CHAPTER-2

INVESTIGATIONS REGARDING PROBABLE VALUES OF VARIABLE PHYSICAL CONSTANTS

2.1 INTRODUCTION

We all are very much familiar with the importance of the 'physical constants', now in these days they are being used in all the scientific calculations. These so-called physical constants are supposed to be changeless. It is assumed that these constants are reflecting an underlying constancy of nature. Recent observations suggest that these fundamental Physical Constants of nature may actually be varying, so it was decided to study in detail regarding all important physical constants used for calculation purpose in the present thesis. There is a debate among cosmologists & physicists, whether the observations are correct or not. In this chapter we discuss how the values of the fundamental physical constants have in fact changed over the last few decades, and suggest how the nature of these changes may be investigated further. There are many constants studied by us, but some constants are more important than others. The following list gives the most generally regarded as fundamental physical constants and used for calculation purpose in this thesis.

Fundamental Quantity	**Symbol**
Universal Gravitational constant	G
Velocity of light	c
Planck's constant	h
Fine structure constant	α
Elementary charge	e
Cosmological constant	Λ

2.2 THEORY BEHIND THE FUNDAMENTAL CONSTANTS

All the above listed constants are expressed in terms of units; for example, the speed of light is expressed in terms of meters per second. If the units change then the constants will also change. Units are arbitrary, dependent on definitions that may change from time to time as described below:

- The meter, for instance, was originally defined in 1790 by a decree of the French National Assembly as one ten-millionth of the quadrant of the earth's meridian passing through Paris. The entire metric system was based upon the meter and imposed by law.
- The meter was again defined, in 1799, in terms of a standard bar kept in France under official supervision.
- In 1960 the meter was redefined in terms of the wavelength of light emitted by krypton atoms.
- And in 1983 it was redefined again in terms of the speed of light itself, as the length of the path traveled by light in 1/299,792,458 of a second. As well as any changes due to changing units, the official values of the fundamental constants vary from time to time as new measurements are made.

International commissions of scientist continually adjust them. Old values are replaced by new ones, based on the latest ‘best values’ obtained in laboratories around the world. The results from different laboratories around the world are selected, adjusted, and averaged to arrive at the latest official value of all the above constants. We will consider the brief detail about following six constants: Gravitational constant (G), Speed of light (c), Planck's constant (h), Fine structure constant (α), Elementary charge (e) and the Cosmological constants (Λ) [25].

2.3 FAITH REGARDING THE UNIFORMITY OF NATURE.

In practice, the values of the constants change. But in theory they are supposed to be changeless. The conflict between theory and empirical reality need attention, because all variations are assumed to be due to experimental errors, and the latest values are assumed to be the best. But what if the constants really change? For the fundamental believer, physical constants must be constant. Most constants have been measured only in this small region of the universe for a few decades, and the actual measurements have varied erratically. The values of the constants as actually measured on earth have changed considerably over the last fifty years. According to physical science, fixed laws and eternal constants govern everything. The laws of nature are the same in all times and at all places. In fact they transcend space and time. The fundamental postulates of the theory of relativity in the laws of science should be the same for all freely moving observers no matter what their speed is. Now it is agreeable that the laws of nature as formulated by scientists change from time to time, as old theories are partially or completely superseded by new ones. Newton worked through his introduction of the universal gravitational constant, and Einstein worked through treating the speed of light as absolute. In modern relativity theory 'c' is a mathematical constant, relating time & space; its value is fixed by definition. The question arises whether the speed of light actually differs from 'c'? For the founding parents of modern science, such as Copernicus, Kepler, Galileo, Descartes, and Newton, the laws of nature were changeless ideas in the divine mind. Evidence for the expansion of the universe has been accumulating for several decades and discovery of cosmic microwave background radiation in 1965 triggered off a great cosmological revolution. The Big Bang theory took over. Instead of an eternal machine-like universe, gradually running down toward thermodynamic heat death, the picture was now one of a growing, developing, evolutionary cosmos. And if there was a birth of the cosmos, an initial 'singularity', as physicists put it, and then once again age-old questions arise. Where and what did everything come from? Why is the universe as it is? In addition, a new question arises. If all nature evolves, why should the laws of nature not evolve as well? If laws are immanent in evolving nature, then the laws should evolve too. If the values of the constants had been different, there would have been no stars, nor atoms, nor planets, nor people. Even if the constants were only slightly different, we would not be here. All kinds of measurements have inherent limitations on their accuracy. But not all the variations in the measured values of the constants need necessarily be due to error, or to the limitations of the apparatus used [26].

2.4 THEORIES BEHIND CHANGING CONSTANTS

Many physicists have speculated that at least some of the 'fundamental constants' may change with time. In pre-relativistic days, it was thought that Newtonian mechanics inadequate for dealing with the dynamics of the universe as a whole, because of unavoidable infinites in the potential, later on, it has been realized that Newtonian mechanics can be used with a few modifications to obtain a number of cosmological model similar to those of general relativity. As pointed out by Linde [18] that the spontaneous symmetry breaking results is a change in the temperature of the medium, which decrease with the increase of the energy and when he says at a certain critical temperature. This implies the dependence of the cosmological constant on the temperature and time as may be seen in W-Salam model [19]. In fact, the space -time of a local inertial frame is not a flat space time unless

$$\frac{\partial^2 g_{ij}}{\partial x^k \partial x^n} = 0 , \qquad (i, j, k, n = 1,2,3,4) \tag{2.1}$$

If the Einstein Tensor vanishes in a local inertial frame then it must vanishes everywhere and in every co-ordinate system, which implies the vanishing of the gravitational field everywhere in the space time. Therefore we will get the equation

(1.24) written in the previous chapter. This equation yields the vanishing of the energy momentum tensor and hence the space time under consideration is empty, which is not true, because of that we always introduce the cosmological term in the Einstein field equation (1.27) written in the previous chapter as:

$$R_{ij} - \frac{1}{2} R g_{ij} + \Lambda g_{ij} = -\left(\frac{8 \pi G}{c^4} \right) T_{ij} \qquad (2.2)$$

One of the important approaches leading towards a variable constant of gravitation is known as Dirac's large number hypothesis [11]. The ratio of gravitational constant to the electrostatic force is of the order of 10^{-40}. There is no convincing explanation of why such a small dimensionless number appears in the fundamental laws of physics. Dirac pointed out that a dimensionless number of the order 10^{-40} be constructed with (*G, h, c*) and the Hubble's constant H_0 . Therefore H is not a constant due to the expansion of the universe then the constant G may vary with time.

2.5 VARIATION OF THE UNIVERSAL GRAVITATIONAL CONSTANT '*G*'.

In the theory of General Relativity, gravitational attraction is explained as a result of the curvature of space-time. This curvature is also proportional to G and is a constant. Planck has also defined G as one of his universal constants and stated that these three constants (*G, h, c*) are the same anywhere in the universe. The 2006 CODATA recommended value of the Gravitational constant is:

$$G = (6.67428 \pm 0.00067)\ 10^{-11} \mathrm{m}^3\, \mathrm{kg}^{-1}\, \mathrm{s}^{-2.} \qquad (2.3)$$

In the Table-2.1, we have listed the time to time measurements of the Newtonian Gravitational constant '*G*' by different scientists along with year, method & reference number from the available literature. We have also calculated the deviation of '*G*' from its present value.

Table-2.1: Variation in the value of Universal Gravitational Constant 'G'

Sr. No.	**Author**	**Year**	**Method**	**G(x10^{-11} $m^3Kg^{-1}s^{-2}$)**	**Ref.**	**% Deviation from CODATA-2006 value of '*G*'**
1	Cavendish H.	1798	Static torsion	6.754 (41)	[27]	+1.19443
2	Reich F.	1838	Static torsion	6.64(6)	[28]	-0.5136
3	Baily F.	1843	Static torsion	6.63(7)	[28]	-0.6634
4	Cornu A, Baille J.	1872	Static torsion	6.618(17)	[29]	-0.8432
5	Jolly Ph.	1873	Jolly balance	6.447(110)	[28]	-3.4053
6	Eotvos R.	1886	Static tortion	6.657(13)	[28]	-0.2589
7	Richarz/K-Menzel	1888	Jolly balance	6.683(11)	[28]	+0.1307
8	Wilsing	1889	Jolly balance	6.594(150)	[28]	-1.2028
9	Poynting J. H.	1891	Jolly balance	6.6984(40)	[29]	+0.3614
10	Boys C.V.	1895	Static torsion	6.658(7)	[28]	-0.2439
11	Braun	1895	Dynamic torsion	6.658(2)	[29]	-0.2439
12	Richarz/K-Menzel	1896	Jolly balance	6.685(11)	[30]	+0.0241
13	Braun	1897	Dynamic torsion	6.649(2)	[28]	-0.3788
14	Burgess	1901	Dynamic torsion	6.64(4)	[28]	-0.5136
15	Heyl P. R.	1930	Dynamic torsion	6.6721(73)	[31]	-0.0327
16	Zaradnicek J.	1933	Dynamic torsion	6.659(4)	[29]	-0.2289
17	Heyl/Chrzanowski	1942	Dynamic torsion	6.672(49)	[31]	-0.0342
18	Rose R.D. et al.	1969	Rotating table	6.674(3)	[31]	-0.0042
19	Pontikis	1972	Resonance tors.	6.6714(6)	[31]	-0.0432
20	Renner Ya.	1973	Dynamic torsion	6.670 (8)	[28]	-0.0641
21	Karagioz	1976	Dynamic torsion	6.668(2)	[28]	-0.0941
22	Rose et al.	1976	Rotating table	6.6699(14)	[29]	-0.0656
23	Sagitov	1977	Dynamic torsion	6.6745(30)	[28]	+0.0033
24	Stacey et al.	1978	Geophysical	6.712(37)	[31]	+0.5652
25	Luther/ Towler	1982	Dynamic torsion	6.6726(5)	[32]	-0.0252
26	CODATA-1986	1987		6.67259(85)	[33]	-0.00025
27	Michaelis et al	1996		6.671540(56)	[34]	-0.00041
28	Bagley & Luther	1997	Fibre torsion	6.6740(7)	[35]	-0.000042
29	CODATA-1998	1999		6.673(10)	[36]	-0.00019
30	Gundlach/ Merkow.	2000	Fibre torsion	6.67422(9)	[37]	-0.000009

Sr. No.	Author	Year	Method	*G*(x10^{-11} $m^3Kg^{-1}s^{-2}$)	Ref.	% Deviation from CODATA-2006 value of '*G*'
31	Quinn et al	2001	Strip torsion	6.67559(27)	[38]	0.0002
32	CODATA-2002	2003		6.6742(1)	[39]	-0.0012
33	Armstron/ Fitzgerald	2003	Strip torsion	6.67387(27)	[40]	-0.000061
34	Hu et al.	2005	Fibre torsion	6.6723(9)	[41]	-0.0003
35	CODATA-2006	2007		6.67428(67)	[42]	Present official value

Interpretation: The problem with all these indirect lines of evidence is that they depend on a complex tissue of theoretical assumptions, including the constancy of the other physical constants of nature. It is easy to see that the constancy of '*G*' is consistent, provided that all actual variations from experiment to experiment, or method to method, are due to some truncation or inherent error.

2.6 STUDY REGARDING VARIATIONS IN SPEED OF LIGHT '*c*'

The speed of light in vacuum of free space is an important physical constant denoted by the letter '*c*'. According to Einstein's theory of relativity, the speed of light in a vacuum is invariant: it is an absolute constant. Much of modern physics is based on that assumption. Therefore a strong theoretical prejudice against raising the question of possible changes in the velocity of light. In any case, the question is now officially closed. Since 1972 the speed of light has been fixed by definition. The value is defined as 299,792.458 ± 0.001 kilometers per second. In the year1987, in the technical report entitled 'The Atomic Constants, Light and Time', Terver Norman and Barry setterfield [43], put forward their evidence in favour of the hypothesis that the speed of light '*c*' has been decreasing in the past. Norman and Setterfield tabulated the result of 163 speed of light determinations by different experimenters & different methods. Based upon the data given in the report we have formed the following table:

Table-2.2: Variation in the value of Speed of Light ‘c’

Sr. No.	**Year**	**Experimenter**	**Method**	**Value of ‘*c*’ in Km/s**	**% Deviation from present official value of ‘*c*’**
1	1740	Bradley	Aberration	300,650	+0.2860
2	1783	Lindenau	Aberration	300,460 (160)	+0.2227
3	1843	Struve	Aberration	300,020 (160)	+0.0759
4	1861	Glasenapp	Jupiter Satellite	300,050 (60)	+0.0859
5	1874	Cornu (Helmert)	Toothed Wheel	299,990 (200)	+0.0659
6	1874	Cornu (Dorsey)	Toothed Wheel	299,900 (200)	+0.0359
7	1876	HarvardObservat.	Jupiter Satellite	299,921 (13)	+0.0429
8	1879	Michelson	Rotating Mirror	299,910 (50)	+0.0392
9	1882	Newcomb	Rotating Mirror	299,860 (30)	+0.0225
10	1882	Michelson	Rotating Mirror	299,850(90)	+0.0202
11	1883	Nyren	Aberration	299,900 (80)	+0.0192
12	1900	Perrotin	Toothed Wheel	299,860 (80)	+0.0359
13	1902	Perrotin	Toothed Wheel	299,803 (30)	+0.0225
14	1902	Perrotin/Prim	Toothed Wheel	299,795 (30)	+0.0362
15	1906	Rosa and Dorsey	Elect. mag. Units	299,802 (30)	+0.0035
16	1923	Mercier	Waves on Wires	299,798 (15)	+0.0008
17	1924	Michelson	Polygonal Mirror	299,786 (100)	+0.0032
18	1926	Michelson	Polygonal Mirror	299,774 (10)	+0.0018
19	1928	Mittelstaedt	Kerr Cell	299,786 (10)	-0.0022
20	1932	Pease/Pearson	Polygonal Mirror	299,774 (10)	-0.0062
21	1936	Anderson	Kerr Cell	299,771 (10)	-0.0072
22	1937	Huttel	Kerr Cell	299,771 (10)	-0.0072
23	1940	Anderson	Kerr Cell	299,792 (3)	-0.0055
24	1947	Essen,Gord.Smith	Cavity Resonator	299,796 (2)	-0.0002
25	1949	Aslakson	Radar	299,792.5 (1)	-0.00002
26	1949	Bergstrand	Geodimeter	299,794.3 (1.2)	+0.0012
27	1950	Essen	Cavity Resonator	299,793.1(0.26)	+0.00001
28	1950	Hansen and Bol	Cavity Resonator	299,793.1 (0.4)	+0.0006
29	1950	Bergstrand	Geodimeter	299,794.2 (1.4)	+0.0002
30	1951	Bergstrand	Geodimeter	299,792.6 (0.7)	+0.0002

Sr. No.	**Year**	**Experimenter**	**Method**	**Value of '*c*' in Km/s**	**% Deviation from present official value of '*c*'**
31	1951	Aslakson	Radar	299,792.85(0.16)	+0.0006
32	1951	Froome	Radio Interferom.	299,792.75 (0.3)	+0.00005
33	1953	Bergstrand	Geodimeter	299,795.1 (3.1)	+0.00013
34	1954	Froome	Radio Interferom.	299,792 (3)	+0.0001
35	1954	Florman	Radio Interferom.	299,792.4 (2.4)	+0.0009
36	1955	Scholdstrom	Geodimeter	299,792.9 (2)	-0.00002
37	1955	Plyler et. al.	Spectral Lines	299,792.7 (2)	-0.0002
38	1956	Wadley	Tellurometer	299,791.9 (2)	0.00015
49	1956	Wadley	Tellurometer	299,792.40 (11)	+0.0001
40	1956	Rank et. al.	Spectral Lines	299,792.2 9(13)	-0.00012
41	1956	Edge	Geodimeter	299,792.6 (1.2)	-0.00002
42	1956	Edge	Geodimeter	299,792.5 (1)	-0.00009
43	1957	Wadley	Tellurometer	299,792.6 (6)	+0.00005
44	1958	Froome	Radio Interferom.	299,792.44 (20)	+0.00001
45	1960	Kolibayev	Geodimeter	299,792.56 (11)	+0.00005
46	1966	Karolus	Modulated Light	299,792.44 (20)	-0.00001
47	1967	Simkin et. al.	Microwave Interf.	299,792.56 (11)	+0.00003
48	1967	Grosse	Geodimeter	299,792.50 (5)	+0.00001
49	1972	Bay,Luther,White	Laser	299,792.462(18)	+0.0000013
50	1972	NBS (Boulder)	Laser	299,792.460 (6)	+0.0000006
51	1973	Evenson et. al.	Laser	299,792.4574(11)	-0.0000002
52	**1973**	**NRC, NBS**	**Laser**	299,792.458 (2)	**Official value**
53	1974	Blaney et. al.	Laser	299,792.4590 (8)	+0.0000003
54	1978	Woods et. al.	Laser	299,792.4588(2)	+0.0000002
55	1979	Baird et. al.	Laser	299,792.4581 (19)	+.00000003
56	1983	NBS (US)	Laser	299,792.4586 (3)	+0.0000002

Interpretation: Data given here indicates that '*c*' does decay with time, and that the decay does have a formal statistical significance. The speed of light was indeed higher in the past; light from distant galaxies thus took less time in transit as atomic processes and light speed are inextricably linked. This means that if the atomic clock has registered an age of, say, 10 billion years for the universe, then light will have traveled a distance of 10 billion light years in that atomic period. However, the dynamical clock could have registered a completely different age. Many cosmologists are working on cosmology with varying speed of light. A changing '*c*' scenario bothers some people because of Einstein's use of '*c*' in relativity theory. However, it can be shown that relativity is still valid with changing '*c*'. Some physicists have proposed an approach that deduces relativity without light entering the argument at all. Others have shown that changes are possible in the physical quantities involved in the equations provided that the effects are mutually canceling.

2.7 VARIATION IN THE VALUE OF PLANCK'S CONSTANT '*h*'

The Planck's constant '*h*' is a physical constant used to describe the sizes of quanta. It plays a central part in the theory of quantum mechanics and is named after Max Planck, one of the founders of the quantum theory. Planck's constant divided by 2π is called reduced Planck's constant (also known as Dirac's constant) and is denoted by $\hbar$ pronounced 'h-bar'. The Planck's constant is the proportionality constant between the energy E of a photon and its frequency ν. The relation between energy and frequency is known as Planck's relation $E= h\nu$. It is expressed in SI units of Joule seconds, is one of the smallest constant used in Physics. The value of the Planck's constant recommended by 2006 CODATA [42] is:

$$h = 6.62606896\ (33) \times 10^{-34} \text{j.s} \tag{2.4}$$

Recent values published after CODATA 2006, were available in March 2007, given by Robinson & Kibble [44] by using a newly improved watt balance reported a value of h as:

$$h = 6.62607095\ (44) \times 10^{-34} \text{j.s.} \tag{2.5}$$

The detail research evidences regarding the value of '*h*' along with the deviation from latest official value is given below for analysis purpose:

Table-2.3: Variation in the value of Planck's constant 'h'

Sr. No.	Year	Author	Ref.	$h(\times 10^{-34}\ joule\ \sec onds)$	% Deviation from CODATA-2006 value of '*h*'
1	1951	Bearden and Watts	[45]	6.62363 (16)	-0.04617
2	1955	Cohen et al.	[45]	6.62517 (23)	-0.01357
3	1963	Condon	[45]	6.62560 (17)	-0.00708
4	1973	Cohen and Taylor	[46]	6.626176 (36)	+0.0107
5	1987	CODATA-1986	[33]	6.6260755(40)	+0.000099
6	1998	Edwin/Richard	[47]	6.62606891(58)	-0.0000007
7	1999	CODATA-1998	[36]	6.62606876(52)	-0.000003
8	2003	CODATA-2002	[39]	6.6260693 (11)	+0.000034
9	2007	CODATA-2006	[42]	6.62606896(33)	Latest official value
10	2007	Robinson & Kibble	[44]	6.62607095(44)	+0.0002

<u>Interpretation:</u> Several attempts have been made to look for changes in Planck's constant by studying the light from quasars and stars assumed to be very distant on the basis of the red shift in their spectra. The idea was that if Planck's constant has changed, the properties of the light emitted billions of years ago should be different from more recent light. Little difference was found, leading to the seemingly impressive conclusion that '*h*' varies by less than 5 parts in 10^{13} per year. But critics of such experiments have pointed out that these constancies are inevitable, since the calculations depend on the implicit assumption that '*h*' is constant; the reasoning is circular. *(Strictly speaking, the starting assumption is that the product hc is constant; but since c is constant by definition, this amounts to assuming the constancy of h.)*

2.8 VARIATION IN THE VALUE OF FINE-STRUCTURE CONSTANT 'α'

The fine-structure constant 'α' was originally introduced into Physics in 1916 by Arnold Sommerfeld, as a measure of the relativistic deviations in atomic spectral lines from the prediction of the Bohr model. It is defined as:

$$\alpha = \frac{e^2}{2\varepsilon_0 hc}, \tag{2.6}$$

where *e* is the elementary charge on the electron, *h* is the Planck's constant, *c* is the speed of light and ε_0 is the vacuum permittivity. It gives a measure of the strength of electromagnetic interactions, and is sometimes expressed as its reciprocal, approximately 1/137. It is a dimensionless quantity, and thus its numerical value is independent of the system of units used. The value of the fine-structure constant recommended by CODATA-2006 [42] is:

$$\alpha = 7.2973525376(50)x10^{-3} = \frac{1}{137.035999679(94)}. \tag{2.7}$$

However after completion of the 2006 CODATA adjustment, an error was discovered, leading to the following value [48]:

$$\alpha = 7.297352570\,(5)x10^{-3} = \frac{1}{137.035999070\,(98)}. \tag{2.8}$$

Physicists have been wondering for many years whether the fine structure constant is really a constant. Historically, a varying α has been proposed as a means to solve some of the perceived cosmological problems of the day [49, 50]. A brief history of the evaluation of Fine structure constant from the available literature along with deviation is given in the following table:

Table-2.4: Variation in the value of Fine structure constant 'α'

Sr. No.	**Year**	**Author /Source**	**Ref.**	**Value of *α***	**Value of α^{-1}**	**% deviation from CODATA-2006 value**
1	1909	Einstein	[51]	0.00714(25)	140 (5)	-0.022
2	1916	Sommerfeld	[52]	0.0072939(53)	137.1 (1)	-0.00047
3	1935	Speddinget	[53]	0.0072780(11)	137.4 (2)	-0.0027
4	1951	Beardon/Watts	[45]	0.007296953(28)	137.0435(5)	-0.000055
5	1953	Lambet et. al.	[54]	0.007297326(64)	137.0365 (12)	-0.0000036
6	1963	Cleland	[55]	0.007297203(43)	137.0388 (8)	-0.00002

7	1963	Condon	[45]	0.007297200(33)	137.03886(62)	-0.000021
8	1969	Taylor	[56]	0.007297351(11)	137.03602 (21)	-0.00000021
9	1973	CODATA-1973	[46]	0.0072973504(59)	137.03604 (11)	-0.00000029
10	1979	Williams/Olson	[57]	0.00729735449(80)	137.035963 (15)	+0.00000027
11	1987	CODATA-1986	[33]	0.00729735308(32)	137.0359895(61)	+0.00000007
12	1999	CODATA-1998	[36]	0.007297352533(27)	137.03599976(50)	-0.0000000006
13	2003	CODATA-2002	[39]	0.007297352568(25)	137.03599911(46)	+0.0000000041
14	2007	CODATA-2006	[42]	0.0072973525376(50	137.035999679(94)	official value
15	2007	Gabrielse/Hann	[48]	0.007297352570(5)	137.035999070(98)	+0.0000000044

Interpretation: Several cosmologists have speculated that the fine-structure constant might vary with the age of the universe, and attempts have been made to check this possibility by analyzing the light from stars and quasars, assuming that their distance is proportional to the red-shift of their light. The results suggest that there has been little or no change in the constant. But as with all other attempts to infer the constancy of constants from astronomical observations, many assumptions have to be made, including the constancy of other constants, the correctness of current cosmological theories, and the validity of red shifts as indicators of distance.

2.9 VARIATION IN ELEMENTARY CHARGE '*e*'

The elementary charge denoted by the symbol ***e*** is the electric charge carried by a single proton or equivalently, the negative of the electric charge carried by a single electron. It has a value $1.602\ 176\ 487 \times 10^{-19}$ C in SI system of units, according to the CODATA-2006 list of physical constants [42]. In the cgs system of units, the value is $4.803\ 204\ 27 \times 10^{-10}$ statcoulombs. It was first measured in Robert Millikan's famous oil-drop experiment in 1909. A brief history of the evaluation of the Elementary Charge from the available literature along with deviation from latest official value is given in the following table:

Table-2.5: Variation in the value of Elementary Charge

Sr. No.	Year	Author/Source	Ref.	Value of e x 10^{-10} statcoulomb	Method	% variation from CODATA-2006 value
1	1913	Millikan	[58]	4.8049 (22)	OD	0.00035
2	1917	Millikan	[59]	4.8071 (38)	OD	0.00081
3	1917	Millikan	[59]	4.8059 (52)	OD	0.00056
4	1920	Millikan	[60]	4.803 (5)	OD	-0.000043
5	1928	Wadlund	[61]	4.7757 (76)	XR	-0.0057
6	1928	Backlin	[62]	4.794 (15)	XR	-0.0019
7	1929	R.T.Birge	[63]	4.801(5)	AV	-0.00046
8	1931	Bearden	[64]	4.8022	XR	-0.00021
9	1935	Soderman	[65]	4.8026 (3)	XR	-0.00013
10	1935	Backlin	[66]	4.8016	XR	-0.00033
11	1935	Bearden	[67]	4.8036 (5)	XR	0.000082
12	1936	R.T.Birge	[68]	4.8029 (5)	AV	-0.00030
13	1936	Backlin/Flemberg	[69]	4.7909 (114)	OD	-0.0026
14	1938	Dunnington	[70]	4.8025 (4)	XM	-0.00015
15	1938	Dunnington	[70]	4.8036 (48)	OM	0.000082
16	1939	R.T.Birge	[71]	4.8022 (10)	AV	-0.00021
17	1939	Miller/DuMond	[72]	4.8005 (4)	XM	-0.00056
18	1941	R.T.Birge	[73]	4.8025 (10)	XM	-0.00015
19	1944	R.T.Birge	[74]	4.8030 (21)	AV	-0.000043
20	1947	DuMond and Cohen	[75]	4.8024 (5)	AV	-0.00017
21	1950	Beardon and Watts	[76]	4.80217(6)	AV	-0.00022
22	1952	DuMond and Cohen	[77]	4.8022 (1)	XM	-0.00021
23	1952	DuMond and Cohen	[77]	4.80288 (21)	AV	-0.000068
24	1955	Cohen et. el.	[78]	4.80286 (9)	AV	-0.000072
25	1963	Cohen and DuMond	[79]	4.80298 (20)	AV	-0.000047
26	1965	Cohen and DuMond	[80]	4.80313 (14)	AV	-0.000015
27	1969	Taylor et. el.	[81]	4.8032500 (21)	AV	0.0000095

Sr. No.	Year	Author/Source	Ref.	Value of e x 10^{-10} statcoulomb	Method	% variation from CODATA-2006 value
28	1973	Cohen and Taylor	[46]	4.8032420 (14)	AV	0.0000079
29	1987	CODATA-1986	[33]	4.8032083 (15)		0.00000084
30	1999	CODATA-1998	[36]	4.80320420 (19)		-0.000000015
31	2003	CODATA-2002	[39]	4.80320440(42)		0.000000027
32	2007	CODATA-2006	[42]	4.80320427(12)		Latest official value

OD = oil drop: OM = oil-drop mean: XR = X-ray: XM = X-ray Mean: XP = X-ray powder method (imprecise): AV = best adjusted value.

In SI system of units corresponding values of the elementary charge '*e*' as per CODATA-1986 onward are given below:

Sr. No.	Year	Source	Ref.	Value of e x 10^{-19} Coulomb
1	1987	CODATA-1986	[33]	1.60217733(49)
2	1999	CODATA-1998	[36]	1.602176462(63)
3	2003	CODATA-2002	[39]	1.60217653(14)
4	2007	CODATA-2006	[42]	1.602176487(40)

Interpretation: The data given in the above table indicates that value of Elementary charge '*e*' is fluctuating. Little changes are still there in the latest official value of '*e*'.

2.10 VARIATION IN COSMOLOGICAL CONSTANT 'Λ'.

Early Universe & Inflation

As we know the standard big-bang model incorporates three important observations about the universe:

First Observation:

The expansion of the universe is discovered by Hubble in 1930.

Second Observation:

The discovery of the microwave background radiation by Penzias & Wilson and its confirmation by other observers.

Third Observation:

The prediction of the abundances of various nuclei on the basis of nucleosynthesis in the early universe, particularly the abundance of He^4 and deuterium, which appear to confirm reasonably with observations. The inflationary models of which the original one was propounded by Guth [20]. Some aspects of inflationary models involve fairly technical queries of particle physics and in particular Grand Unified theories. We are not going in detail at this moment. At high energies, according to the Glashow-Weinberg-Salam unified electroweak theory, electromagnetic & weak interactions behave in a similar manner and consequently there is a phase transition in the early universe associated with this at a critical temperature of about $3\times10^{15}K$. After pointing out some serious conflict with the standard model, the original inflationary model put forward by Guth in 1981 had serious drawbacks. So later on 'new inflation' put forward independently by Linde in 1982 [82] and Albrecht [83].

As discussed above Guth suggested that the early universe has gone through a period of rapid expansion. This expansion is known as inflationary. For increasing rate of expansion, anti gravitational force is required in the model. This may be produced by considering the cosmological term Λg_{ij} in the Einstein field equation (2.2). The role of anti gravitational effect is dominating at the early stages of evolution of the universe. Therefore, if the anti gravitational field is incorporated into the Einstein equations via the cosmological term Λg_{ij}, the cosmological constant Λ must have a positive value for small value of time '*t*'. In the construction of a nonsingular cosmological model by incorporating the f-gravity effect at the beginning of the expansion of the universe, Sinha & Sivaram[16] proposed that

$$\text{At } \ t = 0, \quad \Lambda = \Lambda_f = 10^{28}\, cm^2, \quad G = -G_f = -6.67\times10^{31}\, c.g.s.\ units$$

As described in equation (1.9), with the help of equation (1.27a) &

$u_i = g_{ij} u^j$, we get

$$u_j = \frac{dx^j}{ds} \tag{2.9a}$$

$$(i,\ j = 1,2,3,4)$$

u^j is known as the four velocity vector of the fluid particle.

The space-time for a homogeneous and isotropic universe is given by equation (1.6). Since the fluid particles are at rest w. r. t. the coordinates (r,θ,ϕ), we have

$$u^i = (0,0,0,c) \tag{2.9b}$$

putting the value from (1.6), (1.27a) & (2.10b) into the field equation (2.2), we get the following set of equations:

$$-\frac{2\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} - \frac{kc^2}{R^2} = \frac{8\pi G p}{c^2} - \Lambda c^2 \tag{2.9c}$$

and

$$\frac{3\dot{R}^2}{R^2} + \frac{3kc^2}{R^2} = 8\pi G\rho + \Lambda c^2 \tag{2.9d}$$

Adding equations (2.9c) & (2.9d), we get

$$-\frac{2\ddot{R}}{R} + \frac{2\dot{R}^2}{R^2} + \frac{2kc^2}{R^2} = 8\pi G\left(\frac{p}{c^2} + \rho\right) \tag{2.9e}$$

On differentiating (2.9d), we get

$$-\frac{3\dot{R}}{R}\left(-\frac{2\ddot{R}}{R} + \frac{2\dot{R}^2}{R^2} + \frac{2kc^2}{R^2}\right) = 8\pi(\dot{G}\rho + G\dot{\rho}) + \dot{\Lambda}c^2 \tag{2.9f}$$

which is simplified with the help of equation (2.9e) as

$$\dot{G}\rho + G\dot{\rho} + \frac{3\dot{R}}{R}G\left(\rho + \frac{p}{c^2}\right) + \frac{\dot{\Lambda}c^2}{8\pi} = 0 \tag{2.9g}$$

Multiplying the equation (2.9g) by R^3, we get

$$c^2 R^3\left(\dot{G}\rho + \frac{\dot{\Lambda}c^2}{8\pi}\right) + G\left[c^2\frac{d}{dt}(\rho R^3) + 3pR^2\dot{R}\right] = 0 \tag{2.9h}$$

The conservation equation (1.2) when simplified with the help of equations (1.6), (1.27a) & (2.9b), we get

$$c^2 \frac{d}{dt}(\rho R^3) + 3pR^2\dot{R} = 0 \tag{2.9i}$$

which on substitution in the equation (2.9h) gives

$$8\pi\dot{G}\rho + \dot{\Lambda}c^2 = 0 \tag{2.9}$$

as discussed by Pande & Mishra [7].

The above equation implies that $\Lambda > 0$ for $\rho > 0$.

According to f-gravity theory, the value of Λ in the past should be large as compared to its present value [16]. In the following table value of Cosmological Constant predicted by some cosmologists has been given:

***Table-2.6: Variation in the value of Cosmological Constant* 'Λ'**

Sr. No.	**Year**	**Author**	**Ref.**	**Methodology**	**Value of Λ**
1	1983	Johri, V. B. et. al	[84]	$\Lambda \propto R^{-2}$	$10^{-58} cm^{-2}$
2	1994	Rohlf J. William	[85]	$\Lambda \propto R^{-2}$	$< 3\times10^{-56} cm^{-2}$
3	1996	Kochanek, C.	[21]	$\Lambda \propto R^{-2}$	$< 10^{-56} cm^{-2}$
4	2000	Pande et. al	[7]	$\Lambda \propto R^{-2}$	$10^{-57} cm^{-2}$
5	2001	Carmeli M.	[86]	$\Lambda \propto t^{-2}$	$2.036\times10^{-35} s^{-2}$
6	2001	Carmeli et. al	[87]	$\Lambda \propto t^{-2}$	$2.28\times10^{-35} s^{-2}$
7	2002	Carmeli et. al	[88]	$\Lambda \propto t^{-2}$	$1.934\times10^{-35} s^{-2}$
8	2003	Peebles, P., J. et. al	[89]	$\Lambda \propto R^{-2}$	$\sim 10^{-56} cm^{-2}$
9	2006	Jetzer P. et. al	[90]	$\Lambda \propto R^{-2}$	$\sim 10^{-45} cm^{-2}$
10	2008	Ishak, M. et. al	[91]	$\Lambda \propto R^{-2}$	$\leq 1.29\times10^{-56} cm^{-2}$

Interpretation: It is clear from above table that the value of $\Lambda \approx 10^{-57} cm^{-2}$ is more realistic to consider for calculation purpose (if required).

2.11 CONCLUDING REMARKS

We have seen here the variations in the value of six fundamental physical constants as time goes on. Similar variations are found in the values of the other fundamental constants. These do not trouble true believers in constancy, because they can always be explained in terms of experimental error of one kind or another. Because of continual improvements in techniques, the greatest faith is always placed in the latest measurements, and if they differ from previous ones, the older ones are automatically discredited Also, at any given time, there is a tendency for metrologists to overestimate the accuracy of contemporary measurements, as shown by the way that later measurements often differ from earlier ones by amounts greater than the estimated error. Alternatively, if metrologists are estimating their errors correctly, then the changes in the values of the constants show that the constants really are fluctuating. The simplest example is the fall in the speed of light from 1928 to 1949 as listed in table 2.2 sr.no. 19 to 25. The constant wise interpretation has been given along with the concerned table in the previous sections of this chapter. So far there have been only two main theories about the fundamental constants.

- First, they are truly constant, and all variations in the empirical data are due to errors of one kind or another. As science progresses, these errors are reduced. With ever-increasing precision we come closer and closer to the constants' true values. This is the conventional view.
- Second, several theoretical physicists as referred in the author coloums of the tables (2.1), (2.2), (2.3), (2.4), (2.5) & (2.6) have speculated that one or more of the constants may vary in some smooth and regular manner with the age of the universe, or over astronomical distances.

Various tests of these ideas using astronomical observations seem to have ruled out such changes. But there has been little consideration of the other possibilities:

- The possibility that constants may fluctuate, within limits, around average values which themselves remain fairly constant.

- The idea of changeless laws and constants is the last survivor from the era of classical physics in which a regular and (in principle) totally predictable mathematical order was supposed to prevail at all times and in all places.
- The fluctuating values of the fundamental constants in experimental measurements seem just as compatible with small but real changes in their values, as they are with a perfect constancy obscured by experimental errors.
- Numerical analysis may play a vital role to verify the authentication of the above mentioned values and we wish to continue our investigations in this direction in future.

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