapse of some finite time. The crucial question is how close in "time", an we get to the Big Bang Singularity? Surprisingly as close as $10^{-43}$ seconds.

### *4. Radiation in the Universe*

The Universe consists not only of matter but also of radiation. In fact we learn about the state of the matter in the Universe only from the radiation that we receive in the different band of the electromagnetic spectrum. Figure-3 shows the spectrum of radiation that is encountered typically in a location far away from any single source as deduced from observations in the terrestrial neighbourhood. Even though there are several gaps in the observation, the information available is good enough to give us a general idea of the status of radiation in the Universe. The most dominant component in terms of "energy density" is in the Microwave radiation from millimetre to centimetre range.

The Microwave radiation was discovered accidentally by Penzias and Wilson in 1965. The spectral characteristic of this Microwave radiation as is known now is shown in Figure-4. The spectrum corresponds to that of a black body of temperature 2.96°K. It is well established that the radiation is isotropic at the level of one part in $10^4$.

This very high degree of isotropy provides the best evidence for the assumption of homogeneity of the Universe. The energy density of microwave radiation is ~0.27 ev/cm$^3$ and the Photon density is 400/cm$^3$. George Gamow, on the hypothesis of the Big Bang Universe, had predicted the possible existence of such

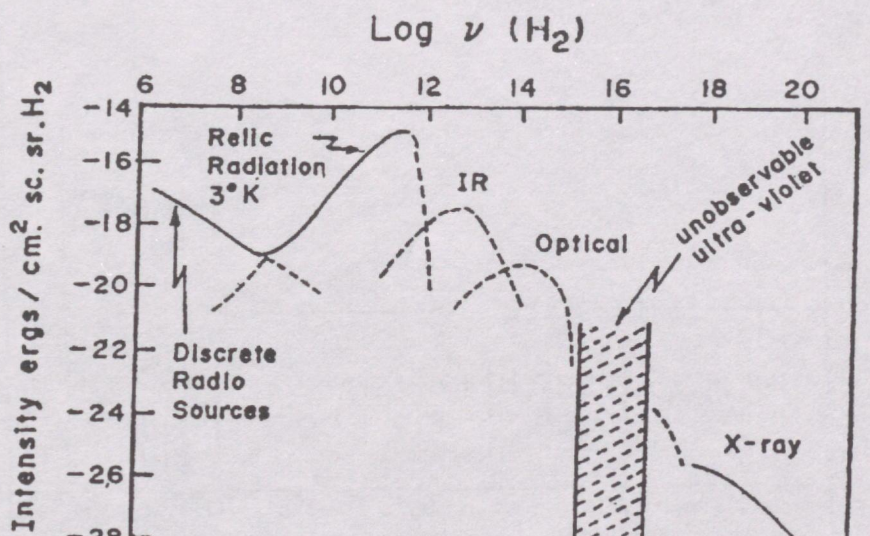



Fig. 3. Spectrum of the Isotropic Background Radiation: Full lines—observation, Dashed lines—theoretical estimates.

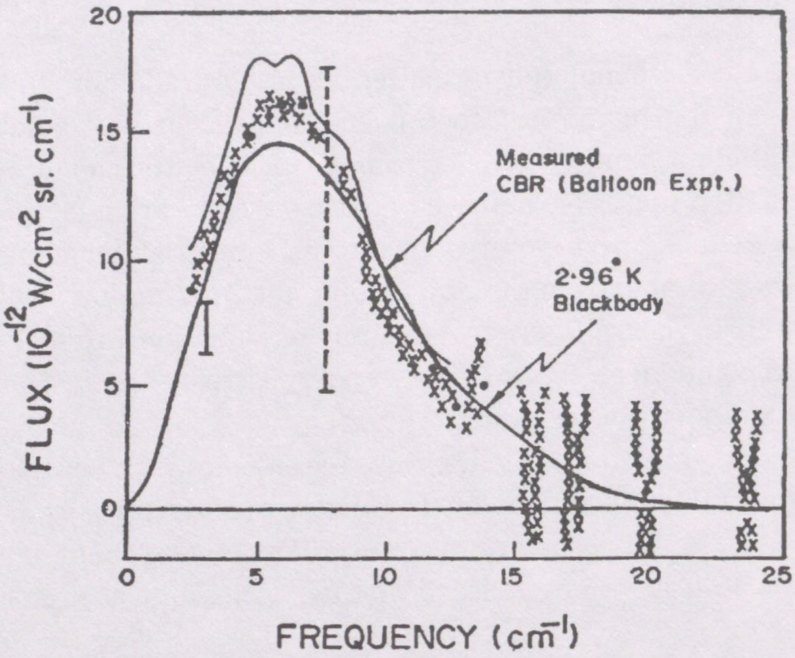



Fig. 4 Spectrum of Microwave Radiation.

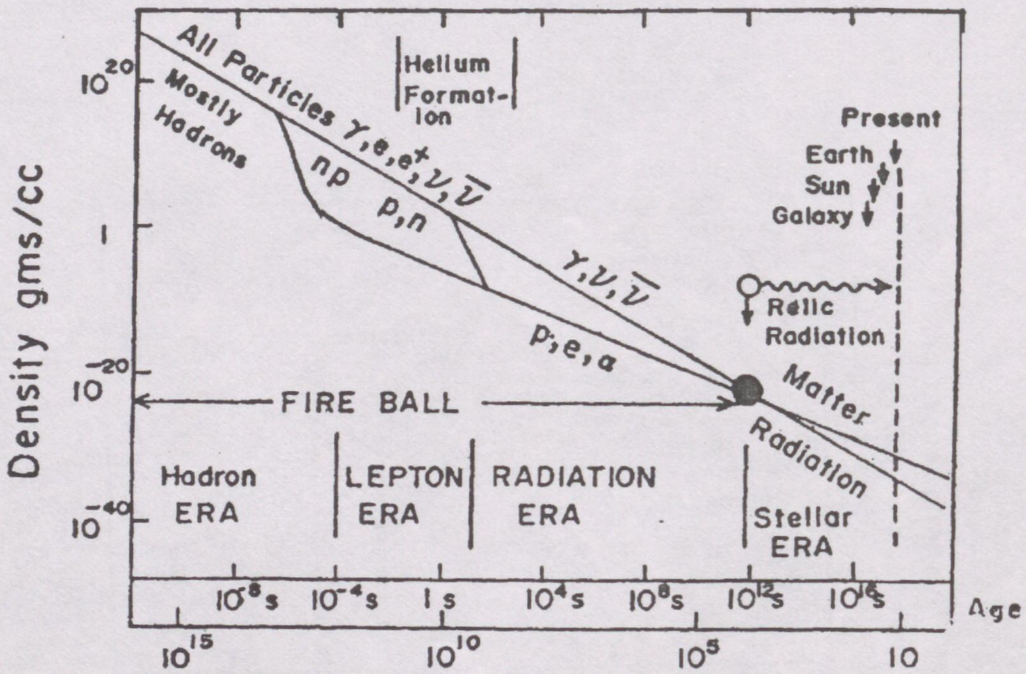



Fig. 5 Plausible Scenario of Evolution of the universe ($10^{-9}$–$10^{-15}$ s)
[From Kleczek—*The Universe*].

a universal radiation as a relic of the initial hot phase and had estimated that its temperature now, would be about 5°K, rather close to the observed value.

The radiation density of 0.27 ev/cm$^3$ at the present epoch compared to the mass density of about $10^{-34}$ gms/cm$^3$ is a thousand time less. The density of other components like the neutrinos are several orders of magnitude lower.

### *5. The Evolution of the Hot Universe*

We shall now go back in time and trace the physical conditions of the Universe when it was smaller and smaller and correspondingly hotter and hotter. Figure-5 shows the rise of radiation and matter density as we go to earlier times. It is seen that the radiation energy density increases faster than matter density and overtakes the latter around a million years from the Big Bang. If we take the present scale of the Universe at say $2 \times 10^{10}$ yrs from the Big Bang as I, then the scale factor becomes 1/1500 around $10^7$ yrs when the temperature shoots up to 4000°K and the density to $10^{-20}$gms/cm$^3$. Around a million years from the Big Bang, the scale factor would be 1/20,000 and the temperature close to 60,000°K. As we get to still earlier times, around a few minutes, the temperature would exceed the billion mark.

Since we are concerned in this paper with "the first moments of the universe", we will not consider the Stellar, Radiation, and Plasma eras which represent the periods of the build up of large scale structures as we seem them today—the ionized clouds, molecular clouds, the stars, the galaxies, clusters of galaxies, etc.

Table V
The Big Bang Scenario: 3 mins to a microsecond.

| Time from Big Bang | Temperature (°K) | Status of the Universe |
|---|---|---|
| 180 seconds | 10° | Nucleo Synthesis—Deuterium and Helium |
| 14 sc | $3\times10^9$ | $e^+e^-$ annihilation, disappearance of Positrons |
| 1 sc | $10^{10}$ | Neutron/Proton ratio freezes out of Thermal Equilibrium |
| $10^{-3}$ sc | $3\times10^{10}$ | Disappearance of all Muons and Hadrons except Neutrons and Protons |
| $10^{-6}$ sc | $10^{13}$ | Quark-Gluon plasma in thermal equilibrium with Photons and Leptons |

We shall proceed straight to a consideration of the happenings earlier than a few minutes from the Big Bang.

### *6. Happenings in the Universe earlier than a few minutes*

As the temperature of the Universe goes beyond $10^9$ K and the density higher than $10^9$ gms/cm$^3$, the application of our knowledge from the field of high energy physics on elementary particle production becomes necessary and relevant. The threshold for the production of electron-positron pairs is $5.93 \times 10^9$ K, for the production of Pi-mesons $1.56 \times 10^{12}$ K and for Nucleon-Antinucleon production $1.1 \times 10^{13}$ K. Table I shows the processes that take place from a microsecond when the temperature of the Universe was $10^{13}$ K, to a few minutes, when the temperature dropped to $10^9$ K. An important feature of this period is the production of Helium-4, which carries almost 24% of the mass of the Universe today and was all produced during this very early phase of the Universe. This is also the phase when all the fundamental particles produced (see table II) earlier than a microsecond disappear due to annihilations except protons, neutrons, electrons and neutrinos and antineutrinos which form the constituents of the present Universe. By this time the dominance in the number of photons over nucleons by a factor of $10^9$—a feature that persists up to the present time was also decided. This radiation dominance is one of the very challenging aspects of the Universe for which an answer has been found in the happenings earlier than a microsecond.

Table VI
The Big Bang Scenario: $10^{-6}$ to $10^{-43}$.

| Time from Big Bang | Temperature | Status of the Universe |
|---|---|---|
| $10^{-6}$ | $10^{13}$ K<br>($10^9$ev) | Pronounced changes in the non-gravitational properties of matter. Weak interactions have the same strength. |
| $10^{-12}$ sc | $10^{16}$ K<br>($10^{12}$ev) | Spontaneous Symmetry breaking; Higgs mechanism operates to generate masses of $W^{\pm}$, $Z^0$ from mass-less boson state. |
| $10^{-43}$ sc | $10^{23}$ K | Unification of Strong and Electro-Weak forces; Production of the lepto-quarks (X, X), Massive Magnetic Monopoles (~ $10^{16}$ Gev/c$^2$) Barrier |
| $10^{-43}$ sc<br>(PLANCK TIME) | $10^{32}$ K<br>($10^{28}$ev) | Quantum gravity becomes important. No good theories yet to make any predictions |

## 7. The very early Universe: $10^{-6}$ to $10^{-43}$ seconds

As we move to a time less than a microsecond from the Big Bang, the temperature rises from $10^{13}\,{}^0K$ to $10^{29}\,{}^0K$ at $10^{-36}$ seconds. Here the crucial question comes up—Can the temperature rise very much beyond the thermodynamical Hagedorn limit of $2 \times 10^{12}\,{}^0K$, that was set on the basis of production of large numbers of mesons at these temperatures? We also move to a distance scale very much less than the nuclear size of $\sim 10^{-13}$ cm. How is this possible? These questions find answers from comparatively recent developments in physics, in particular the discovery that the elementary particles—the hadrons like the protons, neutrons, pi-mesons, etc., are themselves composite particles. They are made of more fundamental units—"the quarks" which have rather strange properties like fractional charge, fractional Baryon number, but are Fermions and have spin 1/2. They are point particles whose dimensions are deduced to be less than $10^{-18}$ cm. Though free quarks with their characteristic properties have not been seen in the accelerator experiments, or in cosmic rays, there are good reasons to believe in their existence. The new theory of Quantum Chromodynamics (QCD) is concerned with the question of "quark confinement" and "quark-quark" forces mediated by the mass-less bosons called 'gluons'. A large number of experimental features discovered at the accelerators are beautifully explained by the quark theory. From the point of view of the very early Universe the most important consequences of the quark theory are the temperature limit of few times $10^{12}\,{}^0K$ can be exceeded by orders of magnitude and one can proceed to dimensions much smaller than $10^{-13}$ cms.

Another important development in high energy physics that is particularly relevant to this very early phase of the Universe is the "trend" that has been discerned towards the "unification" of the four fundamental forces—Strong, Weak, Electromagnetic and Gravitational. The discovery of the intermediate Vector Bosons $W^{\pm}$ and $Z^0$, has put the final stamp on the success of the Electro-Weak theory—the unification of the electromagnetic and weak forces. Further extension of the Gauge Theories which brought about this electro-weak unification in the framework of Quantum Chromodynamics, lead to possibilities of the unification of the Strong and Electro-Weak interactions, to the so called Grand Unification Theory (GUT). This predicts the existence of particles, the lepto-quarks ($X$, $\overline{X}$), in the mass range of $10^{15}$ Gev/$c^2$ — which mediate quark-quark interactions at extremely close range, and also lead to their production. It is clear that the production of such particles which requires energies greater than $10^{24}$ ev, in any terrestrial accelerator is beyond the realm of feasibility. However, the same GUT theories lead to the possibility that the Protons, the stablest of all particles in the Universe, undergo spontaneous decay—of course with a life time in excess of $10^{29}$ years. The three quarks that compose the proton, because of the fact that they are confined to a volume less than$10^{-29}$ $cm^3$, move around with very high velocities; If two of them come very close to each other then they will exchange a massive lepto-quark and lead to the production of a lepton and an antiquark which immediately interacts with the remaining quark to give a meson. Thus the proton will decay into a lepton and a meson. There are many other decay modes possible. There are quite a few experiments in the world including the one at the Kolar Gold Fields in India, which are specially designed to look for this very rare phenomenon of Proton Decay.

These grand unification ideas have important implications to the very early Universe. Figure-6, shows the variation of the coupling strengths of the electro weak and strong interactions as a function of energy. The corresponding temperatures of the Universe at the respective times are also shown in the figure. What this trend means is that before $10^{-36}$ s, all the three forces were one and the same, and the temperature high enough to produce the lepto-quarks—which are the very first species of particles to be produced in this hierarchy of particle production. The lepto-quarks give rise to leptons and quarks as the Universe cools. It is important to point out that at the limiting time of $10^{-43}$ seconds, the size of the Universe is around $10^{-33}$ cms and the density $10^{94}$ gms/$cm^3$. During this phase of Universe, massive magnetic monopoles of mass $\sim$ $10^{16}$ Gev/$c^2$ could be produced, in addition to $X$, $\overline{X}$.

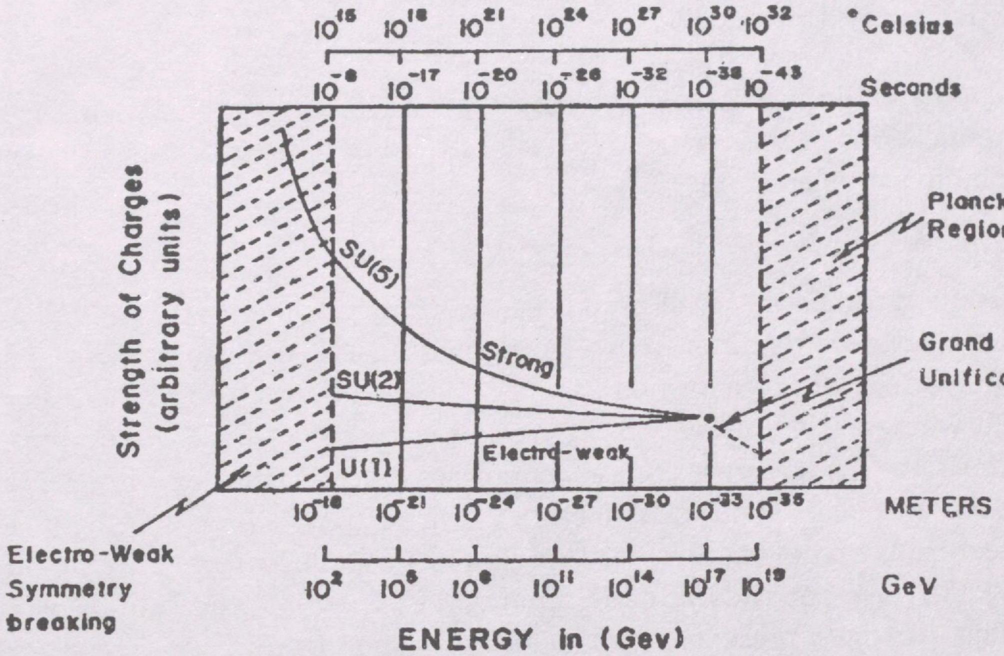
***The Planckian Era***

Why do we stop our considerations at $10^{-43}$ seconds? Why not go to still smaller interval of time?

It turns out that the smallest time interval that can be constructed out of the three familiar constants G, h and c is the Planck time $= \left[\frac{Gh}{c^5}\right]^{1/2} \approx 1.3 \times 10^{-43}$ seconds

and the smallest space interval, the Planck Length $\doteq \left[\frac{Gh}{c^3}\right]^{1/2} \approx 1.6 \times 10^{-33}$ cm.

At these lengths, it is surmised that "quantum gravity" effects will start dominating. There is no good quantum gravity theory yet which can help us to proceed further. There are theoretical efforts based on Super Symmetry, Super Gravity and String Theories to explore this domain. These are still in their early stages.




The very early Universe and Grand Unification
[From M. Green, 'Superstrings', *Scientific American*, Sept. 1986]

### *8. The Big Bang Scenario*

We cannot say anything from 0 to $10^{-43}$ seconds. Immediately after the Planck Era ($\sim 10^{-43}$ seconds) the Universe was at a temperature of $\sim 10^{32}$ $^0$K, density $\sim 10^{94}$ gms/cm$^3$ and dimension $\sim 10^{-33}$ cms. At this temperature the Super heavy particles, the lepto-quarks were produced as also the magnetic monopoles. As the Universe cools the lepto-quarks lead to the formation of the quark-lepton soup. By about a microsecond the Universe consisted of nucleons, antinucleons, electrons, muons, pions, neutrinos, photons and gravitons. By about a millisecond, many of these annihilated leaving the proton, neutrons, photons, electrons and neutrinos and antineutrinos. Deuterium and Helium formed as the Universe cooled further. This was followed by the formation of ionized gases, Stars, Galaxies, etc. The dominance of matter over antimatter, and of radiation over matter can be adequately accounted for on the basis of this scenario.

What is amazing is, that we are able to extrapolate over almost 60 decades of time from $5 \times 10^{17}$ seconds (Now) to $10^{-43}$ seconds, over 128 decades of density from $10^{-34}$ gms/cm$^3$ and over a temperature scale of 3 K to $10^{32}$ K, and come to some quantitative understanding of the early Universe; and its evolutionary course. This has been the combined achievement of astronomy, astrophysics and high energy physics and a synthesis of our knowledge of the micro and macrocosms based on a unification of the forces of nature.

**9. The Inflationary Universe**

Some outstanding problems remains the understanding of which require further ramifications of the very early phase of the Big Bang expanding Universe. The outstanding problems are:

(a) *The Horizon Problem:*

The experimentally well established isotropy of the microwave radiation at a level better than 1 in $10^4$, implies that very distant parts of the Universe, which are beyond each other's horizon (defined as the distance ct, where c is the velocity of light and t is the time from Big Bang) are at the same temperature. Since no physical process that can bring about such an equalisation of temperature can progress faster than light, this feature is one of the unsolved riddle's of Cosmology. The same situation would have persisted at earlier and earlier epochs in the kind of picture that we have presented above. The 3 radiation that we receive from the horizon today decoupled from the hot plasma around $10^5$ years after the Big Bang. If we consider two locations on opposite sides of us in the horizon today, they would be $10^7$ years apart when this decoupling took place and could not have had a causal connection at that time. How then do we understand the situation that the temperature is identical at these locations now?

(b) *The Flatness Problem:*

Will the Universe expand for ever? This depends on whether the average density of the Universe is higher or lower than a critical density which is calculated as $10^{-29}$ gms/cm$^3$ in the Friedman Universe models. We have already seen that the estimated matter density is close to this critical value—around $10^{-29}$ to 5, $10^{-30}$ gms/cm$^3$. The radiation density at the present time is however much lower. But there are reasons to believe that there could be considerable amount of 'hidden mass' in the Universe which is so cold that it is not perceived through the electromagnetic radiation. Also if the neutrinos which are abundant in terms of numbers, do have even a small mass, say of the order of ~10 ev, their contribution to mass density may even exceed the ordinary matter density.

In the Friedman theory, the average density varies as $t^{-3/2}$ in the matter dominated era and as $t^{-2}$ in the radiation dominated era (earlier than a million years from cosmic explosion) where 't' is the Cosmological time. But the "critical density" in the same theoretical model varies only as $t^{-1}$. This means that near to the Planck time ($10^{-43}$ s) the energy density is "fine tuned" to an accuracy of the order of $10^{-59}$. If this was not so the Universe would recollapse immediately after the Planck era. You can imagine how very exceptional our Universe is.

(c) *The Monopole Problem:*

In the era before $10^{-36}$ seconds, the possibility exists of profuse super massive ($\sim 10^{16}$ Gev/$c^2$) monopole production. Their numbers could be as large as that of Nucleons. The monopoles cannot be easily destroyed. There is no evidence for such high intensity of monopoles (also they would upset completely the mass densities. The Universe would have collapsed within 10,000 years of Big Bang). How did the Universe get rid of these monopoles or were they not produced at all?

(d) *Fluctuations:*

The large scale structure in the Universe arose out of fluctuations in density. How did these fluctuations take place in an otherwise highly homogeneous, isotropic Universe expanding uniformly.

All these questions find an answer in a new scenario first proposed by Alan Guth, which has similarity to be Sitter's solutions of Einstein's equation, without the Cosmological constant term. According to Guth, the Universe, beginning in a hot highly symmetric state with all the forces united (GUT), undergoes a phase transition and expands exponentially by a large factor in a short time ($\sim 10^{-30}$ s).

During this phase transition the temperature falls. The conditions that prevail after this transition provide answers to the questions raised above. There is of course a further complication—How to stop this exponential expansion?

There are many Cosmological theories. In fact there are many solutions even to the Cosmological Equations of Einstein, and each one of them leads to a different Cosmology. The Big Bang Cosmology is perhaps the one that explains most of the astronomical observations, especially with the modifications of 'inflation' introduced into it.

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## The Living Universe

Thus far we have discussed the current status of our knowledge regarding the non-living or inanimate part of the Universe. We have seen how insignificant the planet earth is, in the vast scheme of the Universe. However, when it comes to a question of the living Universe, so far at least the definitive evidence for life and its activities is confined only to the planet earth. Efforts to look for evidence of even rudimentary form of life on the planet Mars have not so far yielded positive results. Even our nearest neighbour, the Moon, has no evidence of any form of life. Elaborate searches for signals from advanced extraterrestrial civilizations have proved negative. This uniqueness is attributed to the requirement of very special conditions for the emergence of life from inanimate matter.

According to the Big Bang picture of the evolutionary events, the interstellar clouds which led to the formation of the solar system are dated to be about 4–8 billion years, and the formation of solidified rocky planets to about 3.8 billion years ago. The earliest known forms of life date back to 3 billion years. How did this formation of life from non-living inanimate matter occur as has become the belief of the scientist from the time of Pasteur? It was the Soviet scientist Oparin who proposed that to be able to answer this question, one should simulate in the laboratory the conditions that must have prevailed on the earth 3 billion years ago—the "primal soup" consisting of the chemical molecules—hydrogen, ammonia, methane etc—in an atmosphere free from nitrogen and oxygen. This suggestion was made by Oparin in the late 1920's. The experimental efforts of Stanley Miller and others since 1950's using ultraviolet light or electric sparks resulted only in producing some of the organic chemicals—several amino acids and sugar. However no evidence of the emergence of life has been recorded.

While the fundamental question of the origin of life remains, considerable progress has been made in life sciences especially after the formulation of the theory of evolution by Darwin in the mid 19$^{th}$ century. The two publications of Darwin the *Origin of Species* in 1859 and *Descent of Man* in 1871 are certainly important landmarks in the history of life sciences. Mendel's discovery of the units of heredity—later identified as chromosomes and genes, gave a boost to Darwin's evolutionary theory.

In the middle of the 20$^{th}$ century came yet another landmark, the determination of the double helix structure of the DNA molecule by Crick and Watson. This brought life sciences closer to physical sciences and the new discipline of Molecular Biology was born and has been prospering since then leading to the currently most exciting field of Biotechnology.

The 'Cell' has been recognized as the "unit" of life for a long time now. The human body starts of as a single fertilized cell and multiplies into ten million billion cells ($10^{16}$). There are about 260 types of cells in a man or woman and 100,000 different genes. What is amazing is that each cell has the same DNA molecule in its nucleus. The cells however differ in their functions—blood cells make blood, bone cells make bones, liver cells make lever etc.

George Wald a renowned biologist raises the question "How could it be that a collection of molecules come together, in just the right way to form a living cell?" and addresses it by saying "with very many trials—the unthinkably improbable becomes virtually assured. Time is the hero of the plot. Two billion years (present estimate 4 billion)—given so much time the impossible becomes possible, the possible becomes probable and the probable virtually certain".

Though, not all share this optimistic view, it is undoubtedly the most popular one among biologists. While the reductionistic approach has paid rich dividends in understanding many aspects of both inanimate and animate matter, it is increasingly becoming apparent that for the resolution of some of the key issues like the appearance of "life", of "consciousness" etc., one has to take recourse to a "systemic approach" which is a radical shift from reduction to holism. In this, one looks for organizational principles that lead to the emergence of wholly new properties which are not there in the constituents. In fact the emergent properties are destroyed when the system is broken up into parts. As the Nobel Laureate P.N. Anderson has said "I believe that at each level of organization on scale, types of behaviour open up which are entirely new and basically unpredictable from a concentration on more and more detailed analysis of entities which made up the objects of these higher level studies".

Another very important realisation that has come about in recent decades is that in nature in the inanimate and animate systems, there is a certain amount of feed back from the output to the input which guides the long term behaviour, and even systems obeying deterministic laws become unpredictable because of the uncertainty in the initial conditions. However such chaotic system occasionally lead to very creative outcomes. These are some of the realizations that have come about because of the ability to carry out large scale computer simulations.

The advent of a variety of non-invasive tomographic instruments like fNMR, PET, LASER, Microelectrodes coupled to on-line computers has led to remarkable developments in neurosciences engaged in understanding the most intricate organ of the human body, namely the brain. This enabled Francis Crick, the discoverer of the structure of DNA in the early 1950's to say in the mid 90's that "your joys, your sorrows, your memories, your ambitions, your personal identity and your free will are in fact no more than the behaviour of the vast assembly of nerve cells and their associated molecules" This, Crick calls the most "Astonishing Hypothesis" and tries to justify it (though not to his entire satisfaction), on the basis of neuronal processes that have been mapped out and examined in minute detail. On the other hand Marvin Minsky, expert on Artificial Intelligence says "Many scientists look to Chemistry and Physics as ideal models of what psychology should be like. After all, atoms in the brain are subject to the same inclusive laws that govern other forms of matter. Then can we explain what our brains actually do entirely in terms of these basic principles? The answer is "No" simply because even if we understand how our billions of brain cells work separately, this would not tell us how the brain works as an agency. The laws of thought depend not only on particles of brain cells, but also on how they are connected. All these connections are established not only by the basic general laws of physics, but by the particular arrangement of millions of bits of information in our inherited genes". In dealing with problems of consciousness the relevance of quantum processes in the brain and its accessories is also under active discussion now-a-days.

To summarise, the current knowledge of the physical world with regard to both the animate and inanimate parts, is certainly very different from what it was even a hundred years ago. Despite increasing awareness of the multi-layered microscopic/macroscopic activities in both fields, the general tendency is towards recognizing a unification of the ultimate constituents and forces at the deepest substratum levels which are now accessible for detailed study thanks to the availability of a variety of instruments which in turn are products of advances in basic sciences. Thus the science—technology spiral is enabling us to march ahead in our quest for ultimate knowledge.

## Epilogue

"Matter is made of atoms and void" was the view held by the early Indian and Greek philosophers—Kaṇāda of the Vaiśeṣika school (who envisaged ākāsa in place of void) in India going back to 600 *B.C.* and Leucippus, and his student Democritus in Greece around 550 *B.C.* followed by Epicurus of Samos in 300 *B.C.* The atom which meant "uncuttable" in Greek was the ultimate indivisible unit and Kaṇāda spoke of 'Paramāṇu' which also had the same connotation. Much later Newton (1642-1727) stated:

> It seems probable to me that God in the beginning formed matter in solid, massy hard impenetrable, movable particles of such size and figures and with such other properties ....., so very hard as never to wear and break in pieces, no ordinary power being able to divide what God himself made one in the first creation.

The British Scientist John Dalton (1766-1844) who started his career in meteorology and did extensive studies on the atmosphere by collecting air samples from very many difference places is generally regarded as the father of modern 'atomic theory'. What led him to the atomic theory was the discovery that all the air samples had the same chemical composition and the various gases wherever collected were thoroughly mixed—the heavier and lighter ones. He came to the conclusion: *"All materials are made of small uncuttable particles called atoms. Atoms of different elements have different properties, but all atoms of the same element are exactly same. The whole atom takes part in chemical changes. Atoms are not changed as they enter into chemical compounds. Atoms cannot be created or destroyed".*

This atomic theory of Dalton propounded in the early years of the $19^{th}$ century became one of the foundations of modern physics and chemistry, though in the later part of $19^{th}$ century and in the early decades of the $20^{th}$, the indestructibility of the atom was disproved experimentally. As we saw in the earlier sections, the atoms were smashed, the nuclei split and many new particles created by the bombardment of high energy particles. While radioactivity and collisions by low energy accelerated particles led to the understanding of the atom structure and the nuclear structure, the collisions at very high energies opened up the thoroughly unexpected world of elementary particles. Many of these were extremely unstable and decayed away into other particles in very short intervals of time. The developments in the field of astronomy and the discovery of the expanding nature of the universe and of the universal microwave radiation led to the Big Bang theory of creation of the universe—creation characterized by unbelievably high temperatures in its first moments. This focussed attention on the connection between high energy physics and cosmology, portraying the special significance of the role played by those extremely short lived particles. The most exciting realization that has come about is that very early universe is the highest energy accelerator laboratory through the study of the happenings of which one could test, if at all, the grand unification of all the forces of nature—the gravitation, the strong, weak and electromagnetic. These forces normally behave so differently and are responsible for so much of variety in the universe. Do they converge in the very early moments of the universe to just one type of force? This is the expectation. Will it be established? At the moment only the unification of electromagnetic and weak forces is established unambiguously. The lack of confirmation of Proton Decay has been a fly in the ointment.

Another important consequence of the developments in physical sciences in the $20^{th}$ century is the unification of matter and energy, time and space leading to the idea that in the ultimate analysis, everything arises out of fluctuations of just one entity—just one all pervading substratum. What modern science has been endeavouring to do is to determine what all this substratum should contain in a potential form, and establish the natural laws by which the products that come out of the substratum—space, time, particles, radiations, etc., by spontaneous fluctuation and with passage of time to give rise to the universe that we are cognizing and attempting to understand. Most importantly this whole process should result in the emergence of life and of man. As stated in the opening sentences of this article, man has progressed a lot in this direction and but there is much more to be learnt. As Frost has said "miles to go before I sleep".

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