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Ideas and Researches on Physical Concepts in India*

A K Bag**

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Abstract

The ideas on physical concepts in India have changed through the centuries initiated first by *guru-śiṣya paramparā* (teacher- student relationship), and later extended further based on varieties of quests & experiments. The Vedic & Upaniṣadic schools (c.6500 BC - 500 BC) first expressed anguish as to how the universe was created by Gods, later on giving importance to nature, natural order and the cosmic creation. The Buddhist, Jain, *Sāmkhya* & *Nyāyavaiśeṣika* schools (c.501 BC - 1000 AD) gave central focus to Nature (*prakṛti*), in place of Gods, as a limitless entity which is self-existent. The *Sāmkhya* recognized five elements in nature: *kṣiti* (earth), *āpa* (water), *tejas* (fire), *vāyu* (air) and *ākāśa* (space) both at the atomic (*paramāṇu*) and molecular (*aṇu*) level with *guṇas* [*sattva, rajas, tamas*] as attributes existing in equilibrium. Emphasis on duality concept (*puruṣa* and *prakṛti*, *śiva* and *śakti*, *hara* and *pārvati*, mercury and sulfur) by the Tantrik and Alchemical traditions was held responsible for equilibrium state. The metaphysical explanation of how the *sthula-bhūta paramāṇus* like solid, liquid,, gases, heat & light, ether etc are constituted based on *tanmātrās* (physical energies represented by sound, touch, colour, taste and smell) together with likeness, cause and effect relationship of the combination of the atoms is also explained. The Greek and Islamic thoughts during the period (c.1001-1800) accepted also similar atomic concepts of matter which are no better than those of the Indians. The European knowledge in physical science in the Colonial phase in India (1801-1900) opened up after great initial reluctance, and the knowledge of great stalwarts like, Copernicus (on heliocentric theory), Kepler (elliptical path of planets & planetary laws), Huygens (polarization of light), Newton (motion of body in Cartesian and Polar co-ordinates, periodic motion, law of universal gravitation, sound and its propagation, light), Galileo (telescopic observation of heavenly bodies), Oersted, Faraday & Maxwell (magnetic properties of materials, electricity, charge), Kirchhoff & Planck (radiation), Mendeleyev (periodic table) and others, infiltrated through the local initiatives influencing Indian minds. These helped to establish a Golden phase of science in India (1901-1960) with J C Bose, C V Raman, Meghnad Saha, Satyendranath Bose, S K Mitra, H J Bhabha, S Chandrasekhar and others extending the knowledge in diversified field of physical science. The work was of great order, some of which brought great international fame in global perspectives. The phase (1961–2000) was indeed a period of consolidation in India which led continued emphasis on cosmic ray research, atmospheric studies, search for sub-atomic elementary particles in the formation of building blocks of the universe, classification of forces and of elementary particles imparting importance to Model of Expanding universe with radiation against the Steady state of Big-Bang Model. The observer and observed have however created many a dilemma in present ideas and thoughts in establishing an order between the physical and biological world.

Key words: Bhabha scattering, Big – Bang model, Black hole, Boson, Buddhist schools, Diode detector, European knowledge, Cosmic evolution of matter, C V Raman, Electro-magnetic spectrum, Elementary particles, Golden phase of science in India, Greek schools, H J Bhabha, Ionization theory, Islamic schools, Jaina schools, Laws of gravitation, J C Bose, M N Saha, *Nyāya-Vaiśeṣika* school, Motion of bodies, Nuclear program, Origin of Universe, Periodic table, Physical concepts, Quantum mechanics, Raman effect, Response in plants, *Sāmkhya* school, S Chandrasekhar, S N Bose, S K Mitra, Spectroscopic observation, Expanding universe & Steady state models, Telescopic observation, Upper atmosphere.

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**Editor, *Indian Journal of History of Science*, INSA, New Delhi; Email: akbag99@gmail.com

1. Introduction

India in its more than six thousand years' history has produced many great theoreticians and practitioners of arts and science. The physical concepts are generally recognized as the knowledge or perception about origin of universe including knowledge of its evolution, structure, motion, and properties of body or substance or energy, how they are related, and how the ideas in these concepts have changed through the centuries. The subject, though appear to sound vast, bold and imaginative, there are practically no specialized texts in the early Indian traditions except in the later periods which exclusively deal with them. Each school of thoughts has developed its own physical and metaphysical views. To appreciate the subject, I have discussed the evolution of these concepts in phases.

2. Vedic & Upaniṣadic Schools (c. 6500 BC–500 BC)

The Vedic schools of *Saṃhitās*, *Brāhmaṇas*, *Āraṇyakas*, *Upaniṣads* and of the *Vedāṅgas* flourished during this period c. 6500 BC–500 BC. The antiquity of this prehistoric phase is based on astronomical facts verified by many recent sky-maps (Bag, 2015, pp.3-12, 21-22). The *Ṛgveda* is the earliest of the four *Saṃhitās* (*Ṛg*, *Sām*, *Yajur* and *Atharva*) which, in its well-known hymns (*RV*.X.129.6-7), speaks with wonder about the creation of the universe[1]. The English translation of the verse (Wendy, 1981, pp.25-26; also quoted in Lahiri, 2013, p.142) runs thus,

> 'Who knows, who ever told, from whence
> this vast creation rose?
>
> No gods had then been born—who then
> e'er the truth disclose?
>
> Whence sprang this world, and whether
> framed by hand devine or no –
> Its Lord in heaven alone can tell, if even
> he can show'.

The *Ṛgvedic sukta* (*RV*.X, 90) has also sixteen *mantras* which provided the story of creation giving it a highly philosophical orientation, and indeed constitute a most difficult and complex thought to appreciate. In short, it conceived an idea of a *puruṣa* (Cosmic Being); the derivative, '*pu*' meaning purity, *puruṣa* is one who is pure and untouched. In *Brāhmanic* and *Upaniṣadic* literature, the personification of 'Supreme Being' has profound influence, and in major *Upaniṣads*, *puruṣa* has been emphasized as 'inner consciousness', the essence of man, the *ātman*. This type of metaphysical discussion is also followed in *Sāmkhya* and *Vedānta*. A few other concepts in the period merit attention:

The concept of universe of the Rgvedic people was equally interesting. They first made an effort to develop this concept to establish an order between the outer world and the inner urge of human spirit. The Fire (*agni*), as representative of the Sun in the heaven, was conceived as a great well-wisher, wealth-giver, illuminator and associated him with his own activities through worships and sacrifices. The *Ṛgveda* describes *pṛthivī* (earth), *antarikṣa* (sky, literary meaning 'the region between the earth and the stars'), and *div* or *dyaus* (heaven), as parts of his 'universe' (*RV*.I.115.1; II.40.4). It has even been tried to estimate the distance of the heaven from the earth, of course the values being estimated as 'ten times of the extent of the earth '(*RV*.I.52.11); ' a thousand days' journey for the sun-bird' (*AV*.X.8.18); 'thousand days' journey for a horse' (*Ait.Br*. II.17.8); and so on. All these of course are figurative expressions indicating that the extent of the universe is somewhat infinite. The three primary altars—*Gārhapatya* (circular), *Āhavanīya* (square) and *Dakṣiṇā-vedi* (hemi-spherical or

[1]*ko andhā veda ka iha pravocatkuta ājātā kuta iyam visṛṣṭi / arhāgdevā asya visarjanenāthā ko veda yata āvabhūva // iyam visṛṣṭiryata āvabhūva yadi vā dadhe yadi vā na / yo asyādhyakṣaḥ parame vyomant so anga veda yadi vā na veda //* (RV.X.129. 6-7)

semi-circular), on which the house-holder placed their fires (*agnis*) for daily sacrifice, representing earth, heaven and *antarikṣa* respectively had same ground areas. The shapes of the altars were so designed, for it appeared to them the earth as spherical, heaven as cube (used to indicate four cardinal directions—east, west, north & south), and *antarikṣa* as hemispherical. The same area suggests that they conceived it as obligatory to establish a coordination among these three entities. The perception of three gods— *Agni* in earth, *Indra* (or *Vāyu*) in aerial region (*antarikṣa*), and *Savitṛ* (Sun) in the heaven in the *niruktas* appears to be quite interesting. They had a feeling that *Agni* is protected by Sun and Indra, and all three were always given a prominent place in the worship.

Ṛtam, a cosmic order or a law, which guides the course of things, is also formalized in the *Ṛgveda* (*RV*.IV.40.5). Winternitz in his *History of Indian Literature* (Vol.1, 1927, p.154) used it in the sense of the 'order of the universe'. Keith in his *Religion and Philosophy of the Veda and Upanishads* (Indian reprint, 1970, pp. 83,248) says that *ṛtam* means 'cosmic order' as well as 'moral order'. Or in other words, he clarifies that it is the 'primal principle' which not only guides human activities for his *sat* and *asat karmas*, but also decides purpose of Sun, his all-pervading lights and other external objects, and even the flow of the streams (*RV*.VI.2). Gods are often described in the Vedas as 'Guardians of *ṛtam'*, for gods like Mitra and Varuṇa are often invited by the Vedic people to increase the size of *yajṇas* and preserve it by following the path of truth (*RV*.I.23.5). The apparent movements of sun and moon as seen from the earth is likewise comes under this law. However, Vedic schools are silent as far as the concept of time is concerned, as to when and how the movements of these heavenly bodies began. *Ṛgveda* only says, '*āditya* lights up and creates energy', and the 'appearances of *Uṣas*' and 'illumination of the universe' are in conformity with *ṛtam* (*RV*.III.61.7).

The famous *Nāsadīya sūkta* of the *Ṛgveda* (*RV*.X.129) first conceived primeval water as the first element, and associated it with the process of creation. Later on, the *Bṛhadāraṇyaka Upaniṣad* (*Bṛh.Up*.V.5) speculated, 'In the beginning, this world was just water'. *Chāndogya Upaniṣad* (*Chand. Up*. VII. 10) says,' It (world-stuff) is just water solidified, that the earth... the atmosphere.... the sky.... the gods and men... beasts and birds... grass and trees... animals together with worms... flies and ants, all these are just water solidified'. It also accepted the three elements, water, fire and *ākāśa* as the basis for understanding of *brahmaṇ* as the universal soul. The idea of five elements is also found in the *Maitri Upaniṣad* (*Mait.Up*. III.1 & 2; VI.4). The philosophical conception of five elements has found elaborate extension in the *Sāmkhya* school discussed in the next section.

3. Buddhist, Jain, *Sāmkhya* & *Nyāyavaiśeṣika* Schools (c. 501 BC–1000 AD)

The period is synchronized with the rise of Buddha (b. 563 BC) and Buddhism, Mahāvīra (contemporary of Buddha) and Jainism, and the extent of influence and vast amount of literature produced by their followers in India. Six philosophical schools (*Saḍdarśanas*), the epics—*Rāmāyana* & *Mahābhārata*, the schools of Ayurveda (medicine) and *Jyotiṣa* (*Siddhāntic* astronomy) came out with many basic knowledge about the universe. Buddhist notion of another life or life after death (*parajanma*) and attainment of *nirvāna* (free from the life cycle for good work) have made the concept of time as continuous and infinite. The introduction of *Yuga* as time unit consisting of *Kṛta* (Golden Age of 1,728,000 solar years), *Tretā* (Silver Age of 1,296,000 solar years), *Dvāpara* (864,000 solar years), and *Kali* (Iron Age of 432,000 solar years) maintaining a ratio 4:3:2:1 had a considerable effect on the epics, *purāṇas* as well in astronomical texts. The concept of space, direction and time also got concretized with the recognition of the planets, viz., mercury (*budha*), venus (*śukra*), sun (*sūrya*), mars (*maṅgala*), jupiter (*bṛhaspati*), saturn (*śani*) lying in the same concentric plane, and their revolution with uniform circular motion round the earth (*geometric concept*). All astronomical texts have a section (*Tripraśnādhikāra*) dealing with *dik* (direction), *deśa* (position), and *kāla* (time) with methodology how to find them for a particular position of celestial bodies. Local time was considered as a function of sun's shadow-length and measured by a *śanku* (pole of height 12 *aṅgulas* or roughly 9 inches) from sun's position at different latitudes of the earth.

The **Buddhist metaphysical tenets** also have avoided God as a creator, rather it developed the postulates that the universe is self-existent, having no beginning in time, rather limitless in both directions, past and present. Buddhist influence in Central and South Asia, Alexander's invasion, trades and cultural contacts created a situation (though in a restricted manner because of the various barriers including language), which was fit for free thinking and exchange of knowledge with scholars in India and outside world.

Every age has its own science, beset with new issues, problems and solutions. The spirit of enquiry and skepticism which characterized the growth of Buddhism favored the development of science. New thoughts could be found in the teaching of philosophical schools of *Sāmkhyas*, *Nyāya*, *and Vaiśeṣikas*. The Buddhist *Vihāras* continued to be centres of learning. So is *Jaina* and other schools which followed materialistic traditions and believed in the sense perception as a valid source of knowledge as well as the basis for the reality of natural law. Frits Staal, a well-known historian of science, in his lecture on 'Concept of Science in Europe and Asia' at the Institute of International Institute for Asian Studies in 1993 says, 'My impression is that Indian scientific tradition is as rich as the Chinese, an impression confirmed by Needham's work, which does not only deal with China but abounds in references to western (including Islamic) and Indian sciences'. According to him, 'Pāṇini developed Sanskrit grammar as derivational system in some respects more sophisticated than the deductive system of Euclid', and further emphasized, 'India is richer than China in abstract and theoretical sciences such as mathematics and logic'. The philosophical schools of this period accepted atom as the basic unit and gave a logical structure which attained a unique place.

The ***Sāmkhya* school** extended the Upaniṣadic idea of the concept of element to atomic and molecular level. *Prakṛti*, according to *Sāmkhya* view of cosmogenesis, is formless, limitless, ubiquitous, undifferentiated, indestructible, indeterminate, and incomprehensible infinite continuum without beginning and without end, in which and out of which the un-manifested and differentiated cosmic universe has been evolved through successive stages (Ray, 1966 pp.1-3). It is also an amalgam of three *guṇas* existing in equilibrium. These are: *sattva* (essence of intelligence staff), *rajas* (energy) and *tamas* (mass-stuff or inertia), which according to Seal (1915), are diverse moments with diverse tendencies inherent in *Prakṛti*. The successive stages of cosmic evolution of matter according to *Sāmkhya-Pātanjala* system (*Vyāsa-bhāṣya*, *sūtra* 2, *pada* 2) as described by Seal (1915), Ray (1956 & 1966), Subbarayappa (1966) and others, may be summed up as follows:

Prakṛti evolves → *Mahat* (cosmic matter, or stuff of consciousness);

Mahat → *Ahamkāra* (ego, both objective and subjective);

Ahamkāra → *Tāmasik-ahankāra* (objective modification) + *Rājasik-ahamkāra (*subjective modification);

Tāmasik-ahamkāra → *Sūkṣa-bhūta-tanmātra* (subtle material potencies or matter-stuff) → *Sthūla-bhūta-paramāṇu* (atomic and molecular constituents of gross matter) → finally, *Dravya* (individual substances composed of atoms and molecules);

Rājasik-ahamkāra → *Asmitā* (empirical ego) → *Manas* and *Indriyas* (Mind-stuff, sensory and motor stuff).

This theoretical frame-work shows the cosmic evolution of both matter-stuff and mind-stuff. *Bhutādi* has been conceived as matter in the suprā-subtle state which is absolutely homogeneous and inert, without any chemical or physical property excepting that of quantum or mass. *Tanmātras* likewise was viewed as infra-atomic particles of matter which possesses specific potential energies represented by sound, touch, colour, taste and smell. The *śabda-tanmātra* (sound) has the physical energy of vibration (*parispanda*); the *sparśa-tanmātra* (touch) has the physical energies of impact besides that of vibration; *rūpa-tanmātra* (colour) has the energy of radiant heat and light beside those of impact and vibration; *rasa-tanmātra* (taste) the energy of viscous attraction together with heat, impact and vibration; and *gandha-tanmātra* (smell) the energy of cohesive attraction together with those of viscous attraction, heat, impact and vibration. From *tanmātras* arise the *sthūla-bhūta-paramāṇus—ākāśa* (mono-), *vāyu* (dvi-), *teja* (tri-), *ap* (tetra-), and *kṣiti* (penta *tanmātrik*) atoms. Then these atomic *bhūtas* gives rise to five different types of substances—*kṣiti* atoms give solid, *ap* atoms liquids, *vāyu* atoms gases, *tejas* atoms heat and light, and *ākāśa* atoms ether. Different properties of different substances are responsible from the difference in *tanmātrik* compositions and collation in their atoms. In *Sāmkhya* view, *ākāśa* is conceived in two fold aspects, viz., non-atomic *ākāśa* (*kāraṇākāśa*) and atomic *ākāśa* (*kāryākāśa*) related to each other as cause and effect. The atomic *ākāśa* is charged with vibration potential residing in a non-atomic *ākāśa*, known as space (*avakāśa*), and serves as a building stone of all other material atoms. The Tantrik cult and the Alchemical traditions developed a duality concept like *puruṣa* and *prakṛti*, *śiva* and *śakti*, *hara* and *pārvatī*, mercury and sulfur to neutralize or contain the two opposite forces, and considered them as inherent part of natural process. This concept is comparable with Dirac's hypothesis of '*anti-matter*', which fills the space and from which the matter is continuously created. The concept of non-atomic *ākāśa* as a starting point of material creation reminds one of Fred Hoyle's theory of material creation.

The ***Nyāya-Vaiśeṣika* school** of Indian philosophy have also propounded atomic concepts and allied properties (*paramāṇu-vāda*). **Kaṇāda,** the founder of *Vaiśeṣika* school, developed in his *Kaṇāda-sūtra* a system which recognized four types of atoms—*kṣiti, āpa, tejas* and *vāyu*, has many points in common with that of Greek philosopher Democritus (4th century BC). It is somewhat different from the *Sāmkhya* system which recommended five including *ākāśa* atom. According to Kaṇāda, *ākāśa* has no atomic structure, serving merely as an inert and ubiquitous substratum of sound, which is supposed to travel in the form of waves in the manifesting medium of *vāyu*. Kaṇāda's view about the propagation of sound, though purely speculative, is surprisingly similar to that of modern science. The *Praśastapāda-bhāṣya*, which is an exposition of *Kaṇāda-sūtra*, and *Nyāya-kandalī*, described atom as a logical necessity and added epistemological significance. According to *Vaiśeṣikas*, atoms are eternal, part-less, spherical, and the gross world is formed out of atoms. They also believed in four distinct types of atoms corresponding to four substances viz. *prthvī* (earth), *ap* (water), *tejas* (fire) and *vāyu* (air). Each type has some specific qualities, which sometimes change with the influence of heat (*pilupāka*). As regards combination of atoms to formation of gross bodies, the *Vaiśeṣika* theory prescribes as follows:

Two atoms—one *dyad* (*dvyaṇuka*);

Three atoms—one *triad* (*tryaṇuka*);

One atom combines with another atom under an inherent impulse to form a binary molecule of two atoms (*dvyaṇuka*). The atoms possess an intrinsic vibratory or rotatory motion (*parispanda*). Atoms of same *bhūta* class will unite in pairs and give rise to molecules. The homogeneous qualities of binary molecules is retained corresponding to the original quality of the atoms, provided that no chemical changes take place under the heat corpuscles. The binary molecules then combine among themselves by groups of three (*triad* or *trasareṇu* or *truṭi*, which is visible in sunbeam), four, five and so on to form larger agreegates. The *Nyāya Vaiśeṣika* school assumed that the combination of two atoms is performed by invisible force (*adṛṣṭa*—not visible). However, it was suggested by later commentators (*Nyāyavārtika-tātparyaṭīkā* of Vācaspati Miśra, III, 1. 28) that two atoms of *pṛthvī* combine under the influence of a different atom say, atoms of *tej* or *ap*. Two unlike atoms e.g., one atom of earth and one atom of water cannot under any circumstances combine to produce a *dyad*. Since *dyads* form the basis for all *triads*. The *Vaiśeṣika* system argues that the structural arrangement of *dyads* (*vyūha*) determine the specific character of gross substances.. Atoms are neither created nor destroyed, and are therefore permanent. They are spherical, occupying definite positions inside matter. When matter is destroyed it breaks up into atoms. Atoms and molecules are always vibrating and rotating, and all work and movement can be ultimately traced to the motion of atoms.

Kaṇāda also recognized light and heat as only different forms of one and the same essential entity, *tejas* (radiant energy). He held the view that sound travels in the manifesting medium of *vāyu* (air) in the substratum of *ākāśa* (space). In *Nyāya-Vaiśeṣika* system, the transmission of sound was explained by the motion of waves, while in Greek system it was explained by the particles of sound radiating in all directions in straight lines with a sort of conical dispersion (Latham, pp.146-47). The Indian philosophers also observed the properties of reflection and refraction of light, and of rarefaction and condensation of air particles during the propagation of sound [*Nyāyabhāṣya*, (III. 47. 1) of Vātsāyana; vide also the commentary of Udyotkara (2nd century AD); propagation of sound has been discussed by Bhatrihari in his *Vākyapadīya* (*Mimāmsā*)]. An elaborate account of various types of motion (*gamana*), rectilinear and curvilinear (vibratory or rotatory), momentum or impressed motion (*vega* or *samskāra*), gravity (motion of a falling body), motion due to magnetic attraction, motion due to contact etc is found in the *Nyāya Vaiśeṣika Praśastapāda-bhāṣya* (3-4th century AD). Even the attraction of a straw by amber (electrical attraction) has not escaped the notice of the scholars of *Nyāya Vaiśeṣika*. The ancient Indians do not believe in the theory of vacuum as in the Greeks. They say that when an atmospheric content of a glass jar is exhausted, what remains is not vacuum, but *ākāśa* or *vyoman*. It recognized *ākāśa* as an element which goes as a constituent into the composition of every object.

The **Buddhist schools** had also batted for atomic concept having subtle differences from that of Kaṇāda, and recognized four atoms— *vāyu*, *tejas*, *ap* and *kṣiti*. Four essential properties—extension (with hardness), cohesion (with fluidity), heat and pressure (with motion), along with four subtle sensible of colour, taste, smell and touch were also accepted. So, *vāyu* atoms are touch-sensible having impact or pressure as the characteristic property, *tejas* atoms are colour- and touch- sensible having heat property, *ap* atoms are taste-, colour- and touch- sensible with viscosity as the property, and *kṣiti* atoms are smell-, taste-, colour-, and touch- sensible with dryness or roughness as the property. The four elements (*bhūtas*) formed out of these atoms combine to form aggregates and give rise to organic and inorganic substances. According to *Sarvāstivādin* school, a material atom is composed of seven characteristic atoms, viz., solid (earth), liquid (water), heat (fire), moving (air), colour, taste and odor with sense of touch. How a material object is composed of characteristic atoms is not clear. The later work says that the seven characteristic atoms are set with their apices and centre, and form an octahedron.

The **Jaina schools,** in general, also accepted the atomic theory and based it on the concept of *pudgala* which acts as the vehicle of energy in the form of motion. *Pudgala*, according to them, can exist in two forms, as *aṇu* (atom) and *skandha* (aggregates or molecule), the latter being formed from the former. An *aṇu* has no parts, no beginning, middle or end, and therefore it is an infinitesimal, eternal and ultimate particle of matter. A *skandha* has many forms, diad (*dvyāṇuka*), triad (*tryaṇuka*), or an infinitum (*anantāṇūka*). A *skanda* (aggregate) is therefore made of large number of *aṇus* of first, second, third order and so on. An atom possesses an infra-sensible or potential taste, smell and colour, and two infra-sensible tactile qualities— roughness or smoothness, dryness or moistness, hardness or softness, heaviness or lightness, heat or cold. A *skandha*, however, possesses in addition the physical characteristics of sound, atomic linking, dimension, shape and configuration, divisibility, opacity, radiant heat and light. For chemical combination between two atoms, they must be *unlike in character*, being endowed with opposite qualities meaning roughness and smoothness, or dryness and moistness. The *atomic linking* between two atoms is also important in this context, for it says that linking will not occur or will be very weak, if the opposite qualities (strength or intensity) be very feeble. The particles of like character or similar qualities will not generally unite if they are of equal intensity. The strength and intensity of qualities, although alike, two atoms may differ widely in character. Even atoms of similar qualities may enter into chemical combination. As a result of linking or chemical combination, the properties of atoms suffer a change. A detaled description of the atomic theory and theory of chemical combination is found in the *Tattvārthadhigama-sūtra* (Chap. 5) of Umāsvātī (2nd century AD).

The ***chemical change and heat*** had been closely associated in the *Nyāya-Vaiśeṣika* system. Vātsyāyana (first century AD) also says that chemical changes may occur either by external heat or may result from the operation of the internal heat (*Vātsyāyana-bhāṣya,* IV.1.47). The heat evolved which has undergone changes by combination is believed to exist in a latent form in the fuel for combination. Udayana in his *Kiraṇāvalī* (comm on the *Praśaspada-bhāṣya* of *Nyāyasūtra*) considers solar heat as the ultimate source of all heat required for chemical changes. This invisible heat was also believed to be responsible for the change of colour in the grass, for the ripening of mangoes including its change in colour, smell and taste, for conversion of food into blood and so on (*Nyāyabodhinī* commentary on Annambhatta’s *Tarkasamgraha*, 8th century AD). Heat and light rays were also thought to be consisting of small particles radiating in straight lines in all directions with high velocity forming a somewhat conical dispersion. On striking the atom they may break the up their groupings, and transform as per their physical and chemical character (*Nyāyamanjarī* of Jayadatta, eleventh century AD).

Greek schools, like Indian metaphysicians, gave the impression that basic elements (or stuffs) were four, and they are responsible for making all substances in the universe – earth, water, air, and fire. However, the space as a medium of energy was not included like that of the Indians in their scheme. Aristotle (384–322 BC) assigned the properties : Earth as cold & dry, Water as cold & moist, Air as hot & moist, and Fire as hot & dry, and said that everything on Earth was made of combination of these elements and all changes other than motion take place on the alteration of these proportions

(Taylor, 1964, p.17). The whole concept is based on daily experience. In Greek atomism, atoms and void constitute the universe, and the atoms are in perpetual motion. All physical phenomena have been explained by the use of both atom and void and developed on the basis of mechanical way of thinking. The *Nyāya Vaiśeṣika* atomism has explained a few phenomena from the atomic point of view, and various others by means of *adṛṣṭa* (invisible force), wave motions and so on. Indian atomism is not completely built on a mechanical way, rather characterized by the atomism of sense which explains epistemology of sensation in the human body. Science in both these regions had unique achievements in isolated manner but had no connection with any experiments or social needs. The novelty in atomic concept of matter could not sustain and develop further because of varieties of pressures resulting from classes between higher-caste- minority and lower-class-majority, and also attack from foreign power in spite of brilliant metaphysical ideas.

4. Sultanate and Mughal periods (c. 1001–1800)

This period under the Sultanate and Mughal rulers in India were mostly busy in mundane affairs. The study of physical aspects of matter had almost no patronization, as a result, the interest weakened further. As to academic contacts between India and the Islamic world, Gāzāli (1058-1111), the well known Islamic historian of Central Asia, in his *al-Munqidh min al-dalā* says that out of four types of Islamic thoughts, viz., *bātiniyya* (*Ismālīyya* movement), *mutakallimūn* (followers of atomic concepts), *falāsifā* (rationalists and scientists), and *suffiyyā* (eclectic and esoteric trends), the first had not much influence on India and went underground during the Sultanate period. The last three groups had of course no clash with the Indian rulers and intellectuals. Islamic Caliphate in central Asia which expanded their area of influence from Spain in the west, through middle-east to Turkistan, Iran, up to the border of China came closer to India. The area of Islamic science also grew. To cite a few examples, the astronomical works of Āryabhaṭa, Brahmagupta, Ptolemy, and of Plato and Democritus were translated into Arabic by Baghdad scholars. Al-Khwārizmī (c. 850) translated Indian works on arithmetic and algebra. The central Asian scholar al-Kindi (c. 800-873) of Basra (Baghdad) had interest on physical concepts and wrote on the refraction of light. Al-Hazen (965-1038), a century later, also focussed his attention on reflection & refraction of light on spherical and paraboidal mirrors and the magnification by lenses. Al-Bīrūnī (973-1048) who came to India, stayed here for about fourteen years and spent his time in collecting information on Indian mathematics, astronomy etc and determined the specific gravities of number of metals and precious stones by the method of Archimedes. Ibn Sīnā (980-1077), a cotemporary of al-Bīrūnī and a well-known medical practitioner had all pervading interest in philosophy, mathematics, metaphysics and *sufism*, learnt both Indian methods of calculations (*Hisāb al-Hindi*) and Euclidean geometry, used mathematical principles in all his explanations creating lot of confusion among Indian scholars. His *Dānish Nāma-I'Ālā'l*, an encyclopaedia of Islām in Persian discussed on the question of matter and creation. In fact, Islamic sciences reached India and Europe through Ibn Sīnā's writings. Ibn Sīnā believed in the Qurānic doctrine and accepted God as a creator. He however believed in the theory of continuous creation and atomic concept of matter. His argument was that even the minutest portion of matter could be divided into two. The division may not be possible physically or in practice, but in imagination it can always be done, as is done in mathematics. To cite an example he says,' if we take a small number, its half can also be imagined and the nature of existence of divided and undivided numbers remain the same. He demonstrated that between any two *jawhars* (atoms) another *jawhar* can also be inserted, and *jawhar* can also be subdivided. With this analogy he says, ‘it is impossible for a straight line to intersect another straight line at more than one point’. Though the analogy is wrong, he succeeded in demolishing the atomic concept of matter to a great extent. Al-Hazen had the idea that the incident and reflected rays of light make equal angles with the reflecting surface, and his interpretation regarding relation between the position of the source of light and its image formed by a lens is known as al-Hazen’s problem. He had possibly some fair idea how to make mirrors and lenses and how these could be used to adjust the convergence or divergence of beams of light and bring its rays to a focus during war with opposition. On act of vision he also said, ‘We see something from the seen object passing into the eye’. Spain, specially Cordoba and Toledo, became active academic centres which compiled important Indian and other sources under the encouragement of Califs— Abdar-Rahman and al-Hakam II and others, became an active centre for Arabic ideas and learning. Islamic science flourished but perished within a short time. However, during the sixteenth and seventeenth centuries, European glassware started coming to India which included looking glasses, window-panes, spectacles, telescopes, burning and multiplying glasses, sand- or hour- glasses etc. It is reported that the Portuguese presented a pair of (European) spectacles to an old scholar in the Vijaynagar Empire for reading Sanskrit manuscripts, and Rudolfus, a member of first Jesuit mission in Akbar’s court had used spectacles (Qaiser, 1982, pp.71,75). Dānishmand Khan (original name Mullā Shāfīāi), a native of Yazd (Iran) an educated Iranian, who came to India to build up his career and became Governor in Delhi during the reign of Shejehān (1652), had a great liberal attitude towards science of Ibn Sīnā, works of Sanskrit scholars and of European experts. He even engaged Bernier, the French traveler to translate European works of Gassendi (1592-1655) and Descarte (1596-1650), which created lot of heart-burn among his colleagues. Ibn Sīnā’s works are still taught in Madrassas on India, without assessment. Maharaja Sawai Jai Singh (c.1688-1743) of Amber (Rajasthan) somehow got interested in the stone observatories of Nasīr al-Din al-ṭūsī (1271) of Maragha and Ulugh Beg (1424) of Samarkand, and built up five observatories in Delhi, Jaipur, Benares, Mathura and Ujjain to study observational astronomy in India. To accomplish the task, he commissioned a large number of scholars to compile astronomical texts and collect relevant information from other observatories. In addition, he made effort to manufacture replica of the novel movable instrument, *astrolabe* (well known for its use in Central Asia) for determining solar time and observation of a few stars in cosmos suitable for local latitude. The stone observatories of course had a limited scope and became a place of historical interest with the advent of telescope.

In Indian and Central Asian science, the concept of geocentric universe and the uniform circular motion of heavenly bodies has been still the major focus. From seventeenth century onwards, steel, steam, cannon, maxim gun, printing, etc brought Europe to the peak of dominance. Most clear and sharp expression of scientific revolution is found to blossom in Italy (mainly in the north), France, Holland and in England.

5. European Science in Colonial India (1801–1900)

The nineteenth century brought a new phase in scientific activities in India. It was the period of Colonial rule in India, but no concrete effort was being made to introduce British science in its curriculum.

5.1. Urge for European Science: It is the national movement which urged for fresh inputs of European science. Rammohan Roy (1823), in his letter to Lord Amherst, wished to have Baconian philosophy, which by that time became accepted as a pillar of modern science. Akhshay Kumar Datta, an editor of the *Tattvabodhinī Patrikā* (1843-55), established by Devendranath Tagore, who had working knowledge in French, German, Latin besides Sanskrit, expressed openly for the new European science. His study room was found to have been decorated with the portraits of Isaac Newton, Charles Darwin, T.H. Huxley and John Stuart Mill, besides Rammohan Roy and others. He wrote many tracts on physics, astronomy and other subjects. Bankim Chandra Chatterjee (1838-94) said, 'Hindu method was almost solely and purely deductive; observation and experiment were considered beneath the dignity of philosophy and science'. In this context he refers to the importance of experiments made by Torriceli & Pascal, heliocentric theory (sun is at the centre in stead of earth) of Copernicus, laws of Kepler, law of Universal Gravitation of Newton and many others (Lahiri, pp.48-49). A large number of indologists, and social scientists took great initiatives in favour of western science. Vidyasagar, a great Sanskrit scholar, who served Sanskrit College both as Principal and Secretary, was an ardent votary of western science in India and wished to have a body of men to have western science in mother tongue. In his *Jiban Carit* (1849), he summarized the lives of Copernicus, Galileo, Herschel and Newton, and summarized the European knowledge in science in his *Bodhadaya* ('Dawning of Sense', 1851).

There is no end to the list. With the establishment of three Universities in Calcutta, Madras, Bombay in 1857, many schools and colleges were started, and leaders took interest in European science, and extracted interesting information which is of great historical interest. Five observatories were also established of which the Madras observatory (1792) and Calcutta Observatory (1825) were founded by the East India Company for observing heavenly phenomena and upgrading geographical and navigational data. The remaining three were at Lucknow (1832), Poona (1842) and another at Poona College of Science (1882) established by the Indian monarchs for education in astronomical knowledge.

The colonial period also brought a significant turn when the Idea of a national scientific research institution came through the effort of Dr Mahendralal Sircar (1833-1904), which resulted in the establishment of *Indian Association for Cultivation of Science (IACS)* in Calcutta in 1876 to organize research in different fields of European science including lecture program through his initiative. On a regular basis lectures were delivered on, 'Thermo-Elasticity' by Mahendralal Sircar; 'Practical Class in Physics' by Jagadish Chanra Bose; 'Optical Study of Musical Sound' by Father Lafont; 'Iron Class of Metals' by Rajani Kanta Sen; 'Practical Class in Chemistry' by Ram Chandra Datta; and so on [Vide *Indo-European Correspondence*, February 17, 1886]. Father Lafont gave a demonstration lecture on 'Telegraphy without wire' and said it was the discovery of his student, Jagadis Chandra Bose some years back (*Indo-European Correspondence*, Sept 22, 1897). Jagadish Chandra's demonstration lecture on electric light, sewing machine driven by electric motor and X-ray passing through hand and many other topics are also reported (*Indo-European Correspondence*, 17 August 1888; see also Biswas, 2001, pp.256-331).

Slowly the craze for European science began to grow. Balaji Prabhakar Modak of Ratnagiri district of Bombay Presidency organized annual science exhibition at Rajaram College during Christmas vacation from 1893-96 in order to acquaint public with west scientific inventions, as reported in *Śilpa Kalā Vijñān*, a science journal of 1886 and *Karmānuk* (a Poona based monthly) of January 1897 specially with the grand exhibition of 1896. In another exhibition of 1896 Modok displayed X-ray machine, camera, telescope, microscope, coil illustrating Faraday's law, Morse's telegraphy, Edison's phonogram, water mills, automobiles, engines, along with practical demonstration on electricity, sound and light by volunteers.

5.2. Features of Input: The scientific knowledge in Europe made a gigantic leap forward with the foundation of scientific academies[2] for free discussion and introduction of telescope, spectroscope photographic plate & camera as the instruments for examining observations. The scholars like Galileo Galelei (1564-1642) in Padua and Johannes Kepler (1571-1630) in Tubingen both supported the heliocentric concept of the universe propounded by Nicholaus Copernicus (1473-1543) by using a telescope of refracting type with a lens (concave or convex) at one end of a tube and an eyepiece at the other end for observation. The telescope of course was not free from problems of spherical and chromatic aberrations diffusing images surrounded by colored halos. This problem was solved later with the use of a reflecting type of telescope by using a mirror (speculum or parabolic) by James Gregory (1638-1675), Newton (1642-1727) and later by John Hadley (1682 -1744). It was known that white light passing through a prism breaks into its component colors. Similar spectrum crossed by lines often dark, more rarely bright, was also found by astronomers when a light is passed through a slit. Each line of this spectrum is identified with a given element. This led to the basis for the discovery of Spectroscope, an instrument which helps to see the colored spectrum crossed by thousands of lines, each having different wavelengths throwing light on the physical composition of an individual star. Gustav Kirchhoff (1824-1887) and Robert Bunsen (1811-1899) discovered the application of spectroscope to chemical analysis successfully discovering the elements — Caesium and Rubidium. The photographic plate and camera played equally a significant place in the analysis of the observation. An image of the object as seen by means of a system of lenses thrown for a definite length of time on in a plate or film made of glass, celluloid or other transparent material is important for photography. A steady effort was also made to collect the basic texts and articles for knowledge based on the works of stalwarts in European science. In addition, a number of concepts in physical science enriched and influenced Indian perception towards the end of 19^{th} and beginning of 20^{th} century, a summary of which as developed (Brennan, 1997; Rao, 1999; Pal, 2008) will be of interest:

Motion of body or bodies was of great interest to Newton (1642-1727). To explain, he introduced definitions and axioms in the same way Euclid did. His axioms were interpreted as 'assumptions' by scholar like Ernest Mach. Newton defines mass, momentum, rest, uniform motion and others. In his *Principia* (full title: *Philosophiae Naturalis Principia Mathematica)*, he attempted how inanimately nature could be explained in mechanical terms. He enunciated three laws of motion, viz., (i) Every body preserves in its state of rest (velocity zero), or of uniform motion (moving with constant velocity) in a straight line unless it is compelled to change that state by impressed forces; (ii) Change of motion (i.e. the rate of change of momentum) is proportional to impressed force, and takes place in the direction in which such force is impressed; and (iii) To every action there is equal and opposite reaction. To explain his first law in a plane or space of 2-dimensions, he developed the definitions of *Distance* as $OP = r = \sqrt{(x^2 + y^2)}$, where r is the

[2] Accademia Secretorum Naturae founded in Naples (1560); Accademia dei Lincei in Rome worked from 1603 to 1630; Academia del Cimento in Florence (1657) survived for ten years; Royal Society for the Improvement of Natural Knowledge in Gresham College of London (1662); Academie des Sciences in France (1666); Berlin Academy in Germany (1700), and so on. Italian academies were involved in the conflicts between science and orthodoxy, while the English, German and French Academies in the development of utilitarian science arts & technical processes etc.

distance between O (0,0) and P (x,y); *Displacement* PQ = s = $\sqrt{[(x')^2 + (y')^2]}$ if the point P (x,y) moves to another point Q(x′, y′) in time t ; both distance OP and displacement PQ have magnitude and direction (known as vector quantities, also as position vector and displacement vector respectively), though the position vector OP and displacement vector PQ have different directions. *Velocity* (*v*), is defined as v = d/dt (s), or v = d/dt (x) and d/dt (y) when t tends to zero along either X and Y axis respectively in a one or two-dimensional situation. Velocity is also a vector quantity, and has the direction of displacement vector. *Acceleration* (f) is defined as the rate of change of velocity, f = d/dt (v) or dv/dt, when dt $\rightarrow$ 0 in notation. *Momentum* = mass x velocity = m.v; and so on. In case of 3-dimensional space of three mutually perpendicular axes, the position vector OP [O (0,0,0) and P (x, y, z) are the coordinates] satisfies the *distance* of OP= d′ = $\sqrt{[(x)^2 + (y)^2 + (z)^2]}$ (in Cartesian coordinates]. However, in Polar coordinates of 2-dimension, the length OP [where O (0,0 and P (r, θ) the position vector, r being the radius of a circle, and θ is the angle with reference to an axis, say OX] = magnitude r; if it moves to Q (r + r′, θ + θ′), then the *distance* PQ = s′ = $\sqrt{[(r')^2+(r\theta')^2]}$, for the arc length arc (= rθ′), angle is measured in radian, and r′ being considered perpendicular to each other, when the change of position is small and is taken as good as straight. so is in polar coordinates of 3-dimension. Newton's second law introduces the new conception of force which was not very clear during his time in view of his assumptions of absolute space and absolute time invalidating his mechanics for moving objects, including rays of light, although not for the more slowly moving objects to which Newton applied it. The second law at best could be defined as 'amount of force', given by F = m.f, where F is the force applied which induces a change in the velocity due to mass (quantity of matter in a body, and f is the acceleration defined as the rate of change of velocity. The first two laws of Newton were derived from that of Galileo (1564-1642). Newton's third law of course appears somewhat new which talks about forces exerted by two objects to one another are equal and opposite, or in short, when a body is dragged on a surface with a force, say x, then the surface exerts a backward force x to the body.

***Periodic Motion* in a pendulum**, as observed by Galileo, is a regular to and fro motion, which is termed as *periodic motion*, repeating itself over an interval of time. Or in other words, when a pendulum bob starts moving from one end point reaches to the end point of the other side passing through a position of rest (known as *amplitude*), and swings back to the original point moving through the position of rest, time taken is known as *time period*. Then he introduced a term, *frequency* as the number of such cycles completed in one second (i.e. νT = 1, or, ν = frequency = 1/T, where T is the *time period* for one oscillation). The *harmonic motion* is likewise defined by water-waves at a given point on its surface, with its two consecutive position of crests up and down having amplitude is A or –A along a particular direction, when the time (t = ½T) changes. The motion of the pendulum is almost closer to wave-motion or an *oscillatory* (*vibrational*) motion along a straight line, known as *simple harmonic motion*. In a water-wave motion, the displacement of water particles is found moving in a direction perpendicular to the direction of the motion, known as *transverse motion*. The distance covered between two consecutive crests or troughs is known as *wave length* (λ). If number of crests (ν) pass through a point per second, then the distance through which a crest moves in one second is known as the velocity of the propagation (V = νλ, V= velocity of propagation, ν = frequency and λ = wave-length).

Another key concept, ***Law of universal gravitation*** existing between any two material bodies, which Newton postulated in his *Principia*, was known. He made a basic postulate that two material bodies have always an attractive gravitational force (F) just because of their masses, and the force on each other is, $F = G.Mm/R^2$, where M and m are the masses of two bodies separated by distance R between them and G is the gravitational constant. Comparing with Newton's second law and replacing f by g, which gives $g = GM/R^2$ as the acceleration due to gravity. The value of g remains same for all bodies situated close to each other on the earth's surface. This gravitation theory of Newton is derived from Kepler's law of inverse square and he suggested that the planets move exactly in accordance with Kepler's three laws, viz., (i) The planet moves in an ellipse which has the Sun at one of its foci; (ii) The line joining the Sun to the planet sweeps out equal areas in equal times; and (iii) The square of the time which any planet takes to complete its orbit is proportional to the cube of its distance from the Sun. The first two laws was enunciated by Kepler in his book, *Astronomia nova* (1609) and the third law in his *Epitome Astronomiae Copernicae* (1618). The argument was based on that the earth is not exactly spherical, in which R slightly varies from equator to the poles. For a body taken to a height h, R also is changed to (R+h). On this basis, Newton tried to generalize the motion of two or three bodies (Earth and Sun, or Sun, Moon and Earth) when they attract mutually under gravitational attraction. The last problem is known as 'problem of three bodies', the solution of which attracted lot of attention from the later scholars. The law of falling bodies of Galileo that two bodies of different masses are allowed to fall from rest they reach the ground at the same time (only air is the hindrance), which showed weight ($W= mg$) as product of its mass and gravity. The *kinetic energy* is achieved due to motion when mass and velocity are known [$\frac{1}{2}\, m\, v^2$]. *Work done* by a body when it falls through is found by the product of its weight and height through it has fallen (i.e. mgh). Work done when a force makes a displacement by product of the force by its displacement (i.e. F. s or – F. s towards or opposite to the direction of the force, where F = force applied, and s = displacement). This is based on the hypothesis that there is transformation of energy taking place from one stage to another, but total energy is constant. Newton's law of gravitation, however, was finally modified by Einstein, which recognized the impossibility of determining absolute motion and suggested the *concept of space-time continuum*. The *special theory* is limited to the description of events as they appear to observers in a state of uniform motion relative to one another and is based on two axioms, viz., the laws of natural phenomena are the same for all observers, and the velocity of light is the same for all observers irrespective of their own velocity. The important consequences of this theory are— the mass of a body is a function of its velocity; the mass-energy equation may be meaningful for the inter-conversion of mass and energy ($\varepsilon = \frac{1}{2}\, mc^2$). Fitzgerald-Lorentz combination accordingly appeared as a natural consequence of the theory. His general theory which is applicable to observers not in uniform relative motion, has propounded that the presence of matter in space causes space to curve in such a manner that the gravitation field is set up. The gravitation becomes a property of the space itself. The validity of the theory of relativity has been confirmed by modern experiments.

Sound and its propagation, according to Newton, is produced when there is movement of the particles (in the medium, say air). It generates a vibration which produces periodic compression and rarefaction in the material medium. The propagation takes place from one layer to the next in the same direction of the direction of the particles generating the vibration. Sound waves from a bell moves as *longitudinal waves*, as each particle of air moves alternately towards and away from the bell. The waves of water on a pond is little different, the individual particle of water moves up and down and at right angles to the surface, i.e. the direction of vibration and propagation are at right-angles, called *transverse direction*.. In empty space, there is no material medium, so no sound is produced in empty space. The *intensity* or loudness of sound is proportional to the square of the amplitude of vibration, its *pitch* is determined from the frequency of the vibration. *Octave* is the scales of the musical notes when they are spaced by frequencies differing by a factor of 2. Two notes of similar frequencies (differing in pitch only, e.g. frequency í and n í, where n is an integer) form *harmonics*; when two notes produced from two sources are close to each other producing the same frequency, they are in *resonance* producing a sound easily detected by a trained year. The *quality of the note* is understood from quality of mixture of notes produced by different instruments, for notes of each instrument depends on a strong component together with a small admixture of the higher harmonics, which is somewhat impure.

Light, Newton believed, is nothing but corpuscles. It moves in straight–line and satisfies the law of reflection. Newton, after succeeding Burrow as professor in chair of mathematics in Cambridge published a paper, 'On the theory of light and colour' (1801), which revealed the true meaning of colour. He had made a small hole in the shutter of his room through which a beam of sunlight could enter the room and is made to pass through a prism. He found that the beam had spread out into a coloured band of light called, a *spectrum*, in which all the colours of rainbow, from red to violet, could be seen in the same order as in the rainbow. He understood and explained that different colours meant different degrees of refrangibility, i.e., a ray of violet light had refracted through a greater angle than one of red light at a refracting surface. He arranged for a second refraction in a direction at a right angles to the first, and found that different colours of light retained their identities after the second refraction, red remained red, and violet remained violet, each maintaining precisely the same amount of refraction as before. As to light, Newton had no clear idea, in his *Opticks, he* however expressed it as a strange mixture of *corpuscular and undulatory* theories, which was just a conjecture. Christian Huygens in his *Traite de la Lumiere* (1890) described space as a 'very subtle and elastic medium' and thought that a luminous object set up disturbances at this medium at perfectly regular intervals of time. These regular impulses produced regular undulations in the medium and propagated in all directions in the form of spherical waves. Hooke suggested that light might consist of *tranverse waves*, and each particle of ether moved at right angles to the direction in which the light was traveling. He implied that a ray of light had 'sides' in the Newtonian sense, one in the direction in which the particle moves, and the other in the direction of the wave, which is at right angles to the direction. Newton was aware how the use of lenses, their properties and geometrical knowledge have brought forth the use of telescope at the hands of Kepler and Huygen for viewing distant objects. The correct law of refraction discovered by W. Snell (1621) of the Leiden university emphasized by Descarte was also known to him. That the light moves in waves, and its properties were propounded by Grimaldi (a Jesuit professor at Bologna), Huygens, Franhaufer and Fresnel. Grimaldi, in his book, *Physico de Lumine, Coloribus, et Iride*, first used three screens holding parallel to each other, first having one hole, second having two holes, and the third having no hole When a source of light is hold before the hole of first screen, the light passing through the holes of the first two screens is projected on third screen, it was found that the light at the two points in the third screen is well lighted, but the intermediate areas also showed rhythmical alteration of light and darkness, having the same origin as rainbow. It provided a satisfactory understanding that the light moves in waves. There were experiments made by other scholars justifying the phenomena. By the same time Young supported this interference pattern in light and said that it is possible for monochromatic life., i.e., with light of one single spectral colour. If white light is used, the different constituent colours of light are of different *wavelengths*, and produce different patterns on the screen, the result being complicated patterns of vivid colours. From the dimensions of the pattern formed by any single colour of light, it was possible to deduce the wavelengths of light. Fresnel found in 1821 that red light has about 4000 waves to the inch, and violet light about 80,000, the intermediate colours being of course intermediate in wavelength. The *undulatory* theory had intimate connections that the time of travel of a ray of light attains its minimum value along the path actually travelled by the ray. H.L. Fizeau measured the *velocity of light* in air and found a speed of light about 315,300 km per second in 1849, while J.L. Foucault, his compatriot, performed a series of experiments by a number of different methods, and obtained a more accurate value of 298600 km per second. Michelson has measured the velocity as about 299,770 km (186,300 miles per second). Of course it was found less rapid in a denser medium as per Fermat's theorem. This fixed a final nail in the coffin of the *corpuscular theory of light* of Newton.

Polarization is an important property of light. Huygens observed that when a slab of glass is laid on a page of print, letters could be seen clearly, although a little displaced on account of refraction in passing through the glass. But if a slab of calcite (Iceland spar) is laid on the page, each letter gets double, since calcite has remarkable property of breaking light into two distinct rays travelling in different directions, and it is a case of *double refraction*. *Light is a transverse wave*, the vibrations themselves being at right angles to the direction of the light path. In its isotropic property of vibration it is known as un-polarized, as it moves in all direction. In plane-polarized light, the vibrations confined to one plane, known as plane of vibrations, and the vibrations which are confined to the plane at right angle, is known as the *plane of polarization*. The polarization to a vibration is strictly confined to a particular direction. It is done through passage of un-polarized light through thin plates of Tourmaline crystals. However, polarization through solid crystalline bodies, because of their special crystal structures, can be adjusted to preferred directions.

Magnetic properties, as described in Gilbert's publication of *De Magnete* (1600), dealt mainly with magnetic materials and magnetic properties. Only one small chapter dealt with *electricity*. Magnetic materials had a practical value in the science of navigation. The mariner's compass—a small pivoted magnet had been invented by the Chinese in the eleventh century which was introduced into Europe by the Mohammedan sailors. Among the magnetism materials —Lodestone (an oxide of iron), Ferromagnets (Iron & Nickel), Bar magnet (suspended by a thread points towards north-south, aligning along a direction towards geographical north-south axis of the earth) were quite known. Two poles of a bar magnet near its two ends indicate charges equal in strength but opposite in character. *Magnetic moment* of a bar magnet is calculated by multiplying strength or magnitude each pole by its distance between the two poles. Magnetic moment is a vector quantity, and its direction is conventionally taken from south to north pole, The north (north-seeking) pole of one magnet always attract south (south-seeking) pole of the other magnet, where as two like poles repel each other. Earth is a huge bar magnet as it contains huge magnetic materials. But the magnetic compass indicating north of earth means that the geographical north of earth has the same magnetic character as the south pole of a bar magnet. The magnetic are actually the impact of electric currents passing through the materials, i.e. atoms and molecules of the material carry current on a microscopic scale, and the magnetic moment is the fundamental property of these subatomic particles. In a ferromagnetic substance, the magnetic moments are usually forced to align in a certain direction by suitable physical methods.

Electric property or electricity in the rubbed object, Gilbert explained, that when a piece of amber is rubbed in the proper way it acquires the power of attracting light objects. C.F. du Fay (1733) tried to explain the phenomena of attraction and repulsions on the supposition that all substances contained two kinds of electric fluids, usually present in equal quantity, and then neutralize one another. Benjamin Frankin (1752) suggested that lightning was an effect of electric conduction and confirmed this in his famous kite experiment. In 1773 physicists became also interested in the shocks produced by so-called electric fishes, the *Torpedo* and the *Gymnotus*. George Simon Ohm (1827) replaced the vague descriptions by a more exact scientific terminology, and introduced precision into ideas of quantity of electricity, current strength and electromotive force. Faraday by 1800 introduced most of the present day terminology of electrochemistry, the process of decomposing a substance (electrolysis) into its simpler constituents by a flow of electricity, the resolved substance he called 'electrolyte'. Electricity thus far linked with light and heat, and the foundations were laid on electric lightning and heating. But a far more interesting is the connection between electricity and magnetism.

***Electromagnetism**, b*y 1800, is believed by the physicists that there must be some connections between *electricity* and *magnetism*. H, C. Oersted (1820) of Copenhagen found that a magnetic needle which was balanced on a pivot or hung by a thread is deflected from its position when an electric current flows in its vicinity. This single observation prompted the discovery of telegraph, the tapping of telegraph key (at one point in an electric circuit alternately making and breaking the circuit hundreds of miles away). The same observation made it possible also to discover an instrument called, *Galvanometer*, for measuring intensity of an electric current from its amount of deflection. The French physicist Andre Marie Ampere immediately understood the importance of Oersted's experiment and changed two magnets, which deflect one another in proximity, replaced one magnet, also the other magnet with wire carrying currents, the effect remaining the same. He obtained the result what he anticipated that two currents attract or repel one another just like two magnets. Michael Faraday (1791-1867), an assistant to Sir Humphry Davy at the Royal Institution, London, wondered whether a current flowing in a circuit might not in the same way induce another current in a nearby circuit. He tried many ways but without success, but soon found that the motion of a magnet in the proximity of a circuit induced a current in the latter. In this way the mechanical work of moving a magnet could be used for producing electric current. This made the basis of the structure and operation of dynamo (mechanical production of electric power), and all forms of electric transport—trains, trams, elevators and so on (by following a converse procedure of transforming the energy of an electric current into mechanical energy). In this experiment Faraday hinted but not clear about the line of force which the magnet or electric charges are acting in case of ether which was imagined to fill all space. Clark Maxwell (1831-1879) followed the line of Faraday and published a paper in 1864 in mathematical language, by attributing electric and magnetic action to pressures and tensions in the ether showed that any disturbance created in the ether by electric and magnetic changes would be propagated through it in the form of waves. The speed with which these electromagnetic waves would travel in space is the same as the speed of light. In such waves the electric and magnetic forces would be at right angles to one another, and move also to the direction in which the wave was travelling. These waves would be propagated at a uniform speed which could be calculated and proved, to within the limits of experimental error, to be precisely equal to the speed of light (*Maxwell's Electromagnetic theory*). Further, Maxwell pointed out that these electromagnetic waves would extend over a wide band of wave lengths and exhibit properties of heat (infrared), light, ultraviolet, x-rays, γ-rays. Heinrich Hertz (1857-1894) in 1887 succeeded in making electrical sources emit waves and were shown to possess all properties which Maxwell's theory required of them, as well as known properties of light-waves, except that they were of much greater wavelength. They were in fact what is now known as 'radio-waves' of very short wavelength.

Radiation, Wavelength, Frequency and Charge have important relationship with matter. It was observed by some experimenters by end of 19th century that their electric instruments discharged themselves with out any apparent reason and conjectured that there must be some kind of radiation (the invisible rays that is emitted from a source). They were of the same intensity by night and by day, could arrive at the southern hemisphere when the Milky way was not visible, it was thought it might be extra-terrestrial and the result of some cosmic process, and became known as 'Cosmic radiation'. Following Kirchhoff, the inventor of Spectroscope by 1869, Max Planck in 1900 first noted that all objects radiate energy. A black body (a theoretical object) absorbs all frequencies of light of various intensities of wave lenghts, and when it is heated it radiates all frequencies of light.

Radiation is described in terms of its wavelength (distance between the successive wave crests). So is frequency as number of crests that arrive per second. It was also noticed that when the wavelength is short, the frequency is high and vice versa. Various forms of radiation compose the electromagnetic spectrum. The radio waves have very long wavelength (very low frequencies) followed by infrared heat radiation, visible light, ultraviolet radiation, x-rays, gamma and cosmic rays with very shorter wavelength (very high frequencies). Ordinary sunlight being a mixture of waves of seven colours (seen sometimes as a rainbow) have continuous range of frequencies. The smallest frequency (having the largest wavelength) produce a sensation or radiation of red colour in our eye, and the largest frequency (having the smallest wavelength) violet in the eye in the normal visible range (wavelength varying from 10^{-7} to 10^{-6} meters, roughly 10^{-5} cm). But the number of different frequencies in the high frequency range is greater than the number in the low frequency range.

It was argued that if a blackbody radiates all frequencies of electromagnetic radiations equally, then virtually all the energy would be radiated in the high frequency range. *Infrared* has higher wavelength (0.8 μm to 10^{-4} metres) than immediately following red, and *ultraviolet* has wavelength smaller than violet (4×10^{-7} to 5×10^{-9} meters), both are invisible to human eye. Above the infrared, the spectrum of wavelengths increases through the waves of micro and millimeter wavelengths and *radiowaves* in the range of metre wavelengths. Beyond ultraviolet on the other side, *x-rays* (5×10^{-9} to 6×10^{-12} metres approximately) and γ- *rays* (10^{-12} to 10^{-13} metres) which is emitted by atomic nuclei, have extremely short wavelengths. X-ray is also measured in Angstrom unit (1 Angstrom = $10^{\mathbf{-8}}$ cm or 10^{-10} metres). The frequencies are measured in Hertz (Hz) after the name of Heinrich Hertz, who first succeeded in making electrical sources in the laboratory emit waves. Hertz, SI unit of frequency of a periodic phenomenon is so named and derived in which the periodic time is one cycle per second. Other bigger units are kilohertz (1 kHz = 10^3 cycles per second), and megahertz (1 MHz = 10^6 cycles per second) [Fig. 1].

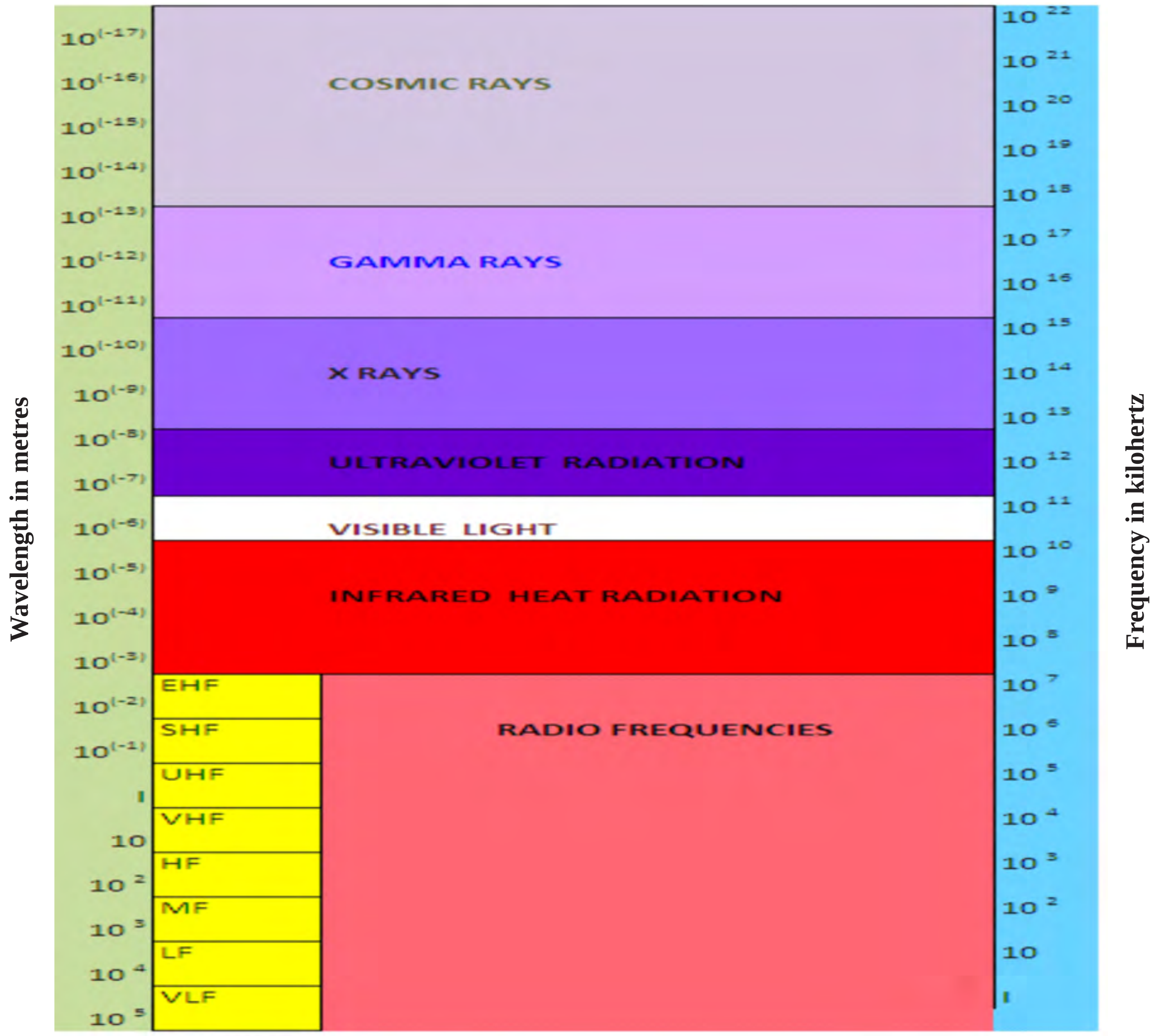

Fig. 1. Electromagnetic Spectrum – Radiated energy in terms of wavelength and frequency; when the wavelength is short, the frequency is high and vice versa

Periodic table of element, structure of atom, atomic number, mass, and charge opened up as another very important area for study of matter in this context. From the position of an element in the periodic table its properties may be predicted with a fair measure of success. By seventeenth century almost twenty elements – Copper (Cu), Iron (Fe), Silver (Ag), Gold (Au), Mercury (Hg), Carbon (C), Tin (Sn), Lead (Pb), Antimony (Sb), and Sulfur (S), Zinc (Zn), Cobalt (Co), Nickel (Ni), Platinum (Pt), Arsenic (As), Bismuth (Bi), Nitrogen (N), Oxygen (O), Phosphorus (P) and Hydrogen (H), were roughly identified by various countries.. Robert Boyle described them as simple, unique, unmixed material bodies and were made up of other similar and dissimilar bodies. Lavoisier (1743-1794) of France in 1789 first published a list of 23 elements, following a method of chemical decomposition, and adopting a method of weighing reactants and products in chemical reactions. He for the first time explained the nature of combustion, and that water is a chemical compound of two gases— hydrogen and oxygen, and air consists of molecules of two gases— nitrogen and oxygen. The word 'gas' was commonly used in place of 'element'. Priestley discovered nitric and nitrous oxides, hydrochloric acid gas, sulfur dioxide and several other gases. With more and more understanding of the properties of elements, an urge was felt to arrange them in an order according to their properties. By 1869, Mendeleyev (1834-1907), the great Russian chemist, published a periodic table, but his table had many gaps and he had no idea of inert gases (or noble gases) –Helium (He), Neon (Ne), Argon (Ar), Krypton (Kr), Xenon (Xe), Radon (Rn). These inert gases have no colour, odour, taste, and also do not react chemically with other elements. In 1896 Becquerel discovered Uranium as radioactive material (radioactivity) and Madam Curie Polonium (Po). For an over all idea of elements, the concept of the structure of atom was a necessity. J.J. Thompson (1904) discovered 'electron' as an important constituent of atom of all elements, and proposed that it has negligible mass, and negative charge too. Thompson and Rutherford of the Cambridge University (UK) described atom having *nucleus* at the core consisting of *neutron* (neutral charge) and *protons* (positively charged), surrounded by electrons (negatively charged). They assigned mass number (sum of protons and neutrons in the nucleus), atomic number (equal to the number of protons in the nucleus). Atoms are neutral because they have the same number of protons and electrons. Isotopes of element having atomic number but different mass numbers were also recognized. By 1900 Max Plank believed that atoms were the basic building blocks of nature, and energy is continuous, radiated in waves, irrespective of heat, sound and light waves. He introduced the word, '*quantum*' (plural '*quanta*') as the unit of energy radiation, and formulated a relationship (ε = hf, where ε is the unit energy radiation, f = frequency of vibration, h = Plank's constant) by saying that if quantum's energy and frequency of radiation times are inversely proportional to the wavelength, then both were directly proportional, as accepted later on by Neil Bohr. In 1913 he proposed that electrons move around nucleus in orbits, and each orbit has a quantum number having a specific energy. Electron can jump from one orbit to another, and in such a case energy change occurs accompanied by absorption of radiation (or, $\varepsilon_2 - \varepsilon_1$ = h f, i.e. h f is the energy changes from 1st orbit ε_1 to 2nd orbit ε_2, where f = frequency of radiation, h = Plank constant, an extremely small number and recognized as one of the fundamental constants of the universe = 6.626×10^{-34}). *Spectrometers* are often used to measure absorption and emission of light for electron jump. The frequency of radiation is again related to wavelength (i.e f = c/λ, where λ = wavelength, c = velocity of light = 3×10^8 ms^{-1}). Electron, just like light, has wave properties, known as orbitals, and rules have been formulated for calculating energies of different electron orbitals. The systematic classification in the Periodic table with their physical properties along other seminal ideas helped the physicts greatly. Thousands of compounds were identified from naturally occurring substances and many have been discovered in the laboratory. As many as 110 elements are known, vide Periodic Table [Fig. 2].

The knowledge confined to various elements with atoms as basic units was initially thought to be highly empirical, until Mendeleyev could put them into a profound order and forecast the existence and properties of the then undiscovered elements by means of his original table, supported by vast array of spectroscopic data, and to arrange them in the Periodic Table. It was also understood that atom, within the framework of quantum mechanics, was not an elementary particle, rather a composite object, with electrons orbiting around a central heavy nucleus (with linear dimension 10^{-4} or 10,000 times smaller than the size of the atom) in a 'shells', defined by four elements— atomic number, mass number, periodicity, and similarities, in accordance with the Pauli Exclusion principle. The same theoretical framework provided a

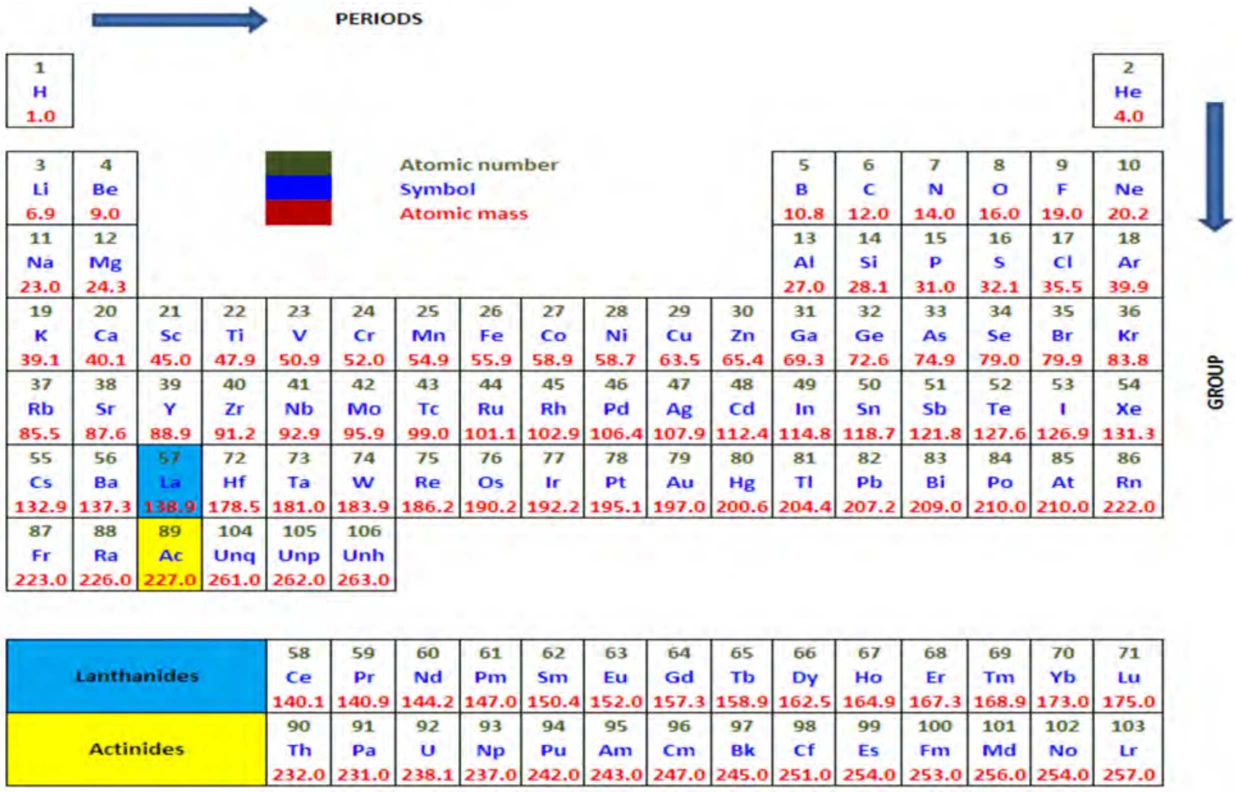

Fig. 2. Periodic table : Elements display similar properties at regular periods and elements in a group are similar

natural understanding of molecular bonds having diverse chemical properties of matter in an integrated fashion. This is specially important, for it introduces for the first time an idea of group concept in the understanding of matter.

6. Golden Period of Physical Science in India (1901–1960)

By the University Act of 1904 the three universities of Calcutta, Madras and Bombay were allowed to conduct teaching and research on physical science and other subjects. A large number of qualified teachers and research students went to Europe for various expertise and higher degrees. Research in physical science started with great vigour in all these universities. A survey of research output made by S.N. Sen and Santimoy Chatterjee (*IJHS*, 1992-93) in the field of physical science made during 1800-1950 will be of interest. In this context, it may also be noted that there are many papers left out from this list, for which INSA Biographical M emoi res of well-known scientists and similar publications may be consulted.

A few prominent names in this list, are — Jagadish Chandra Bose, C.V. Raman, Megnad Saha, S.N. Bose, S.K. Mitra, Homi Bhava, S. Chandrasekhar, and others. The European science paved the way but Indian physical scientists raised the boundaries of knowledge in the field to a great height. Publications were mostly done in top international journals like *Transaction of the Royal Society* (Edinburg), *Transaction of the Optical Society* (London), *Transaction of the Faraday Society* (London), *Transactions of the Chemical Society* (London), *Nature* (London), and many other Journals abroad, besides Journals in India, like the *Proceedings of the Asiatic Society of Bengal* (1776), *Bulletin of the Calcutta Mathematical Society* (1908) etc. All contributors were extremely motivated and took research as a

Research Output during 1901-1960

Electricity, Conduction, Discharge & Biophysics	19 papers in 19th & 204 in 20th century (first half)	Jagadish Bose (109 papers), P.C. Mohanti (15), S.K. Kulkarni Jatkar (14) and others
Acoustics	2 papers in 19th & 258 in 20th century (first half)	C.V. Raman (58 papers), R.N. Ghosh (29), M. Ghosh (15), S. Parthasarathy (13) and others
Heat & Thermodynamics	8 papers in 19th & 204 in 29th (first half)	M.N. Saha (17 papers), D.S. Kothari (16) and others
Magnetism & Electromagnetism	12 papers in 19th & 302 in 20th century (first half)	D.M. Bose (12 papers), A. Bose (11), S.S. Bhatnagar (32), K.S. Krishnan (20) and others
Optics & Radiation	5 papers in 19th & 659 in 20th (first half)	C.V.Raman (113papers), K.S.Krishnan (28), R.S. Krishnan (24), S. Bhagavantam (19), G.N. Ramachandran (16), K.R. Ramanathan (15) and others
Atomic & Molecular Structure	104 papers (1920-1950)	D.M. Bose, C.V. Raman, K.R. Ramanathan and others
Crystal Structure & Properties	313 papers (1920-1950)	C.V. Raman (35 papers), K.S. Krishnan (45), S. Bhagavantam (16), K. Banerjee (15) and others
Radioactivity, Nuclear physics & α-,β-,γ-rays, Cosmic rays	417 papers (1910-1950)	D.M. Bose (16 papers), M.N. Saha (14), R.S. Krishnan (12), H.J. Bhabha (53), K.C. Kar(18), Vikram Sarabhai (12) and others
X-rays	236 papers (1920-1950)	C.V. Raman (19 papers), B.B. Ray (25), G.N. Ramachandran (10), S.R. Das (13), P. Krishnamurti (12) and others
Astronomy & Astrophysics	80 in 19th & 431 in 20th century (first half)	M.N. Saha (26 papers), N.R.Sen (26), A.C. Banerjee (14), D.S. Kothari (20), V.V. Narlikar (11), S. Chandrasekhar (78),P.L.Bhatnagar (10) and others
Geophysics	200 papers in 19th & 617 in 20th century (first half)	S.K. Mitra (72), M.N. Saha (11 papers), K.R. Ramanathan (28), S.K. Banerjee (27), S.R. Khastagir (12) and others
Statistical mechanics, Wavemechanics & Wave statistics		S.N. Bose, K.C. Kar, K.K. Mukherjee and others.

way out in their national movement and wanted to assert that they are no less competent than European scholars. A few of these scholars, as identified, will be taken here to have an idea of their contributions in the field.

In nineteenth century there was practically no research in physical science in India other than the effort taken by IACS at Calcutta. Sir Jagadish Chandra Bose of Presidency College, Calcutta, gave regular lectures at IACS and conducted research in short electromagnetic waves and other topics which achieved international fame in spite of various limitations in space, instruments, funds and so on. His biography and contribution along with others in applied research are considered here as a case study and will be of interest. It is known that most of his instruments were locally manufactured with great novelty.

6.1. Jagadish Chandra Bose

Fig. 3. Sir Jagadish Chandra Bose (1858-1937)

Jagadish Chandra was born on 30 November 1858 in the town of Mymensigh in Bengal, where his father, Bhagwan Chandra Bose was then posted as Deputy Magistrate. He had his school education in Faridpur, and obtained his BA degree in Physical Sciences from St Xavier's College, Calcutta. He went to Cambridge for Tripose examination. For this examination he had to take training both in physical and biological sciences when he came under the influences of well known teachers (Lord Rayleigh, Sir James Dewar, Sir Michael Foster and Francis Darwin). In 1884 he obtained his degrees in BA (Cambridge University) and BSc (London University), and came back to India and joined Presidency College, Calcutta in 1885 as Assistant Professor of Physics. He obtained his D.Sc. from London University in 1896, and made a number of visits for lecture tours to Europe and USA between1896 to 1930. He was recognized as Jagadish Chunder Bose during his life time. He retired as professor of Physics from the college after 30 years' service. He was knighted in 1917 and elected Fellow of the Royal Society in 1920. After his retirement from Presidency College in 1915, he was offered the post of Palit Professorship in Physics of the Calcutta University, but he regretted his inability to accept it in order to fulfil his dream to build up a research institute on the model of the Royal Institution, now known as Bose Institute (Bose & Ray, p.274). He collected all his personal savings and public donations for this institute which was build up at Upper Circular Road, Calcutta, and inaugurated in 1917. He became its first Director and continued his investigations here till to his death in 1937. The Bose Institute carries his touch, paintings, frescoes, beaten metal works, portraits of great savants of his time like Nandalal Bose, Abanindranath Tagore, Gaganendranath Tagore, Rabindranath Tagore and others.

Jagadish Chandra published 128 research articles besides 11 monographs (vide his list of publications in the *Biographical Memoires*, Vol I, pp.7-21, published by INSA). His scientific pursuits may be classified in three phases:

1894-1900: Articles include his work on polarization of electric rays by double refracting crystals, construction of electro-polariscope, determination of wavelength of electric radiation, construction of apparatus for the study of electric waves, construction of a compact apparatus for generation of electromagnetic waves of wavelength 25 mm to 5 mm, and analysis of their quasi-optical properties; rotation of the plane of polarization of electric waves, self-recovering coherer and the study of *cohering* action of different metals; electric touch and the molecular changes produced in matter by electric waves;

1901-1907: Investigation concerned with behavior of plant tissues under different modes of stimulation, construction of delicate and accurate instruments for automatic recording of plant responses; preparation of inorganic models of bio-physical phenomena underlying electrical and mechanical responses to stimulation, the transmission of excitation in plant and animal tissues, and of vision and memory; results are published in his book, *Comparative Electrophysiology* (1907);

1907-1933: Investigation of response phenomena in plants the complexity of which lies intermediate between those of inorganic matter and of animals.

Jagadish Chandra first focused his research attention in the construction of a compact instrument for the **generation of short electromagnetic waves** and to study their optical properties. Most of the scholars believe that he was possibly influenced by Oliver Lodge's paper on "Heinrich Hertz and his successors", published in 1894. However, immediately after joining Presidency college in 1895, he started his experiments in a small enclosure (laboratory) adjoining a bath room at the College, on refraction, diffraction, polarization and transmission of millimeter waves. He was a great innovator. To receive the radiation, he used a variety of different junctions connected to a highly sensitive galvanometer. He plotted in detail the voltage-current (non-linear) characteristics of his junctions, and devised ingeniously diffraction-grating for millimeter waves by using polarizers, made of cut-off metal gratings of a book Railway timetable with sheets of tinfoil interleaved in the pages, and inserting these plates at regular intervals. He even used twisted jute bundles in order to rotate polarization of millimeter waves. In 1895 he demonstrated wireless communication, rang a bell and exploded some gunpowder (placed in room at a distance and separated by more than one wall) using millimeter waves in Calcutta.This achievement was reported in 1896 in Daily Chronicle of England thus: 'The inventor (J. C. Bose) has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel' (Emerson, p.33; Bhattacharyya, p.46). In December 1895 Russian scholar Popov who was doing similar work expressed that he was still hoping to achieve remote signaling. However, in May 1897 Marconi obtained patent right on wireless signaling, which was already reported a public demonstration of wireless signaling in 1895 in Calcutta.

Bose invented a **diode detector of wireless waves**, then known as self-recovering coherer. He fixed an *emitter* and a *detector*, attaching his emitter of microwaves in a cylindrical or rectangular metal tube, a precursor of wave guides, and used an antenna pyramidal electromagnetic horn in his compact electric apparatus for better electric radiation. This was possible by selected metals, by adjustment of pressure and applied e.m.f. In the process he classified two groups of metals for his detector, i.e. in positive group—galena, iron, nickel, magnesium, tellurium, in which current increased in the circuit with absorption of radiation, and in negative group—potassium and specially precipitated silver powder in which galvanometer current is decreased on absorption of electric radiation. The current voltage curves with the current axis were found to be concave with the positive groups, and convex with the negative groups. Bose found galena crystal as a perfect detector not only for absorption of perfect radiation, but also for absorption of light radiation, from ultraviolet to infrared. He also explained the construction of a reflecting metal strip concave grating with which he measured the wavelengths of the electric radiation given out by one of his radiators. These he found to be of the order of 20 mm wavelength. On invitation from Rayleigh, Jagadish Chandra reported about his microwave (millimeter-wave) experiments to the Royal Institution and other societies in England with wavelength ranging between 2.5 cm to 5 mm (Emerson, p.33). Patent rights for the use of galena crystals for making receivers both for short wavelength radio waves, for white and ultraviolet light were granted to him in 1904. K. F. Braun and G. Marconi (joint Nobel Prize winner of 1909) in their Nobel lecture referred initial problem of increasing the range of spark gap in wireless transmitter, how after 1901 they have sorted out the problem by using galena (lead sulphide) based contact detector discovered by Jagadish Chandra (Bondyopadhyay and Banerjee, pp. 28-29) is not clear. Pearson and Brattain in their report on 'History of Semiconductor Research, 1794-1955' (Proceedings of I.R.E., Vol. 43) gave priority to Bose for the use of semiconducting crystals as detector of radio-waves. Sir Neville Mott, Nobel Laureate in 1977and expert on solid-state electronics remarked on this discovery of Bose that 'J.C. Bose was at least 60 years ahead of his time' (Emerson, p.33). In the Royal Society lecture Bose also speculated on the electromagnetic radiation from the sun, so-called solar emission or radiation for which solar or terrestrial atmosphere might be responsible.

By the end of 19th century, Jagadish Chandra turned his interest from **electromagnetic waves to response phenomena in plants** including studies of the effects of electromagnetic radiation on plants. His studies produced by electricity on living and non-living substances was presented at the 'International Congress in Physics' in Paris (1900). For further investigation, he stayed in DavyFaraday Laboratory of the Royal Institution and in about two years time, he published eight papers, compiled in a monograph, *Response in the Living and Non-living* on the basis of extensive experiments on the animal tissues like muscles, and electrical excitation in other tissues like nerves or retina, stimulation by light (in retina) producing changes. He found that not only animal tissues, but vegetable tissues also make similar electric responses under various kinds of stimuli (mechanical, application of heat, electric shock, chemicals or drugs). As regards response to inorganic systems, he observed that certain chemical dissolved in the water can increase the electric current while other chemicals can depress the flow of electricity. This is somewhat analogous to the effect of stimulants and depressants on living tissues.

In the third phase, he concentrated on ***Biophysical Studies*** results of which are published and compiled in his book, ***Comparative Electrophysiology* (1907)**. It shows that he devised a number of inorganic models providing analogous response effect in metals to varieties of stimuli. He has also attempted to group together the response effects in living and non-living matter, which are mechanical (i.e. the response for change of length); electrical (like change in conductivity, production of galvanometric current); and those which result in transmission of excitation. He also devised special models to illustrate the physical basis of memory. His query was, how the memory is storing information? If the information is stored in a location in a living or a mechanical system, how it could be made use of ? If it is stored in the brain, in which side of the brain it is stored? Nothing was known during his time. What Bose did he used ferromagnetic properties of matter to provide as a model for storage of information as memory. He prepared a surface coated with a phosphorescent paint, in which a pattern had been cut out, is covered with a cardboard. Then this covered screen is illuminated for sometime and light is extinguished. The cover is then removed and it was found that the illuminated portion under the cover glows brightly for some time. The phosphorescent screen is again exposed to diffuse illumination, it was found that the area which had been previously exposed to light begins to glow much earlier than the unexposed portion of the screen. This, according to Bose, can be used as model of revival of latent memory by an act of will. Bose has also given other models of memory. This has been reported by Moss (Proceedings of I.R.E., vol.43, p.1869 in his review of Photoconductors.

Jagadish Chandra used local materials for his research and was far ahead of his time. Bose Institute was the epitome of his dreams. D.M.Bose, the second Director was the torch-bearer of the institute along with others. Besides being a great scientist, his scientific articles in Bengali rejuvenated great spirit in Bengali mind.

6.2. C V Raman

Fig. 4. C.V. Raman (1888- 1970)

Chandrasekhara Vekata Raman, the second son of R. Chandrasekhara Iyer (a graduate in Physical science and teacher of physics and mathematics in a local college) of Trichinopoly in South India, was born on November 7, 1888, and died on 22 November, 1970 at age of 82. He had acquired a remarkable mastery in English language and developed a test for science studies at a very early age. He had his graduation from Presidency College, Madras, in 1904 with first class and obtained Gold Medal in Physics, besides a college prize for English essay writing. During his M.A. course, he had no regular classes in the first year and prepared himself for exam in mathematics, and also in physics by reading classical books of physics, like Helmholtz's *Sensations of Tone*, Rayleigh's *Theory of Sound*, Ewing's *Magnetic Induction in Iron and other Metals*, and so on. In the second year he took literature, history, economics, and other allied subjects, and cleared M.A. in first class obtaining record marks.

He passed also the Finance exam in 1907 in which he stood first and got busy for the next ten years with his appointment in Indian Finance Department with postings in Calcutta, Rangoon, Nagpur and again in Calcutta. Here in Calcutta he came to know about IACS founded by Mahendralal Sircar in 210 Bowbazar Street (central Calcutta) and started his research work in physical science in his spare time beyond office hours and on holidays. From his last posting in Calcutta in 1911, he became a sensitive and serious in his research work and got involved for systematic publications from this centre, and remained attached with it for the next 20 years. In 1917 he joined Calcutta University as Palit Professor on the invitation of Sir Asutosh Mookherjee, the then vice-Chancellor of the University. Raman was elected FRS by the Royal Society of London in 1924, knighted by British Government in 1929, Hughes Medal of the Royal Society in 1930, and became Noble Laureate in Physics the same year. He also received *honoris causa* the D.Sc. degree from many universities outside and in India. He was a brilliant scientist and had an electrifying personality and a great leader in science. His scientific work has several distinct phases and was mainly focused to clear some of the doubts and mysteries of the universe. Raman's scientific work is varied in its range and depth (vide, list of his paper in C.V. Raman Centenary Supplement published in *Science and Culture*, pp. 41-51), even though the number of published papers may be more. However, the work areas may be listed in phases thus:

1906-1920: Worked on Newton's rings in polarized light, Huygen's secondary waves,acoustical observations, Doppler effect and molecular scattering of radiation; [papers published from IACS independently and/or with collaborators — S. Appaswamiyer, A. Dey, P.N. Ghosh];

1921-1932 (at Calcutta): Study included sounds of musical instruments, of splashes, vowel sounds, whispering galleries, colours of mixed plates, visibility of distant objects, colour of the sea, molecular scattering of light in liquids & liquid mixtures, solids & amorphous solids, and dense vapours & gases, by liquid and solid surfaces, by liquid boundaries and its relation to surface tension, by anisotropic molecules; molecular structure of amorphous solids, molecular diffraction of light, molecular scattering of light in water and colour of the sea, ice in glaciers, spectrum of neutral helium, diffraction of light by spherical obstacles, by metallic screens, by transparent laminated screen, X-ray diffraction in liquids, Compton effect, magnetic double refraction in liquids, electrical double refraction relating to polarity and optical anisotropy of molecules, Maxwell effect in liquid, Compton effect & Kerr effect verification, secondary radiation & new class of spectra, change of wavelength in light scattering, polarization of scattered light, molecular spectra in infrared, new radiations by light scattering, molecular scattering of light (Noble Lecture, 1930), photon spin from light –scattering, Doppler effect in light-scattering; [papers published independently from IACS & Calcutta University and/ or with collaborators—

B Banerjee, S Kumar, A Dey, G Sutherland, K Seshagiri Rao, K R Ramanathan, A S Ganesan, K S Krishnan, L A Ramdas, S K Datta, I Ramakrishna Rao, C M Sogani, S Krishnamurti, S Bhagavantam, S W Chinchalkar].

1933-1948 (at IIS, Bangalore): Colours in birds, shells, diffraction of light by high frequency sound waves, ultrasonic waves, acoustic spectrum of light, Haidinger's rings in soap bubbles, new X-ray effect with change of frequency, quantum theory of X-ray reflection, spectroscopic investigations of solid and liquid states, physics including nature, origin, structure, properties and vibration spectrum of crystal lattice of diamond, infrared spectrum and vibration spectra of crystals, and X-ray reflection of crystals; [papers published independently and/or with collaborators—B V Raghunatha Rao, N S Nagendranath, K Subbaramiah, V S Rajagopalan, P Nilakantan, G R Rendall, S Ramaseshan, S Bhagavantam].

1949-1970 (at Raman Research Institute, Bangalore): Diffraction of light by transparent spheres and spheroids, luminescence of diamonds, vibration spectra of crystals and specific heats, origin of iridescent crystals (potassium chlorate, agate, opal, labradorite, moonstones, shells) — their structure & behaviour, X-ray studies of polycrystalline gypsum, fibrous quartz & crystals, thermal energy and elasticity, specific heat of crystals & alkali halides, quantum theory and crystal physics, diffraction of X-rays by diamond, infrared behaviour of diamond, sodium fluoride and their structure and behaviour, light, colour and vision, floral colours and physiology of vision, colours of roses, varied colours of verbena; [major areas, papers published independently and/or with collaborators—S Ramaseshan, J Jayaraman, A Jayaraman, D Krishnamurti, M R Bhat, A K Ramdas, K S Viswanathan, and S Pancharatnam].

Raman concentrated in the first phase mainly on **vibrations, sound and musical instruments** (bowed strings, violin, pianoforte, stringed instruments—*tanpura* and *veena*, and musical drums). After becoming Palit Professor of Physics in the University of Calcutta in 1917, he continued his research in IACS. During tour to England in 1921 as a delegate to the Universities Congress at Oxford, he visited St Paul Church and was struck by the well-known whispering gallery of the dome and made a study of the phenomenon. After returning to India he made a thorough study of a number of whispering galleries, e.g., the *Gol Gumbaz* at Bijapur, the *Victoria Memorial* at Calcutta, the Granary at Bankipur, Patna and the Calcutta General Post Office. During his return journey from England in ship he got struck with blue colour of the sea and focused his research also on scattering of light. His research, known as Raman Effect, earned him Noble Prize in 1930 during his work in Calcutta. From 1933 onwards he concentrated mostly on the studies of spectra and diamonds through the diffraction and reflection of light in crystal beside others. A few of his contribution will be of interest.

The ***Raman effect***, the most pioneering result for which C.V. Raman was awarded the Noble Prize in 1930 was discovered in 1928. Interestingly three independent reports on this phenomenon were published by Seshagiri Rao and C.V. Raman (1923), by K.R. Ramnath (1923), and by K.S. Krishnan (1925). 'A New type of secondary radiation' by Raman and Krishnan (Raman effect) came out as a note in *Nature*, dated 31 March 1928, followed by another communication by Raman to the same journal under the title, 'A change of wavelength in light scattering'. Raman and his students succeeded in superposing two light scatterings in transparent liquids and solids on which a new type of modified, rather very weak, florescence (scattering) was observed. Compton in 1927 was given the Nobel Prize for the inelastic scattering of X-ray photons (known as Compton effect). Towards the end of 1927 it suddenly appeared to Raman that their observation of moderate scattering may be an optical analogue of the Compton effect, and is actually due to the rotation and vibration spectra of liquids and solids occurring in regions which could be visually observed, or more comfortably with *spectrographs*, sensitive to the visible and ultraviolet regions. He was convinced and sent immediately the paper in his individual name to *Nature*, and announced his discovery (which earn him the Noble Prize) through a Press Conference in 1928 held on February 28 to avoid any other claim. This is the reason that February 28 is recognized as National Science Day in India.

Raman spectra of organic and inorganic substances was more clearly known from the study of Raman and Krishnan. When the intense mercury lines in the region of 3650 to 4358 A° were used as incident ray, the spectogrums of scattered radiations from benzene, toluene, pentane, ethyl & mythyl alcohols, water and carbon tetrechloridem the result clearly established that the frequency difference between the unmodified and modified lines is independent of the wavelength of the incident line. It also observed that there is some agreement between the shift of frequency of the modified lines with certain characteristics of infrared frequencies of the molecule. With a single Raman spectrograms it became possible to get all the infrared frequencies of the molecule much more accurately than the infrared spectrometer. The study of the Raman spectra in liquids was far extended by Raman's colleagues—S. Bagavantam, S. Vekateswaran, P. Krishnamurthi and others. It put the theory of Raman effect to see deeper for its further use in physical studies. Origin of wings in the spectrum of the scattered light in liquids and also of very low frequency lines found in crystals are attributed to the hindered rotation of the molecules in the liquid and to the flexural oscillation in the solid. The discrete lines when melted are changed into wings which become broader with the rising temperature. The influence of symmetry of the crystal on the polarization characters of the Raman lines have also been widely investigated by others.

The ***Theory of Diffraction of Light*** *by ultrasonic waves* is another very important area investigated by Raman and his colleagues. According to them, the light in passing through the field of ultrasonic waves suffers changes of phase in proportion to the amplitudes of the sound waves. Various results like, effect of oblique incidence, diffraction by superimposed waves, periodic visibility of the diffraction effects and so on, have been worked out, and effort was made for quantitative explanations. Attempt was made to determine the ultrasonic velocities in hundreds of organic liquids, and to study the dispersion of velocities in the acoustic spectrum. It was also observed that the diffracted light has a frequency different from the incident light, and the frequency difference being equal to that sound waves. This effect, though remains undetected with ultrasonic waves, could be demonstrated with hypersonic waves. These waves reflect the light waves, resulting in a change of frequency as in the Doppler effect. When two frequencies are symmetrically displaced on either side of the incident frequency, the unmodified central line indicate the presence of molecular cluster. Studies made on the frequency shifts have made it possible to calculate the velocities of the supersonic waves. It was also observed that the hypersonic velocity in case of highly viscous liquids such as glycerine is appreciably higher than the sonic and ultrasonic velocities, showing that such liquids exhibit appreciable rigidity at these high frequencies and pass over into solid state.

Crystal physics is related to the physical and magnetic properties of crystals. Raman along with Krishnan studied the magnetic anisotropy of crystalline nitrate and carbonates, magnetic behavior of organic crystals relating to crystal structure. Atomic vibrations in crystals was considered another very important area. The vibration spectrum of a crystal lattice consists of a finite number of discrete frequencies, the modes of vibrations corresponding to these frequencies being such that equivalent atoms in neighbouring cells in the lattice vibrate either in the same or in opposite phases. The results have been worked out for a number of crystals having simple structures and as to their number of characteristic frequencies. These are verified by Raman spectra by using a technique of special radiations of the quartz mercury lamp. This has resulted in the studies of large number of crystals thoroughly like, calcite, quartz, barites, gypsum, topaz, diamond and so on. The results on diamond deserve special mention, since the lines in this case have shown to remain sharp even under very high dispersion because of vibration frequencies being highly monochromatic. The atomic vibration technique in crystals has also been used to calculate the specific heat and thermal expansion of a number of crystals.

For obtaining ***dynamic of reflections in crystals****,* interesting technique was applied by Raman and his colleagues. Change of frequency was noticed when the infra-red vibrations in crystal interacts with visible or ultraviolet light in the scattered light. Change of frequency was also noticed for lattice vibrations in X-rays. The change of frequency of the X-rays, though found very small to be determined, but the interaction of X-rays with crystal lattice results in a tilting of the reflecting planes of the crystal, and helped to get a new dynamic reflections in directions away from the Laue reflections. Such dynamic reflections were obtained for large variety of crystals. The investigations with diamond support the theory well. Whether the extra reflections are due to the infra-red vibrations causing sharpness and spectacular nature and position of the reflections has been partly verified and accounted for.

Structure of Diamond was another area in which Raman took active interest. Raman initiated a general discussion on the structure and properties of diamond and dwelt on the crystal symmetry and structure of diamond. Bagavantam studied the normal oscillation of diamond-structure and calculated the elastic constant, G.N.Ramachandran took the X-ray topographs, determined the crystal structure and explained the nature of origin of laminations in diamond crystals. Raman and his other collaborators studied the lattice structure which gave the correct interpretation of the vibration frequency 1332 cm^{-1}. Raman had a huge collection of diamonds, and from investigations it was found that the diamonds show large variations in its properties from one specimen to another, which was attributed to inherent variations in its structure and not due to the presence of any extraneous impurities. He found that the internal structure of diamond is based on two interpenetrating face centered lattices of carbon atoms. According to him, these tetrahedral (solid figure enclosed by four triangles) can point either way, so that there are 2×2 or four possible forms of diamond, two of which have tetrahedral and the other two octahedral symmetry. In actual specimen, these four structures can occur side by side or intermingled with each other. It is the variations in the nature and extent of the interpenetrations of the different structures that gives rise to the variations in the physical properties of diamonds. Experimental verifications are now being put forward that there are actually four varieties of diamonds.

Raman left a permanent stamp in the history of science in India as a great experimental scientist a theorist of great order, and a man of magnified personality with full of vanity. He made a world of his own, and could be compared to the nucleus of an atom around which his collaborators used to move like electrons in specified orbits. He was possibly one of the best scientists that India has ever produced.

6.3. Meghnad Saha

Fig. 5. Meghnad Saha (1893-1956)

Meghnad Saha was born on 6 October 1893 in a village Seoratali in district Dacca, now in East Pakistan. He was the fifth son of his father who had a small shop, M eghnad had his Entrane & Intermediate from Dacca, B.Sc (Math Hons) and MSc (Applied Mathematics) from Presidency College, Calcutta. He had a brilliant career standing second in order of merit while the first position was to his lifelong friend S N Bose. In 1917, he, along with S N Bose, joined Department of Physics, Calcutta University, as lecturer. (About a year later C.V. Raman joined the Department as Palit Professor of Physics). Saha worked in the field of electromagnetic theory and radiation pressure for which he was awarded D.Sc degree in 2018 from the same university. In 1920 he went to England, came back in to join the Calcutta University as Khaira Professor of Physics, but took up the Professorship of Physics along with headship in the university of Allahabad in 1923 and remained there for 15 years. In 1927 he was elected FRS by the Royal Society of London. In 1938 he came back to Calcutta University as Palit Professor of Physics and remained there till his retirement in 1952.

From 1953 he served as Director of the Laboratories of Associations of the Institute of Nuclear Physics till to the time of his death in 1956. His service to society as General President of the Indian Science Congress Association, President of the Asiatic Society (Bengal), President of the Asiatic Society, Science & Culture as editor, CSIR, University Education Commission, Member of Indian Parliament (1951) and to many other positions made him very special in the planning of Indian Science. However, his research contributions in the area of physical science may be considered in phases.

1917-1922: Focussed on Maxwell's stresses, pressure of light, dynamics of electron, radiation pressure and problems of the solar atmosphere, spectrum of hydrogen, ionization in the stellar atmosphere, elements in the sun, problems of nova acquila III, Ionization in the stellar atmosphere, stellar spectra, H- and K- lines of calcium in stellar atmosphere, Ionization of gases by heat; [major areas, papers published independently or with collaborators, S. Chakravarty, S.N.Bose & P. Gunther];

1923-1938 (at Allahabad): Worked on physical properties of elements at higher temperatures, thermal ionization, Influence of radiation on ionization equilibrium, phase rule and its application to problems of luminescence and ionization of gases, spectrum of Si^+ (once ionized silicon), absolute value of entropy, entropy of radiation, radiation on ionization equilibrium, nitrogen in the sun, spectrum of neon & nebulium, spectrum of solar corona, negatively modified scattering, statistical mechanics, spin of proton, absorption spectra of saturated chlorides, complex X-ray characteristics spectra, β-ray activities of radioactive bodies, upper atmosphere, stratosphere solar observatory, ultraviolet sunlight on the upper atmosphere, ionization of upper atmosphere; [papers published independently and/ or with collaborators—N K Sur, R K Sur, K Majumder, B B Ray, P K Kichlu, D S Kothari, R C Majumder, A C Banerjee, S C Deb, A K Datta, S Bhargava, L S Mathur, R N Rai and others);

1939- 1956 (at Calcutta): Electromagnetic waves in the atmosphere, structure of atomic nuclei, theory of solar corona, nuclear energetic and β-activity, radio waves from sun and stars, micro-waves of radio frequency range from sun, vertical propagation of electromagnetic waves; [papers published independently, or with collaborators—S C Sircar, D Basu, A K Saha, B D Nagchaudhury, B K Banerjee].

In the first phase of his research Saha took interest on **Harvard classification of stellar**

spectra and theory of ionization, He went to England by the end 1919 spent considerable time with A. Fowler of the Imperial College whom he accepted as his mentor. Then he went to Germany, Switzerland, and tried to contact Mount Wilson and other observatories for spectroscopic data. His work on ionization of course was recognized by the Americal astrophysicists, H.N. Russel and others. After his return he joined Allahabad University as professor and focused his attention to entropy and other problems, including nuclear physics. In the third phase his interest was devoted to installation of cyclotron, institute of nuclear physics and other projects in Calcutta. A few of his contributions will be of interest.

Thermal Ionization is Saha's one of the greatest contributions. The theory of high-temperature ionization and its application to stellar spectra has been well accepted and recognized. The ionization theory was formulated by Saha working by himself in Calcutta (as reported by Professor D.S. Kothari). During his work with the spectra in the sun and stellar bodies, Saha could not identify the spectra of elements known in the earth, and also not otherwise. In the spectrum of the sun's chromospheres, as well as during total solar eclipses, certain puzzling facts were observed, i.e. the H- and K- lines of calcium were found much higher in the sun's atmosphere than the corresponding lines of the lighter elements like hydrogen, helium or sodium. This fact was puzzling and created confusion. Saha estimated the quantity of energy liberated when the normal calcium atom (in vapour state) has lost an electron in ionized state, for he knew :

> $Ca = Ca_+ + e - \varepsilon$, where Ca= normal atom of calcium in vapour state (1 gm of atom is considered), $Ca^{\mp}$ = an atom which has lost one electron, ε= quantity of energy liberated;

He calculated the 'reaction isobar equation', taking into account the total pressure and temperature, the quantity of the Ca atom ionized, and the classical constant as per Sackur-Tetrode-Stern relation. On his ionization formula, Saha and his students (N.K. Sur, K. Majumdar) carried out several experimental investigations at Allahabad later. This resulted verification of ionization of gases by heat, physical properties of elements at high temperature, experimental test of thermal ionization of elements.

Entropy of the law of classical thermodynamics was of interest to Saha and his colleagues. Of the two laws, first speaking on the conservation of energy, and the second establishing a direction in time by defining a quantity, called entropy, that increases in all real physical processes. In fact, *entropy* was defined as a measure of the degree of disorder or as the tendency in any physical system towards breakdown. The effect of increased entropy indicates that a physical system evolves from a state of relative order to one of disorder, and with this disorder there is increased complexity. It was noted that the changes of entropy can only be calculated for a reversible process. For this system it was defined as the ratio of the amount of heat taken up to the absolute temperature at which the heat is absorbed. The total entropy of a system must either increase (irreversible process) or remain constant (reversible process).The total entropy of the universe is therefore increasing towards a maximum, corresponding to complete disorder of the particles in it (isolated system). In collaboration with N K Sur, he worked not only the absolute value of entropy but also tried to calculate the entropy of radiation. F C Auluck of Delhi University worked on the entropy of Fermi-Dirac gas.

Nuclear physics is another area Saha got interested in Allahabad. After Chadwick's discovery of neutron in 1932, Saha along with his student D.S.Kothari thought that neutrons could be smuggled more easily into the *nucleus* of the atom than the *proton* or *alpha* particle to induce nuclear reactions in all atoms. They vehemently tried for a donor who could gift a small amount (1 gm) of radium for research work but remained unsuccessful. At the same time Fermi's work on *neutron*-induced-reactions came out, for he received about a gram of radium from the Italian Government for their successful experiment. From the time of his visit to Europe and USA in 1936, he developed an idea of having an Atomic Energy Program for peaceful utilization and welfare of the society. After his return to Calcutta University, he wanted to establish a *Cyclotron* at the Calcutta University, for which his student B.D. Nag Chaudhuri was deputed to Berkeley University for proper training. A Cyclotron was installed at the University and Saha felt very happy when nuclear fission by splitting a heavy atomic nucleus (e.g., uranium) into two equal parts, at the same time emitting nucleus and releasing very large amount of nuclear energy, was started in 1939. This gave the impetus to establish the Institute of Nuclear Physics in Calcutta. The helplessness for not having 1 gm of radium before came out at the opening session of the Institute of Nuclear Physics in Calcutta inaugurated by Marie Irene Joliot Curie (1957).

A ***Stratographic Observatory*** was visualized by Saha in 1936 while he was attending a Summer School in Astrophysics at Harvard. He gave his impression what could be seen above the ozone layer and how this observatory will help in this investigations. How Saha's dream came true and predictions verified has been elaborated by Harold Shapley in his Saha's 'Obituary' published in the *Journal of the Asiatic Society* (1957).

Dirac-Saha Equation in 1949 was his masterly re-derivation of Dirac's quantization condition for magnetic monopole. Magnetic monopole is a hypothetical unit of magnetic charge analogous to electric charge. No evidence has been found for the existence of a separate magnetic pole, for they are always found in pairs. Saha estimated from classical consideration the mass of magnetic monopole to be 2.54 times that of a neutron (approx. 2.5 Gev). The verification of this result will be tested when magnetic poles are detected.

S. Rosseland, in *Theoretical Astrophysics* (Oxford University Press, 1939, Introduction) writes about Saha's contribution thus,' It was the Indian physicist Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of the atomic theory. The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the substantial work has the character of refinements of Saha's ideas'. J V Narlikar in his book *Scientific Edges* (Penguine Books, 2003, p.127) writes, 'Meghnad Saha's ionization (c. 1920) which opened the door to stellar astrophysics was one of the top ten achievements of 20th century Indian contribution in science and could be considered in the Noble Prize class'.

Saha's role in building a large number of scientific organizations, e.g., Indian National Science Academy, CSIR institutes, Saha Institute of Nuclear Physics, a prestigious bulletin like *Science and Culture*, are also some of his positive initiatives. Beside being a great scientist, he was a true nationalist and a spirit behind building of modern India with science and scientific temper.

6.4. S N Bose

Satyendra Nath Bose was born in January 1, 1894 in Calcutta. His father, Surendra Nath Bose, was originally from the district of Nadia, an accountant in East Indian Railway. He was the first child of his father followed by six other sisters. He had a brilliant career standing first in order in

Fig. 6. S N Bose (1894-1974)

his B.Sc. (Honours in Mathematics) and MSc (Mixed Mathematics). He was appointed lecturer in Physics of the Calcutta University in 1917, left for Dacca University and joined it as Reader in Physics in 1921.

In 1945 he came back to Calcutta University as Ghosh Professor of Physics and Dean of Faculty of Science. He obtained *honoris causa* (honorary D.Sc. degrees) from many universities in India (Calcutta, Jadavpur, Allahabad, ISI Calcutta and Delhi), General President of Indian Science Congress (1945-48), President of National Institute of Sciences in India (1949-50),became Padma Vibhusan (1954), FRS (1958), Vice-Chancellor of Visvabharati University & National Professor (1958-74). The number of his research articles are hardly 25 (for details, vide INSA Biographical Memoires of the Fellows, Vol.7, 59-79):

1917-1920: Worked on finite volume of molecules and equation of state, stress equation of equilibrium, deduction of Rydberg's law from quantum theory of spectral mission [papers published independently and/or with collaborator M N Saha]

1921-1944 (at Dacca): Planck's law and hypothesis of light quanta (first paper to Einstein), Thermal equilibrium between radiation and matter and a different law of probability for elementary particles (second paper to Einstein),moment coefficient of D^2 statistics, progress in nuclear physics, anomalous dielectric constant of artificial ionosphere, electromagnetic waves in the ionosphere, studies of Lorentz group of equations and solutions of the equation : $\Delta^2\varphi - (\partial^2\varphi/c^2\partial t^2) = - 4\,\pi\rho\,(x,y,z,t)$, note on Dirac equations and the Zeemann effect [papers published independently and /or with collaborators, S R Khastgir, S C Kar, P K Datta, K Basu].

1945-1956 (at Calcutta): Integral equation relating to hydrogen atom, extraction of germanium from sphalerite (collected from Nepal), affine connection in Einstein's new unitary field theory, Albert Einstein; [9 articles published independently and /or with collaborators, R.K. Dutta, B.C. Dutta, J. Sharma].

S.N. Bose was brilliant as a student standing first in all most all the exams; among his colleagues a few distinguished names are: Maghnad Saha, Nikhil Ranjan Sen, Jnan Chandra Ghosh and others. He was a man of simple habits, deep thinking, and a great intellectual. To begin his career, he translated Einstein's paper on theory on relativity from German language into English along with Saha. His article to Einstein, printed with Einestein's rejoinder, is a landmark in history. Bose's paper on radiation theory and other topics are equally brilliant. His trip to Paris during 1924-25, working with Madame Curie, Maurice de Brooglie, meeting in Berlin with Einstein set the tone in his life. An account of his originality has been given by many of his colleagues including Mehra and Rechenberg (1982), Mukunda(1994), Ghosh (2005), and many others. However, some of his contributions will be of interest:

***Radiation and the Ultra-Violet Catastroph*e** was the pet subject of Bose. While he was giving his lectures in the university of Dacca, he reiterated that the contemporary theory on radiation was inadequate because it predicted results not in accordance with the experimental results. He predicted that Maxwell-Boltzmann distribution would not be true for microscopic particles where fluctuation due to Heisenberg's uncertainty principle will be significant. Thus he stressed the probability of finding particles in the 'phase space made state' having volume associating the distinct position and momentum of the particle.

Boson, Bose- Einstein Statistics & Bose-Einstein Condensate are best known when Bose in early 1920 prepared a paper on, 'Planck's law and hypothesis of light quanta', and made a request to Einstein to translate it into German for its publication. It came out in *Zeitschrift fur Physik* (1924) with Einstein's German translation with his own rejoinder. Bose's main interpretation was that since photons are indistinguishable from each other, one cannot treat any two photons having equal energy as being two distinct identifiable photons. According to him, all particles in the universe whether elementary or composite, have been found to belong to one or two classes, viz, one which exhibit integral spin, named as 'Bosons' by Dirac, and the other having half- integral spin, known as 'Fermions' by Pauli. No exceptions to this rule have been found so far, provided all possible degrees of freedom are taken into account. Bose's explanation is known as Bose-Einstein Statistics'.The result derived by Bose laid the foundation of 'Quantum Statistics'. Einstein combined Bose's theory and De Brogli's hypothsis (Ph.D thesis after it is examined by him) on the quantum theory of gases. This led to the prediction of existence of phenomenon which became known as Bose-Einstein condensate, a dense collection of bosons (particle with integer spin), which was demonstrated to exist by experiment in 1995). Schrodinger later said that the discovery of wave mechanics and the Schrodinger equation was largely influenced by this paper. It is Bose Statistics, Bose condensate and Boson which emphasize the impact of Bose's work. Bose was not a Nobel Laureate, but In this context the reference of the press release of 2001 Noble Prize in Physics will be of interest. It says,

> 'This year's Noble Laureates have succeeded in discovering a new state of matter, the Bose-Einstein condensate (BEC). In 1924 the Indian physicist Bose made important theoretical calculations regarding light particles. He sent his results to Einstein who extended the theory to certain type of atom. Einstein predicted that if a gas of such atoms were cooled to a very low temperature all the atoms would suddenly gather in the lowest possible energy state. The process is similar to when drops of liquid form from a gas, hence the term condensation. Seventy years were to pass before this year's Noble Laureates, in 1995, succeeded in achieving this extreme state of matter'.

Radio- waves* and *Wave-equation are few such areas in which Bose was also interested. He investigated the problem of total reflection of radio-waves in the ionosphere, by solving the classical Lorentz equation by the method of characteristics. From the general scheme he found four different possible conditions for the total reflection of radio-waves only under different sets of simplifying conditions. He published another paper on Lorentz group in which a four dimensional transformations was decomposed into two factors which led to the spinors from algebraic considerations. He along with S.C. Kar gave a complete solution second degree differential equation involving four-dimensional space-time continuum; a similar equation has been found to be used by Bhabha during his lecture on problems of cosmic rays in the Calcutta University Department of Mathematics (1941). Bose along with K.M. Bose gave an exact solution of Dirac's equation for hydrogenic atom in a magnetic field (1943), and deduced an integral equation for Schrodinger's wave –equation for hydrogen atom in the momentum space and discussed the physical problems from the integral equation.

Bose's contribution have been relatively few but remarkable. His contributions in physical science and mathematics got international ovation. Over and above, he was founder of *Bangiya Vijnan Parishad* and his main aim at the fag end of his career was to popularize science in Bengali. He was a great lover of arts, fond of instrumental music (seldom missed an art or painting exhibition or musical concert, specially of classical type), and himself played on the *Esraj* like a master. He is a genre of his own and known for inner sparks in his thoughts.

6.5. S K Mitra

Fig. 7. S.K. Mitra (1890-1963)

Sisir Kumar Mitra, the son of Joykrishna Mitra was born in Calcutta. His father was originally from Konnagar, Hoogly, came to Calcutta for the medical education of his wife in the Campbell Medical School, and shifted to Bhagalpur, as his wife got an appointment in the Lady Dufferin Hospital at Bhagalpur after obtaining her degree. Young Sisir had his school education from Bhagalpur, B.Sc. and M.Sc. degrees from Presidency College, Calcutta. He joined the Calcutta University as lecturer of Physics in 1916 and obtained D.Sc. degree of the University in 1919. From 1920-23 he stayed in Paris and obtained another doctorate degree from the university of Sorbonne. He then returned to Calcutta University and joined as Khaira Professor in Physics in 1923.

His associations with Wireless Laboratory, Ionosphere Research school, Haringhata Ionosphere Field Station at Calcutta, Upper Atmosphere and Space exploration with artificial Satellites made many significant contributions. He became Chairman of the Radio Research committee of CSIR (1943-48), President of the Asiatic Society of Bengal (1951-52), President of the National Institute of Sciences in India (1956-58). He got FRS from Royal Society London (1958), *Padmabhusan* (1962), National Research Professor in Physics by the Government of India.

1918-1923: Worked on illumination curves in oblique diffraction, Sommerfeld's problem of diffraction by a semi-conductor screen, diffraction by apertures with curvilinear boundaries, diffraction figures observed in a heliometer, radio waves, electric oscillations (papers published independently).

1924-1947: Beats by high frequency interruption of light, refraction of light by electrons, periodic classification of elements, resistance of thermionic valves at high frequencies, spontaneous oscillations in low pressure discharge, recording wireless echoes at the transmitting station, effect of solar eclipse on the atmosphere, study of the upper ionized atmosphere in Bengal by wireless echoes, earthquakes, effect of a meteoric showers on the ionosphere, transmission of radio waves round the earth, knowledge of ionosphere, dielectric, absorbing layer and the ionosphere at low heights, magnetic double refraction of ionized air, need for a radio research board in India, wireless echoes from low heights, radio waves from middle atmosphere, distribution of gases and their pressures in the upper atmosphere, E-layer of the ionosphere, ozone-sphere and E-layer of ionosphere, ultraviolet light theory of aurora and magnetic disturbances, atomic oxygen elastic collision with electrons and the region of F absorption, zodiacal light and light of the night sky, active nitrogen and N_2 ions, after-glow brightness of active nitrogen, night-sky emission and region F ionization, radar, auroral spectrum, geomagnetic control of region F_2 of the ionosphere, microwaves, the upper atmosphere and some unsolved problems; [papers published independently and/or with collaborators, D Banerjee, H Rakshit, B C Sil, P Syam, B N Ghose, S S Banerjee, A C Ghosh, J N Bhar, S P Ghosh, A K Banerjee, B B Ray, S Das Sharma].

1948- 63: N_2^+ ions and some nitrogen after-glow phenomena, active nitrogen in aurora, the Upper Atmosphere (2nd edition), thunderstorms and sporadic E ionization of ionosphere, aeronautics and electronics, electronics in the service of medicine, upper atmosphere and space exploration with artificial satellites, physics of the earth's outer space [published independently and/or with collaborators, M R Kundu].

His foreign trips to Paris during 1920-23, working under Charles Fabri of the University of Sorbonne on a topic, 'Determination of Wavelength in the region 2000-2300 A^0 of the copper spectrum' and training in 'radio valves circuits and radio communications in Gutton's laboratory, Institute of Physics, University of Nancy were considered very useful for his increasing interest in upper atmosphere. In the Ionospheric research, the technology of radio physics and electronics played an important role, and in this field the works of S K Mitra, G R Toshniwal and S R Khastagir are prominent. However, Mitra and his group studied the effect of solar eclipse on the ionosphere, measured atmospheric height at Calcutta during Polar year, height of the absorbing layer, the C region and the origin of E layer of the ionosphere, anomalous dielectric constant of artificial ionosphere, and the radio-wave propagation in ionosphere. However some of his results are of interest:

Upper Atmosphere and the space beyond hundreds and thousands of kilometers above the surface of the earth was of interest to Mitra The period : 1925-35 was, according to Prof Mitra, was a difficult period for the ionosphere workers to go through the collections of many research centres, and publications made in the form of reports and research papers on ionosphere. What he did, he collected all these details containing world picture of ionosphere, which he presented in his opening speech organized by National Institute of Sciences in India in the year 1935, under the title, 'Report on the Present State of our knowledge on Ionosphere'. The book in its enhanced form was published by the Asiatic Society in 1947, of which 2000 copies of the book was sold quickly worldwide. Another revised edition came out in 1952 followed by Russian translation.. The knowledge has been greatly enhanced with the help of artificial satellites. The launching of artificial satellites has actually been started with the program of International Geophysical year (1957 1st July to 1958 31st December).

Systematic efforts have now been made to place earth satellites in orbit, moon rockets and other types of satellites by the Russian, American, Chinese and other developing countries, may be just out of sheer curiosity, but ultimate challenge of manned satellite into space was as to how to overcome the earth's gravity. Earlier there were only two widows to the screening of the atmosphere through wide range of electromagnetic measures, either corresponding to light waves or through radio waves. But the satellite program has made it possible to collect reliable data of the physical conditions in inaccessible remote regions of the atmosphere and outer space, specially in the area of radio communication and meteorology. The earth-satellites (Explorer I, IV, VI, VII,; Vanguard I & II, Sputnik II & III, Discoverer VII & VIII), and Moon rockets (Pioneer I, III, & IV; Lunik I, II & III), launched between1958 and 1959 supplied valuable data in this connection.

Density, Pressure, Temperature Distribution at some selected heights in Upper Atmosphere were areas selected by Mitra for investigation. In this context he developed a model constructed in 1952 based on certain assumptions (Table 1). The density distribution is now generally computed from the orbital data of the satellite. The orbit of the satellite is not fixed, and changes continually, firstly due to drag effect specially at its perigee when it passes through comparatively dense atmosphere, and secondly due to irregular gravitational pull of the earth differing considerably the ideal central pull of a spherical earth. The geomagnetic disturbance is also associated with with solar corpuscular emission, and the upper atmosphere density is effected by

Table 1. S.K. Mitra model (1952)

Height (km)	Density (gm/cm^3)	Pressure (mm of Hg)	Temperature (^{0}K)
800	3.67×10^{-17}	2.13×10^{-10}	3040
500	7.00×10^{-16}	2.25×10^{-2}	1840
300	2.11×10^{-14}	3.83×10^{-8}	1040
110	4.98×10^{-10}	2.70×10^{-4}	270
100	1.74×10^{-9}	1.00×10^{-3}	240

Table 2. A.P. M itra and S.B. M athur model (based on rocket and satellite data, 1959)

Height (km)	Density (gm/cm^3)	Pressure (mm of Hg)	Temperature (^0K)
800	6.00×10^{-17}	4.81×10^{-10}	2068
500	1.54×10^{-15}	9.46×10^{-9}	1591
300	4.97×10^{-14}	1.85×10^{-7}	1023
130	2.74×10^{-11}	3.46×10^{-5}	462

heating by heating due to absorption of such emission. Revised data based on high altitude rocket and satellite data has been suggested by A.P. Mitra and S.B. Mathur in 1959 (Table 2).The data at 800 km height is significantly different in both the tables.

***Ionosphere* studies** by him have indicated that while *stratosphere* extends approximately 11 km from the surface of the earth, the *Ionosphere* extends to much greater heights and merges with the interstellar gas at a distance of several tens of earth's radius. It produces a number of effects on the radio signals transmitted through it from a first moving satellite. To estimate the electron concentration in the ionosphere at great height, all the effects detected on the radio signals and the positional data of the satellite are taken into account. These measurements are of considerable importance, as the transmitter located on the ground do not catch any electron concentration in regions above the level of maximum ionization of the F_2 layer (the region between 300 km and 500 km). The ionospheric effects on satellite radio signals are mainly of three types, viz., Faraday fading effect (because of changes of the plane of polarization as the satellite changes its position due to rotation), Doppler effect (shift in frequency of the transmitted signal due to motion of the satellite) and Refraction effect (due to radio-rising and radio-setting of satellite, when the bending of the radio waves entering the atmospheric layer is away from the normal, refractive index being less than unity). The distribution of the Electron concentration at different heights are given along with densities of the neutral particles (Table 3).

Table 3. Height distribution of electrons (deduced from radio-rising and radio-setting of the satellite)

Altitude (km)	Electron concentration (N per cm^3)	Density of neutral particles (N per cm^3)
3,100	1×10^2	< 1
2,450	1×10^3	20
1,800	1×10^4	2×10^3
1,150	1×10^5	2×10^5
600	7×10^5	1×10^7
400	1.4×10^6	6×10^8
320	1.8×10^6	......
200	1 × 105	......

The figure in the last column—density of neutral particles at great heights—are obtained from consideration of the life time of free electron in these regions. It is the time that elapses between the production of the electron by ionization and its disappearance by recombination, which is in the order 10^5 to 10^6 seconds or more in over 24 hours. Taking this into account, the density is 10^7 at height 600 km (Table 3) is comparable with the density value 10^6 at 800 km (Table 1).

Corpuscular Radiation Belt was believed to be a zone whose outer belt contains streams of charged particles emitted from the Sun and the inner belt contains possibly the inner ray neutrons produced in the atmosphere. The solar origin hypothesis of the outer radiation belt explains a long standing difficulty of the *auroras*. For the solar corpuscles, if they are to reach the *auroral latitudes* (with in 25^0 of the magnetic poles), the electron or proton speed will not be able to ionize the atmosphere at the height of the most frequent occurrence of *aurora* (round 100 km), then how? There are many opinions, not discussed here. As regards *neutron hypothesis* of the inner belt it is assumed that the particles have their origin in the neutrons produced by interaction of cosmic rays with atmospheric particles.

Cosmic ray data in the atmosphere as obtained from the satellite radio-telemetered from

Sputnik II observations were also analyzed by Mitra. The latitude and longitude dependence of the cosmic rays showed that the lines of equal intensity do not follow the geomagnetic parallels. It confirmed the view that the cosmic ray equator does not coincide with the geomagnetic equator. It also came out that above 200 km the intensity of the cosmic rays increased with height. At 700 km it was about 40% more than that at 200 km. The increase with height was assessed for two reasons—decrease of intensity of earth's magnetic field with height, and reduction of the screening effect of more particles from the earth reaching the satellite. Fluctuations on intensity was also observed, the reason of which was not clear. Beyond 10 and 17 earth-radii (the outer most point of the observation), the counting rate of the main counter appeared to reach an asymptotic value, and the counter gave the value of 3.2 cm^2/sec between interplanetary distance at this height.

Mitra was laborious, extremely methodical, known for his devotion to duty, precision and perfection. He was a lover of order, cleanliness and beauty besides being a good scientist.

6.6. H J Bhabha

Homi Jehangir Bhabha, son of Jeehangir H Bhaba, M.A.(Oxon), Barrister -at-Law, was born on 30 October, 1909. He had his education at the Cathedral and John Connon Schools, Elphinstone College, and Institute of Science in Bombay. From his childhood he had developed a keen sense and love for music, recorded symphonics, concertos, quartets and sonatas of Beethoven and Mozart and others, for his aunt (wife of J.N. Tata) who lived across the road had a huge collection of records. In 1927 he joined Caius College in Cambridge, obtained Tripose in mechanical sciences in June 1930, and became a research student in theoretical physics. During his research tenure in 1932 in the Cavendish Laboratory, he was exposed to the experiments on the existence of neutron, transmutation of light elements by high-speed protons, cloud chamber photographs of the production of electron pairs and showers by gamma radiation. In 1939 Bhabha came back and joined Indian Institute of Science, Bangalore as Reader in Physics and stayed there for five years.

Fig. 8. H.J. Bhabha (1909-1966)

He became the first Director of Tata Institute of Fundamental Research (TIFR), and was appointed Chairman of the Atomic Energy Commission in August 1948. Subsequently the Bhabha Atomic Research Centre (original name-Atomic Energy Establishment, Trombay) for atomic research was founded on 12 January 1967. Bhabha became FRS in 1941, Padma Bhusan in 1954, Adam's prize and many other prizes for his work on elementary particles. He received *honoris causa*, i.e., honorary doctorate degree from many universities in India and Abroad. Bhabha published about 82 research papers (Vide *Biographical Memoires of the Fellows* of the National Institute of Sciences in India, Vol. 2, 1970, pp.78-97).

1933-1939: Concentrated on the annihilation of fast positrons by electrons in the K-shell, creation of electron pairs, electron-positron scattering, passage of first electron through the matter, wave equation in conformal space, passage of fast electrons and the theory of cosmic showers, negative protons in cosmic radiation, proton-neutron exchange interactions, penetrating components of cosmic radiation, heavy electrons and nuclear forces, theory of *mesotron* (meson),bursts and the spin of the meson, classical theory of electrons and mesons (published independently with collaborators, H R Hulme, W Hettler, H Carmechel, C N Chou).

1940-1960: Classical theory of spinning particles, point dipoles, spinning particles in Maxwell's field, scattering of charged meson and spinning particles in meson field, classical and quantum theories of neutral meson, protons of double charge and the scattering of meson, particles of half spin and Compton effect, radiation reaction relating to scattering phenomena, cascade theory with collision loss, separation of electronic and non-electronic components of cosmic radiation, relativistic wave equations for the proton, meson intensity in the sub- stratosphere, latitude effect for mesons, equation of motions in point particles, relativistic wave equations of spin 3/2, production of mesons and localization of field energy, heavy mesons of a solid emulsion block; (collaborators, B S M Rao, D Basu, S K Chakravarty, Harish Chandra, R R Daniel, H J Talor, J R Heeramaneck, A Ramakrishnan, N B Prasad, W B Lewis);

1961-1966: Atomic power in India, atomic energy in Indian economy and underdeveloped countries; (Collaborator, M. Dayal).

Cosmic ray was one area on which Bhabha showed wide interest. From the time he had been student at Gonville and Caius College, Cambridge, UK, he studied theoretical physics under N.F. Mott and P.A.M. Dirac, and his paper on cosmic ray, 'Absorption of cosmic radiation' came out from W. Pauli's laboratory at Zurich in 1933. His papers on cosmic radiation, cosmic showers, electron showers on cosmic rays, and penetrating components of cosmic radiation were quickly published before he came back to India. Here he collaborated with S.K. Chakravarty and carried out a number of theoretical studies with cascade theory of electronic showers with collision loss, nature of primary cosmic rays and the photons associated with cascade theory. According to M.G.K. Menon, the second Director of TIFR, the period 1940-45 in IISc was extremely fruitful to Bhabha. In 1945 he became the Director of TIFR. His interaction with the stalwarts like, Wolfgang Pauli and Enrico Fermi in Rome, and Neils Bohr in Copenhagen helped him to plan his research on cosmic rays including its interaction with matter. This led to the discovery of electron pairs, *muons* and so on.

Bhabha Scattering gained international recognition after Bhabha established a correct expression for probability of electron relating to positron scattering and meaningful method for measuring the cross section. In this context, his work on Compton scattering on the reduction of energy of a photon in its interaction with a free electron, R-process, and nuclear physics are quite noteworthy.

Absorption of Cosmic Radiation features and *electron showering production* in cosmic rays were areas of concern to Bhabha, who made experiments and offered suitable explanation. In 1936 he published two papers on 'The Passage of Fast Electron' and the 'Theory of Cosmic Showers', in which he used the theory how primary cosmic rays from outer space interact with the upper atmosphere to produce particles observed in the ground level. Bhabha and Heitler then made numerical estimate of the number of electrons in the *Cascade process* at different altitudes for different electron initiative energies. The *Cascade process* is actually used for separation of isotopes. It consists of a series of stages connected in such a way that that the separation produced by one stage is multiplied in several stages. In a simple cascade method, the enriched fraction is fed to the succeeding stage and the depleted fraction to the preceding stage. The calculation made by Bhabha and his colleague agreed with the experimental observation of cosmic ray showers by Bruno Russi and Pierre Victor Augar.

Nuclear Program was planned by Bhabha stage by stage. First Apsara (1 MW) was built designed and built by Indian engineers. It was made for engineering experiments, material testing and isotope production. Second was Canadian Indian Reactor (40 MW) under Colombo plan to process monazite sands of Kerala beach and to separate rare earths—thorium and phosphates, thorium hydroxide and uranium fluoride and so on. His plan was power generation in three stages, from Thorium (rather than Uranium), total reserve of Thorium being rich to the tune of 500,000 tons; second the Plutonium obtained from the first generation power station can be used in the second generation of power station, designed to produce electric power. The process will convert Thorium into U-233 or depleted Uranium into Plutonium with breeding gain. The second generation of power stations may be regarded as intermediate step for breeder power station of third generation which will produce more U-233. Then they will begin in the course of producing power.

Bhabha had a smart personality and was a man of great caliber, artist, having many other qualities. Many of his contemporaries remember him for his sketch of Niels Bohr and piano playing, besides being a top class nuclear scientist.

6.7. S Chandrasekhar

Subramanyan Chandrasekhar was born in Lahore on October 19, 1910.His father settled in Madras in 1918 when he was Deputy Accountant General of Northern Railways. Chandra was number three in a family of ten children (4 sons and 6 daughters). He learnt German language during his under graduation in Presidency College, Madras, and showed a great interest in science research through his articles on Pauli's paper on quantum mechanics, Compton scattering and New Statistics (published in *Proceedings of the Royal Society*, 1929) in his student days. In 1930 he got a Government of India scholarship on the recommendation of the college Principal and admitted the same year at Trinty College, Cambridge and discovered a critical limit of the life of white dwarf star. In 1933 he received Ph.D on his thesis, 'Distorted Polytropes', FRS (1944) from Royal Society (London). Joined the university of Chicago as an undergraduate student in 1955, served its faculty till to the time of his death in 1995. Received many prizes of international repute, and won Nobel Prize for Physics (1983) on the structure and evolution of stars. Government of India honoured him with *Padmavibhushan* in 1968. His phase-wise research work may be noted as under:

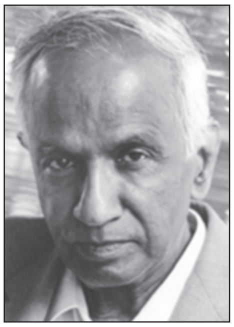

Fig. 9. S. Chandrasekhar (1910-1995)

1930-1942: Chandrasekhar limit, white dwarf stars, stellar structure, stellar dynamics, statistical theory of stellar encounters; complex statistical mechanical problems; [Vide his books on *Stellar Structure* and *Stellar Dynamics*]

1943-49: Absorption and emission lines in stellar spectra, radiative equilibrium in stellar atmosphere, radiation field in the atmosphere, analysis of radiative transfer of stellar atmosphere, illumination and polarization of the sunlit sky, formulation of fundamental equations governing Rayleigh's problems and their solutions, systematic use of non-linear integral equations and a special class of such equations (Chandrasekhar's X and Y functions) and their solutions, classical treatment of polarization of light, neutron transport and diffusion; [Vide his books on *Ellipsoidal Figures of Equilibrium*, and *Radiative Transfer*]

1950-1960: Studies on quantum mechanics, electrodynamics & optics, mathematical theory of relativity, stability problems, and plasma physics; hydrodynamics and hydromagnetic stability, quantum theory of the negative ion of hydrogen, theory of turbulence, confirmation of these theories at a special laboratory at the university of Chicago, formulation of stability theory using variation principles, (studies compiled in his books, Plasma Physics, *Hydrodynamics and Hydromagnetic Stability*);

1961-1995: mathematical theory of black holes, and colliding gravitational waves; [See his books, *Mathematical Theory of Black Holes; Truth and Beauty*].

Chandrasekhar got interested in the state of matter in stellar interior, source of stellar energy, stellar models and the problems of white dwarfs and highly condensed stars, including estimation of maximum mass. His early work was concerned with thermodynamics of the Compton effect with reference to the interior of the stars. As to the opacity coefficient of degenerate matters essential for the calculation of temperature of this type of stars, Chandrasekhar, besides D.S. Kothari and R.C. Majumdar, has done wonderful work. His publications on physical state of matter and pressure in the interior of stars and also of their constitution were studied intensely by him. Some of his results will be of interest:

Theory of White Dwarf stars which are not like other normal stars has been a major area of interest to Chandra. These dwarfs are highly 'under-luminous', much fainter, and are judged on the basis of an average star of the same mass. A typical dwarf star is the companion of Sirius which has a mass equal to that of the Sun but whose luminosity is only 0.003 times that of the Sun, i.e. only 0.3 percent. In addition, white dwarfs are characterized by exceedingly high values of mean density. Moreover, Sirius has mass equal to that of the Sun and has a radius of approx. 20,000 km, astonishingly small for such a great mass. This implies a density of 61,000 gms/cm^3, or just about a ton/ inch^3. But why the dwarfs are of such low luminosity was still a matter of great theoretical importance. It was found that for a given effective temperature, the white dwarfs are much fainter than a star on the main series, or in other words, to maintain the same luminosity, the white dwarf will need a very much higher effective temperature (for much whiter) than the main series stars. To get an answer, Chandra based his calculations on Einstein's special theory of relativity and the new quantum mechanics, and found that if the mass of the star exceeded a certain critical mass, expressible in terms of the fundamental atomic constants, the star would not become a white dwarf. For sufficiently large mass, special relativity comes in eventually and quantum mechanical pressure cannot compete with the gravity nor with the classical thermal pressure. A star will keep on contracting in this limit as it radiates away energy, and will eventually suffer a worse fate. It was admitted before that no radiation could escape from a star if it contracted to less than its Schwarzschild radius. Such a state of invisibility is what we know as a **black hole**. The importance of this discovery is now firmly established and well adopted by astronomers, in spite of initial objection and criticism by Sir Arthur Stanley Eddington.

A maximum mass limit of white dwarf stars, Chandra suggested, as 1.44 solar masses, which is known as *Chandrasekhar Limit*. He says that a star becomes unstable before they reach this limit. Or in other words, if the star mass is greater than 1.44 times the solar mass, the minimum mass which must be exceeding for a star may ultimately collapse. While working on general relativistic problems, it became clear to him that the stars more massive than this limit might have exhausted their nuclear fuel, could contract to much denser *neutron star*. Even though they have a similar but larger mass limit, these massive stars could contract to *Black holes*, if they do not explode completely as *supernova*. *Black hole* is a region on space-time from which gravity prevents anything including light from escaping. It is expected to form when very massive stars collapse at the end of their cycle. After a *Black hole* is formed it continues to grow by absorbing mass from its surroundings. The limit was calculated by Chandrasekhar in 1930 during his voyage to Cambridge from India. It took nearly three decades before the full significance of the discovery of *Black hole* was recognized. *Chandrasekhar limit* has now entered the standard lexicon of physics and astrophysics. His mathematical theory of Black hole was published in 1983.

Distribution and motion of stars was also a favourite area of Chandra. He calculated in detail the factors responsible for their slowing down due to gravitational drag of the neighbouring stars. His studies on stellar structure and stellar dynamics (1932-42) established that that stars experience dynamical friction and suffer from a systematic tendency to be decelerated in the direction of the motion. This dynamical friction is one of the consequences of the fluctuating force acting on a star due to the varying complexion of the neighbours. On stellar dynamics, he and his colleague, Von Neumann applied the statistical analysis of the stellar encounters. His treatise on rotating objects began to be appreciated after two decades of its publication.

Stability in hydrodynamics and hydromagnetic problems was formulated very comprehensively using variational principles of mathematics. Starting with a discussion of the classical Benard convection problem of transferring of heat through a liquid or gas and setting up a convection current, Chandra generalizes it by including the effect of rotation of magnetic field, then extending it to their combined effect, followed by discussion on the problems of thermal stability in fluid spheres, spherical shells, stability of coquette flow and more general flows between co-axial cylinders, jets and cylinders and some problems of gravitational stability. His book on *Hydrodynamic and Hydromagnetic Stabily* (1961) is a master presentation in the field.

Chandrasekhar Number was discovered when he was busy shorting out magneto-hydrodynamical problems (1961). For assessing friction in fluid motion Mach number of the flow of fluid and Reynolds number for assessing the friction in fluid motion were already popular. Turbulent flow was also decomposed into various components by Reynolds or Navier-Stokes equations or by direct numerical simulation. N.R. Sen and his student H.P. Majumdar gave solution of equations for early stage of turbulence. Chandrasekhar, however, gave a numerical solution of Heisenberg's homogeneous isotropic turbulence exhibiting uniform properties throughout in all directions. He has also used an important dimensionless number for magneto-hydrodynamics, named as *Chandrasekhar number*.

Chandra's interest in classical physical ideas was renewed when he started writing a commentary on *Newton's Principia* from modern perspectives in the fag end of his career and published it for common readers. Even his work on mathematical reasoning of the scattering of light has drawn attention.. Chandra was an extremely methodical and talented teacher and researcher who is an example for others.

Chandrasekhar was a great astrophysicist and much ahead of his time. He was a teacher in the true sense, and made everything appeared simpler through exhaustive and critical analysis. According to Martin Schwarzchild (the well-known astrophysicist), 'There is not one field that he's worked in, where we are now daily using some of his results'. In his Noble Lecture (1983), Chandra himself emphasized in the concluding remark of his Nobel Lecture about **Beauty, Truth and Symmetry** in the Universe, leading us into the realms of both scientific features of nature and metaphysics of science.

7. Period of Consolidation (1961-2000)

The previous section has given an account of some excellent experimental and theoretical scientists of first half of the twentieth century in India. It is somewhat satisfying when we think how wide was their research field, and how had they achieved international fame in spite of varieties of limitations with no government grant, better not to speak about facilities for basic research, tools, techniques, source materials, and experimentation. The research was only guided by the urge of doing something great. India became free from Colonial rule in 1947, and the gap between experimental and theoretical knowledge was visible and became the demands of the day. Efforts were made not only to build new institutions under TIFR, CSIR, DAE, IIS, BARC,RRI, etc, but also under old and new universities, the main aim being how to minimize the gap between theoretical and experimental understanding and to make India self-sufficient. In astronomy, astrophysics and physics, the general thrust in physical science was to set up major observation facilities in cosmic ray, optical, infrared, millimeter and radio wave bands of electromagnetic spectra to get a realistic picture of the universe and to know more about their characteristics.

The ***cosmic ray research*** was of course originally started by D.M. Bose and his group in Calcutta, who detected cosmic ray particle tracts in photographic plates exposed in the Himalayan region, and also successful in identifying new particles with a mean mass 200 times that of the electron, much before Powell's systematic development of photographic emulsion method, and *pi-mesons* in cosmic rays. It was generally believed that the cosmic rays enter the atmosphere from outside the earth, i.e. from extra-terrestrial sources. Cosmic ray in its penetrating power can be perceived after their traversing the whole column of earth's atmosphere, equivalent to a layer of water ten meters thick, can reach any points on the earth. TIFR cosmic group under the initiative of Homi Bhabha, the then Director of the Institute, took lot of initiative and used balloon flights for study of cosmic ray. MGK Menon, who was the second man in-charge of TIFR and the right hand man of Bhabha was a student of W. Pauli and also an expert on cosmic rays. He took great interest in the preparation of high-precision measurement techniques and use of large strapped emulsion stacks in the flights to obtain important results like properties of strangeness (quantum attributes of elementary particles), decay mode of heavy unstable particles—called K-*mesons*, associated production in pairs, produced by cosmic rays. Menon also took initiative for cathode ray experiments in Kolar Gold Fields in Mysore (KGF), found to be an ideal place having pits of various depths extending up to 2 miles below the surface. The experiments were carried out in collaboration with groups from England and Japan which collected most comprehensive depth-intensity data for *muons* up to the depth of 9,600 ft below the ground. The first natural atmospheric *neutrino* interactions were also detected in KGF (1965). The *nucleon*-decay experiment to a life span of 10^{31} years was also carried out with detector which was operational in 100 ton category. BARC (Bhabha Atomic Research Centre) provided early leadership from the time of Bhabha (since 1960) in using inelastic scattering (i.e. when the scattering particle looses energy by causing excitation of the struck nucleus) to prove elementary excitations in condensed matter. RRI (Raman Research Institute, Bangaluru) some time in 70^{s} took systematic studies specially on liquid crystals and in library-scale studies in new arrangements of liquid crystals, and decoding stage with a stacking of disc-like molecules, this being possibly the highest point in the life of RRI during 1970-78.

The ***atmospheric studies*** which started also in Kolkata carried out important work on low frequency propagation in the ionosphere, aeronomy and the ozone layer in the upper atmosphere (15 to 30 km above the earth's surface and responsible to absorb a large proportion of Sun's ultraviolet radiation).The work in radio astronomy also started in Calcutta and renewed with great interest and in a large scale in TIFR in 1962 under the active interest of Bhabha and Menon. It was through the encouragement of Menon, Govind Swarup and his group was successful in setting a large telescope indigenously in Ootacamund (Ooty) on a hill with a slope of the same latitude of the place and barrel placing in parallel to the axis of the earth. It had a parabolic cylindrical antenna (530 m × 30 m) stretched towards north-south with facilities of scanning eastern sky, and began active participation since its commissioning in 1970. Ooty Radio Telescope (ORT) is used for observing sensitive and high angular resolutions of extra galactic sources at a frequency of 327 MHz using the method of lunar-occultation (Ramakrishna,2010). It has also enabled extensive observations of pulsars, supernovae, apparent angular size of galaxies with their energy flux, The optical telescope facilities also dates to this period and supply interesting data on discovery of rings surrounding Uranus, measurement of star clusters and their kinematics. GMRT (Giant Metrewave Radio Telescope, Bangaluru) was also ser up by TIFR consisting of 30 antenna each of 45 m diameter works over a wide frequency of 150-1500 MHz, effort being made to widen the frequency range to 40 MHz – 1500 MHz. Signals from all antennas are brought to a control room to correlate using hardware and software correlators to process 32 MHz of bandwidth around the operating frequency. RRI and IIA (Indian Institute of Astrophysics, Bangaluru) and various other institutes work in collaboration in mapping of the sky and exchanging important data between them.

Various efforts were being made to correlate the theoretical and experimental understanding and the search continued for more and **more subatomic particles and their characteristics**, since they were generally conceived as the building blocks in the formation of matter in the universe (Mehra and Reichenberg, 1962; Mukherji, 1971-72; Mitra,1984; Hawking, 1987; Gell-Mann, 1994; Pal,2008;). Major focus was obviously given on the *compositeness of atomic nucleus*. With the discovery of *neutron*-particle which is electrically neutral, and yet found to be a basic constituent of atomic nucleus (where atomic mass is concentrated), and was also on par with the *proton*, it was found that both lie within the same 'shell structure'. Under nuclear spectroscopic instrument, it was also noticed that the atomic spectra and molecular spectra have a striking resemblance thereby suggesting that the nuclear constituents (i.e. 'nucleons' consisting of *proton* and the *neutron*) serve a similar role in shaping nuclear structure, as it is in the case of molecular structure (with their electronic degrees of freedom energetically suppressed so that they behave effectively like elementary constituents). The '*nucleon-like state*' was also observed by experimental scientists in cosmic rays produced in high energy accelerators, and in resonances produced by the bombardment of *pi-meson* beams on proton targets in the laboratory. It was first conjectured by that the *nucleons* must be held together by short-range forces (because of the much less dimension of the *nucleons*), or '*meson*' (heavy *quanta*, the rest mass of these *quanta* was estimated to be about 200-300 times heavier than the electron estimated by using 'Uncertainty Principle' of Heisenberg). This was known as '*pi-meson*' (or '*pion*'), but it entered into lot of controversy for not having the strong interactive properties as expected. Later on it was found that '*pi-meson*' has a partner, '*kaon*' in cosmic rays, which could produce powerful *meson resonances* at its excited states by energetic *pion*- beams, in parallel with the corresponding nucleon (or baryon) in the laboratory. Following this process a large number of *nucleon*- and *pion*-like particles (collectively called '*hadrons*', signifying large, massive particle like *mesons* and *baryons*) were found which created serious doubt as to the property of elementarity of atom. It was of course found that some of the fundamental particles of atom could be better understood if they were made up of even smaller components, an idea that lead to the concept of *quarks* (as a fundamental particle that combines to form other particles, including *proton* and the *neutron*, the particles that make up the atomic nucleus). Initially, *quarks* were conceived having three fold properties of forces (or *flavours*, proposed by Gell-Mann)—Up (charge + 2/3, mass 0.378), Down (charge – 1/3, mass 0.336), and Strange (charge – 1/3, mass 0.540), combing as doublet, triplet composites of more elementary constituents. [The mass is expressed in *Gigaelectron volts* (GeV) following Einstein's mass and energy formula]. These three *flavours* together with their *antiparticles* proved adequate for the description of about 300 *hadrons* and their resonances (***hadron* sector**).

Fourfold classification of forces — electromagnetic, strong-nuclear, weak-nuclear and gravitational, which govern particle interactions of different kinds (called ***Lepton* sector**) were also attempted. Of these, the electromagnetic forces have already been encountered in atomic interactions, and strong-force in nuclear level interactions. The gravitational force is of course is most tangible, but conceptually most baffling of all. The weak-nuclear force is noted in phenomena like β-decay whose feature of missing energy and angular momentum has been introduced in the concept of '*neutrino*' (partner), a mass-less, charge-less particle, which can travel thousands of miles unnoticed to accompany the β- particle (*electron*). Its existence as a partner of *electron* was also experimentally proved. Some particles of course exhibit both weak and electromagnetic force interactions and are given the generic name of '*lepton* particles'(means small or light), which have maintained their elementarity (along with their partners which makes them weak). Three more quark *flavours* but much heavier than the earlier three were also postulated as properties of quarks. These are—Charm (charge + 2/3, mass 1.500), Beauty (charge – 1/3, mass 4.720) and Top (charge + 2/3, mass 174.000). The theory behind the colour force is called quantum chromodynamics (QCD). The *muon*-particle which has properties similar to electron but 200 times heavier also participates in weak and electromagnetic interactions, so is *tau*- particle which is 17 times heavier than *muon*-particle, their partners are being searched out. Attempts are also made to explain effects of interaction of these forces through the use of *group structures* and their effects in terms of various field reactions and properties. Mendeleyev's classification of elements through group structures might have prompted the idea of field for better understanding of the particle properties. First, the Electromagnetic theory of Maxwell was examined and it was found that electromagnetic field has not only the underlying unity of both electricity and magnetism, but also supports the theoretical properties like, *charges* and their conservation, *gauge fields* as force media and charge carriers (invariance under gauge transformation leading to conservation of charge, a kind of symmetry for translational and rotational invariance)besides particle interpretation at the hands of Planck, Bose and Einstein. The *gauge concept* gave a new meaning to the entity called '*charge*', not only as a measure of force between charged particles, and is strictly conserved as a result of its universal coupling to a '*gauge field*', of which the photon once again is a non-trivial example. The theory of *quantum electro-dynamics* (QED) based on photon field (having mass-less vector, *boson*) has got spectacular experimental success in predicting the effect of electromagnetic interactions (1 in 10^{12} accuracy). It has also a theoretical property, known as '*Renormalizability*', which ensures free calculation of physical effects to infinity (any arbitrary order) through suitable redefinitions of electron mass and charge. In this sense it is a universal carrier of electric charge but does not possess any charge of its own. May be colour carrying *gluon* (a type of *boson* responsible for the strong force between *quarks*) field, photon field, vector field or others which is a right kind of vehicle as carrier of charges, as required by the theory to explain the forces. The way the periodic table was based on group structures, the similar approach is possibly being attempted for a possible solution.

***Boson-Fermion Classification* of particles** was another revolutionary concept. S.N. Bose (1924) had advocated a new form of counting of quantum states for truly indistinguishable particles, a revolutionary concept which drew constant endorsement not only from Einstein but also from Schrodinger (1926), Heisenberg (1927) and Dirac (1928). According to the Principle of Indistinguishability, the wave-function of a truly identical particles must be totally symmetric with reference to an interchange of the labels of any two of them. The *photon* was the first non-trivial example of this principle. Thus the wave-function for an n-*photon* state, specified by their respective and states of polarization (or *spin*) should have this *symmetric* property. For any other of identical particles whose intrinsic angular momentum or spin is an integral multiple of Planck's constant (h), the corresponding wave-function must be totally *symmetric*. There is another class of (identical) particles of intrinsic angular momentum or *spin* is half-integral (of Planck's constant h) which obey the *anti-symmetric* property with respect to the interchange of any two particle lebels. The anti-symmetric property automatically ensures that such particles must obey Pauli's Exclusion Principle (their wave-function would vanish when any two particles with identical numbers occupy the same position in space). The counting rule for the second type of particle was given by Fermi (1926) with appropriate modification to Bose's rule. The electron (*spin* ½ h) was the first non-trivial example of the second type. A few particles have been identified as : Boson particles (with integral spin)—photon, alpha-particle, pi-meson, W-boson and gluon which satisfy Bose-Einstein statistics; and Fermions (half integral spin)—electron, nucleon, triton, neutrino and quarks which satisfy Fermi-Dirac statistics. Pauli has further suggested that Boson-Fermion classification can be axiomatically derived from the very foundation of *quantum field theory* under general conditions (Lorentz invariance, causality and locality of basic field operators). A new symmetry between Boson and Fermion systems has now been proposed to erase this distinction.

Another situation was seen when Newtonian equations which admitted a *relativistic generalization* for first moving objects, and Hamiltonian equations of motion (or ***quantum theory****)* for small objects/particles, the latter being adaptable to Heisenberg form of quantum mechanics (alternative to Schrodinger form). The small particles, not fast enough, created lot of problems. In order to make a compromise between the two opposite concepts (Dirac floated the idea) of ***particle* and *anti-particle*** on the basis of mathematical formalism, and argued for relativistic quantum mechanics of *electron as an antiparticle of positron* having opposite mass and spin, opposite sign for charge, magnetic moment and lepton number, result being simultaneous destruction of both as particles and the entire mass converted into energy. Though the existence of *anti-particles* for all types of *fermion*- particles were generally believed, it was taken as a non-trivial solution in the absence of experimental verification. The concept of charge with reference to *nucleon* were thought to exist in two distinct charge states much like two spin states of an electron, viz., *isospin* and *flavor*, the former is the simple manifestation of the latter. The *isospin* space (or isotropy of charge space) in a preferred direction and symmetry of near equality of masses are maintained for *isospin* multipliers. Strong interactions at the *hadronic* and *quark* levels indeed respect this symmetry. Weak interaction violates *isospin* symmetry as seen from the rather large mass differences within its multiples. Various symmetry of group representations like U (1), SU (2), SU (3), SU(6), were applied for explanation of these interacting forces. More sophisticated use of group symmetric theory was first made in unifying first the electromagnetic and weak interactions, and then put under Grand Unified theory (GUT) of electro-weak and strong interactions. It has been found that each physical process leading to infinite variations due to the participation of *fermion* is cancelled in the same way an offending *fermion* is replaced by a companion *boson*. ***Boson-Fermion symmetry*** (SUSy) is virtually a doubling of number of elementary particles since each particle or field of conventional type now requires that a *boson* particle to have an identical SUSy partner. Thus, *photon* and *photino* (spin 1 & ½ respect.), *gluon* and *gluino* (coloured spin (1 & ½ respect.), *lepton* and *slepton* (spin ½ & 0),*W boson* and *wino* (spin 1 & ½), *Higgs boson* and *Higgsino* (spin 0 & ½), *Graviton* and *Gravitino* (2 & ½) and so on are *fermion* - particles and their SUSy partners. Thus each conventional *boson* must have a fermion SUSy partner having identical charges, for example, *boson* and *photino* (photon's SUSy partner) would have a spin ∓ ½ (charge neutral) and vice versa. None of these hypothetical particles have yet been observed but the theoreticians are hammering on incessantly. Presently, a theoretical framework, '*theory of super-symmetry*' has been worked out for prediction of a rich crop of new heavy particles.

However, ***classification of elementary particles*** is explained by a Standard Model based on weak, and electromagnetic fundamental reactions, using mediating *gauge bosons*, like *gluons*, $W^{(-)}$, $W^{(+)}$ and Z *bosons*, and the *photons*. Apart from 24 fundamental particles (12 particles and their associated anti-particles) which are the constituents of all matter, it also predicts the existence of a type of *boson*, known as *Higgs boson* (after the name of Edinburg University physicist, Peter Higgs, existence of which is now experimentally verified). This has been known for several years, and most particle- physicists of course do believe that the model is an incomplete description of nature. A few deviations have already been noticed like, *neutrino* particle mass has already been detected through experiments, though it was originally thought to be mass-less particle; *tachyon,* another hypothetical particle was floated by ECG Sudarshan that moves faster than light. It is a great challenge and strikes at the base of particle physics and breaks Lorentz invariance and the theory underlying special relativity. Feinberg proposed that *tachyonic particles* could be *quanta* of a quantum field with negative squared mass and soon realized that excitations of such imaginary mass field do not in fact propagate faster than light theory, rather represents an instability known as *tachyon condensation*. No compelling evidence for their existence has been found. Apart from this fact, the work of Virendra Singh on Regge pole theory for coupling *coulomb scattering* (caused by the electrostatic field surrounding nucleus), *pion-nucleus scattering* are note worthy. His investigation of SU(3) as an octet operator of decay interaction, the decay of *baryon* decuplet into *baryon* and *mason* octet was investigated along with a new provision of sum rule connecting various decays (known as Gupta- Singh rule). The SU(6) symmetry for assessing correct spectrum of *hadron* states were also put- forward leading to SU(6) mass formula (known as Beg-Singh formula). Singh's investigations of boot-strap theory for understanding spectrums and their coupling leading to the discovery of strong interaction coupling constant as well as strong coupling theory based on Skyrmion dynamics and its relation to Large N QCD are considered important contributions by scholars in the field. Another interesting branch, called *string field theory* on the basis of duality concept between strong and weak interactions, where small one-dimensional string replace the point particles of quantum theory, suggested by Ashok Sen of Harish Chandra Institute in Allahabad, has brought a major breakthrough in the field with wide implications, according to one group of scientists. Interesting activities are being pursued in the areas like, *branes*, *tachyon* condensation and the energy landscape of string field theories.

An active engagement in researches has been found in this period between the **particle-physics (microphysics) and astrophysics (macrophysics)**. This two-way traffic perhaps provides the biggest challenge for physical science as a whole, which has been occasioned by major strides in both fields. Some likely consensus has indeed evolved in the form of Standard Model for weak and electromagnetic interactions, and QCD for the strong interaction between *quarks* and *gluons*. The still bigger unifying principles of GUT, SUSy etc may be regarded as attempts to deal with further unanswered questions like, mechanism of coupling electro-weak and strong interactions at a very high energy state, theoretical speculation of existence of a very massive particle, e.g. X-boson awaiting experimental verification and so on.

The astrophysicists have apparently given a solution to this problem by put-forwarding a model, known as '**Big Bang Model**'. It explains that Big Bang during the early evolution of the universe acted as Nature's powerful accelerator and collisions were very frequent, the temperature and density were very high. As a result, a variety of particles, some very massive and difficult to detect since they interact too weakly produced in this early phase and dropped out of the equilibrium configuration, because the reaction rate could not cope up rapid expansion and cooling of the universe, leaving behind only the relics of those particles. The masses, lifetimes, and interactions determine their relative survival rate as well as the manner in which they presumably influenced the subsequent evolution. It is not easy to get near the steady state moment of Big Bang (on a logarithmic time scale) which implies a huge extrapolations in time of presently expanding Hubble flow of distant objects in the universe, to the epochs when the matter in the universe was much denser and hotter than it is today. However, the observations by Edwin Hubble had shown that the universe was expanding (**Theory of expanding universe**), and as such the thought of static universe (Steady State theory propounded by James Jeans, Fred Hoyle, J. Narlikar and others) is untenable under general relativity. Refutation of steady state was further verified by the cosmic microscopic background radiation. According to Stephen Hawking, the discovery of microwave radiations put a final nail in the coffin of the steady state theory. However, various interpolations are being made for better understanding. These two way traffic between micro- and macro-physics are moving at a rapid pace. Indian physical scientists survive in this dilemma and between these two lines.

8. Concluding Remarks – A Dilemma

In fine, it may be said that the concept of universe and physical ideas related to it get a meaningful and concrete picture in its evolutionary process through the centuries. The *Sāmkhya* and other Indian philosophical schools conceived atom as the basic unit of matter and of universe, and gave a hypothetical as well as speculative explanation of five elements, earth, water, fire, air and *ākāśa* (space, the atmospherical region between the earth and the sun) based on atoms having varieties of properties like, motion, touch, colours and flavours etc. Even duality principle, like *puruṣa* and *prakṛti*, *śiva* and *śakti*, sulfur and mercury, was adopted in containing the energies of two opposite forces to neutralize. Greeks had a similar atomic concept, but not so clearer as that of the Indians. Scientists from sixteenth century onwards have made persistent effort to penetrate deeper and deeper into Nature through telescopic, spectroscopic and satelite observations to understand and interpret it in all its aspects. The concepts of atomic, sub-atomic and cosmic world-view have come to a stage, by observation, experiment and application, to a point beyond which the scientists cannot proceed. Even the modern explanation of the properties of charge of *quark* by colour and flavour, and the concept of *anti-particle* reminds the metaphysical concepts of the early Indians leading us to varieties of paradox in our modern day explanation. Just as physical sciences have given us control over the physical world, so the life sciences also enable us to control the inner world to a great extent. This holds true both in case of physical world and biological world, the boundaries of knowledge of which appear to have been reached which is difficult to cross. This is due not to any lack of experimental technique or the inadequacy of the dialectic tool but to the nature of things inquired into. The scientists are now faced with questions which belong to realms of metaphysics and philosophy. They are concerned with questions, such as coexistence of the external and the internal world, possibility of natural laws being products of the human mind, relationship between the observer and the observed and that between mind and matter, and the criterion of certainty. Scientists' knowledge is to create and satisfy material needs through discoveries and inventions, and should have to face questions of philosophy which were once thought to be mental exercises only. The basic assumption of scientific enquiry is that there exists a real world of matter and energy in space-time independent of the observer. It does not perhaps represent the whole truth. The observer is perhaps an inseparable part of the world he is observing. He has taken him out only for the sake of convenience to systematize the knowledge of what is outside of his self. He has in a way dichotomized Nature into an internal subjective world and an external objective world. He is trying to have a closer view in such a way as if a part is trying to understand the whole. The physical scientists of today is closer to the philosophy that Man is one with Nature, that mind and matter are only different facets of a single reality. The laws of the external world are creations of the human mind, and the existence of the human mind requires possibly an indispensable partnership with Nature.

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