Precession of the Equinoxes and its Importance in Calendar Making

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Just like the axis of a rotating top, the axis of the Earth moves in a conical path about the ecliptic pole and completes it in about 25800 years. This motion of the Earth is known as precession. Due to this precessional motion, the equinoctial points experience a westward motion and hence the cardinal points shift their positions with the passage of time. In this article, the causes of precessional motion and its effect on calendar preparation are discussed.

The night sky appears to us as a huge inverted cauldron in which celestial bodies like stars, planets, etc. are depicted. This imaginary inverted cauldron is called celestial sphere. We, the inhabitants of the northern hemisphere, can see only a part of the entire celestial sphere while those in the southern hemisphere can observe the other portion of it. These two parts constitute entire celestial sphere. If you want to know the exact location of a place on the surface of the Earth, we have to find out the latitude and longitude of that place. This means that equator and prime meridian constitutes a reference frame for finding any place on the surface of the Earth. Similarly, the reference frame, which helps us to locate celestial bodies on the celestial sphere, is called astronomical coordinate system.

Astronomical Coordinate System

We know that the Earth revolves around the Sun as well as rotates on its own axis. If the axis of rotation of the Earth is produced towards north and south then the fictitious points where the axis of rotation is supposed to pierce the celestial sphere are called celestial North Pole and celestial South Pole, respectively. In *Figure* 1, P is the celestial North Pole and P′ is the celestial South Pole. The imaginary circle (EγE′ Ω in *Figure* 1) in which the equatorial plane of the Earth (i.e. the imaginary

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plane drawn through the equator of the Earth which divides the Earth into northern and southern hemisphere) cuts the celestial sphere is called the celestial equator.

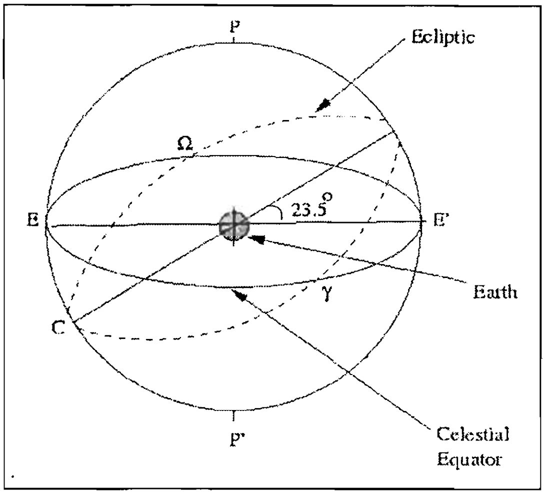


Figure 1. Astronomical co-ordinate system.

Since the north and south celestial poles are in opposite direction, so any observer on Earth can see only one pole at a time. At present, the north celestial pole is situated at an angular distance of about one degree from the pole star (Polaris). The apparent path of the Sun (CγC′ Ω in *Figure* 1) in the sky is called ecliptic. Ecliptic makes an angle of 23.5 degrees, known as obliquity of the ecliptic, with the celestial equator. The two fictitious points where the ecliptic cuts the celestial equator are known as ascending node and descending node. The more familiar names of the two nodes are First Point of Aries and First Point of Libra. The path of the Sun while going from south to north in its apparent motion, cuts the celestial equator at First Point of Aries (the point γ in *Figure* 1) and the First Point of Libra (the point Ω in *Figure* 1) is the point where the path of the Sun cuts the celestial equator while moving from north to south.

On 21st March, i.e., on the day of Vernal Equinox, as the Sun stays on the First Point of Aries, the durations of day and night are equal throughout the world. After crossing the First Point of Aries, the Sun steadily moves towards the north till it reaches the summer solstice (the point C′ in *Figure* 1) on 22nd June. As the Sun reaches the summer solstitial point, its northerly motion is stopped and it starts moving towards south. In its southernly motion, the Sun reaches the First Point of Libra (also known as autumnal equinoctial point) on 23rd September and again on that day, the durations of the day and night are equal throughout the world. After crossing the point of winter solstice on 22nd December (the point C in *Figure* 1). After that, the southernly motion of the Sun is stopped and it again starts moving towards north. The duration of the day in the northern and southern hemisphere is maximum while the Sun stays at the summer and winter solstice, respectively. The summer and winter solstitial points are also known as First Point of Cancer and First Point of Capricorn, respectively. The Vernal Equinox, autumnal equinox, summer solstice and winter solstice are known as cardinal points of the ecliptic.

Zodiac

It was observed by ancient astronomers that although the apparent path of the Sun in the celestial sphere remains the same, the moon and the planets show some deviations in their motions. The moon and the planets move to some extent towards north and south of the ecliptic. This deviation for the moon does not exceed much more than 5 degrees, while the planets deviate more than that. For instance, the deviation of Venus can be as much as 8 degrees. For this reason, ancient astronomers imagined a strip (or belt) like region extending up to 9 degrees north as well as 9 degrees south of the ecliptic. The motion of the moon and the planets are bounded within this region. This 18 degree wide region is known in astronomy as the zodiac.

The entire zodiac is divided into 12 regions, each extending up to 30 degree and each region is termed as a zodiacal sign. The zodiacal signs are named after animal, human being, fish, etc.; depending upon the configurations of the stars of that sign. Since, the ascending node of the ecliptic lies very close to the zodiacal sign of Aries (Ram), the first zodiacal sign is termed as Aries and the ascending node is known as First Point of Aries. On the other hand the descending node of the ecliptic is very close to the zodiacal sign of Libra and hence descending node is known as First Point of Libra. The signs of the zodiac begin at Aries and end at Pisces (*Figure* 2). *Table* 1 lists the positions of the signs in the zodiac, their Latin name, English name and Indian name.

If one observes the entire region from the western to eastern horizon, then he (or she) will find the zodiacal signs one after

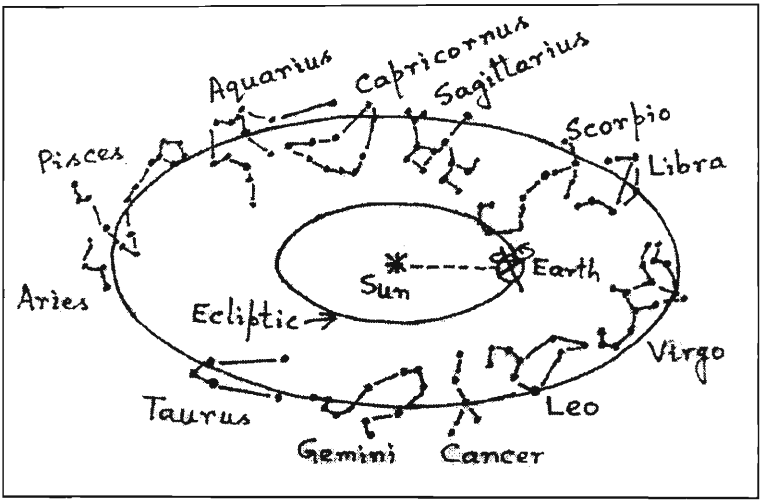


Figure 2. Ecliptic and zodiacal signs.

another and at anytime six signs will be observed because the angular separation of eastern and western horizon is 180 ° and each sign covers an angular distance of 30 °. For instance, if at any instant Cancer is observed in the western horizon, then Leo will be found 30 ° above it, Virgo will be 30 ° above Leo and so on till Sagittarius is observed in the eastern horizon.

Precession of the Equinoxes

Although ancient astronomers believed that the positions of the

Table 1.

Position in the Zodiac	Latin name of Zodiacal signs	English name of Zodiacal signs	Indian name of Zodiacal signs
0°-30°	Aries	Ram	Meṣa
30°-60°	Taurus	Bull	Vṛṣa
60°-90°	Gemini	Twin	Mithuna
90°-120°	Cancer	Crab	Karkata
120°-150°	Leo	Lion	Siṁha
150°-180°	Virgo	Virgin	Kanyā
180°-210°	Libra	Scale	Tulā
210°-240°	Scorpio	Scorpion	Vrischika
240°-270°	Sagittarius	Archer	Dhanu
270°-300°	Capricornus	Goat	Makara
300°-330°	Aquarius	Water Bearer	Kumbha
330°-360°	Pisces	Fish	Meena

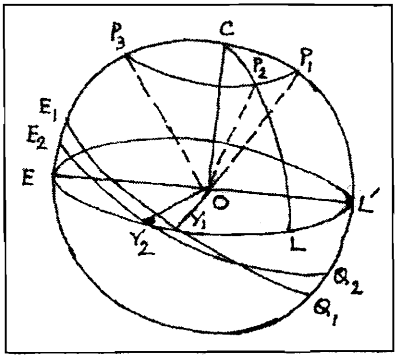


Figure 3. Motion of the first point of Aries.

equinoctial points remain unchanged, later on it was revealed through observation that the First Point of Aries and First Point of Libra have a westward motion. Although the amount of motion is very small in a year, but the motion being unidirectional, the positions of the equinoxes change sufficiently over a long period of time. This positional shift of the equinoctial points is known as Precession of the Equinoxes.

The first astronomer who drew the attention of the scientific community towards this precessional motion was Hipparchus. Comparing his own observational result with that of his predecessor, Timocharis, Hipparchus found that the bright star Spica of Virgo constellation had shifted about two degrees from the point of autumnal equinox as that of its position at the time of Timocharis. From this observation, Hipparchus could conclude that First Point of Libra as well as First Point of Aries undergo a westward shift of about 5.1 arc second per year. Afterwards, more accurate calculations showed that this amount is about 50.2 arc second per year. This means that the First Point of Aries make a complete round along the ecliptic in about 25800 years. In *Figure* 3, C is the pole of the ecliptic ELL′. Suppose in any year γ_1 be the position of the First Point of Aries. Then the celestial North Pole is at P_1 and $E_1\gamma_1Q_1$ is the celestial equator. Due to precessional motion, the First Point of Aries moves towards west in the direction $\angle\gamma_1$ along the ecliptic. If in the next year γ_1 moves to γ_2, then the celestial North Pole reaches from P_1 to P_2 along the small circle $P_1P_2P_3$, where $\angle COP_1 = \angle COP_2 = \angle COP_3 =$ obliquity of the ecliptic. For this reason the new position of the celestial equator will be $E_2\gamma_2Q_2$. In 505 AD, the Vernal Equinox was very close to the star ζ- Piscium (Zeta Piscium) of Pisces. Since that star was again in the neighbourhood of Aries, then the point of Vernal Equinox was named as First Point of Aries. In the last 1500 years or so, the point of Vernal Equinox undergone a translation of about 23 degrees towards west and at present is situated at the end of Pisces. In spite of this, the point of Vernal Equinox is still referred to as First Point

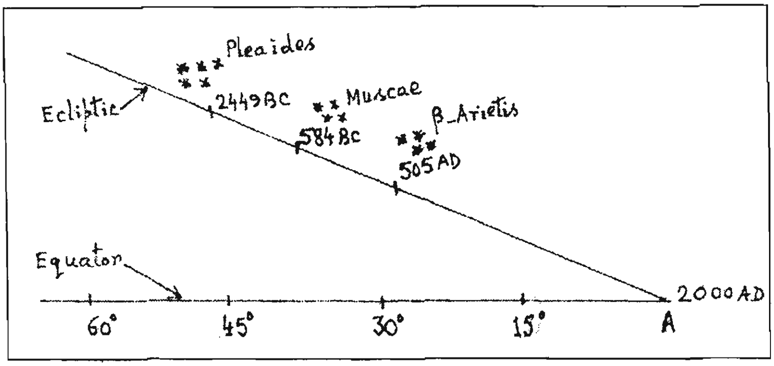


Figure 4. Positions of vernal equinox in different ages (Not in scale).

of Aries. *Figure* 4 shows the positions of the Vernal Equinox in different ages while *Table* 2 lists the positions of the same point relative to apparently fixed stars.

Causes for Precessional Motion

All of us are familiar with the motion of a top. If the spinning axis of the top remains oblique and not vertical during the rotation of the top, then the axis of rotation of the top traces out a conical path about the vertical (upward direction). This motion of the top is precessional motion. This motion occurs due to the torque generated by the gravitational attraction of the Earth on the top. Similarly, Earth's rotational axis is inclined at an angle of 66.5 degree to the ecliptic plane (i.e. at an angle of 23.5 degree to the normal to the ecliptic plane) and hence it also describes a cone about the line directed towards the ecliptic pole (*Figure* 5). As a result of this the equinoxes experience a precessional motion towards west. Precessional motion is explained (*Figure* 5) in the light of Newton's laws of motion.

If Earth were a homogeneous sphere then, as a first approximation, we could calculate its orbit by assuming that the mass of Earth is concentrated at its centre. But the Earth is not a homogeneous sphere, rather it is an oblate spheroid with its equatorial diameter larger than its polar diameter by 43 kms. So, for Earth there occurs an equatorial bulging of matter. As a result of this,

Table 2.

Period	Position of Vernal Equinox
2449 BC	Pleaides
584 BC	Muscae
505 AD	Zeta Piscium
2000 AD	Present position

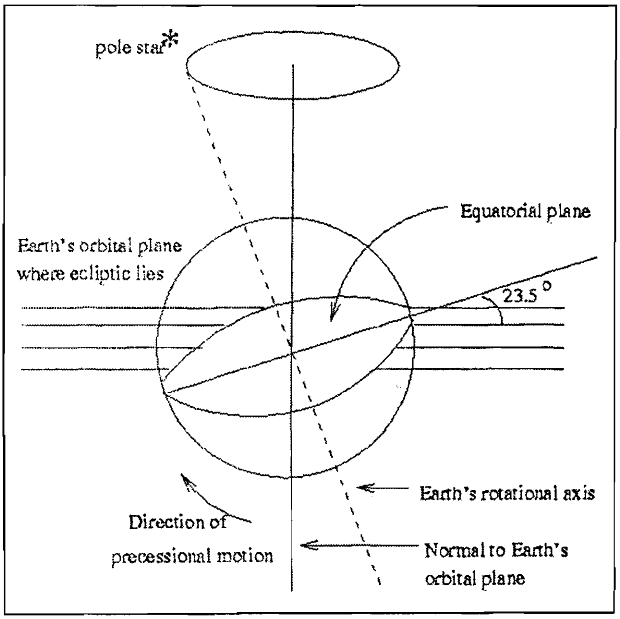
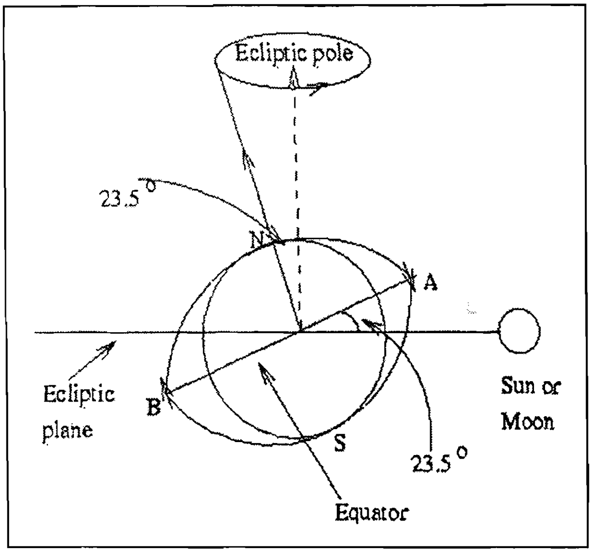


Figure 5. Precession of Earth's axis.

the force experienced by Earth due to the presence of Sun or moon is a combination of a force passing through the centre of the Earth and a torque (at the equatorial bulge) that acts perpendicular to the plane formed by the Earth's spinning axis and the normal to the plane of the ecliptic (*Figure* 6). This torque is responsible for a slow but steady precessional motion of the rotational axis of the Earth about the normal to the ecliptic plane. But the angle between the spinning axis of the Earth and the ecliptic plane remains the same. The presence of the moon causes a larger amount of precessional motion than that of the Sun.

The amount of precessional motion due to the presence of the moon is about 34.4″ per year. But the orbit of the moon does not lie in the plane of the ecliptic. The inclination of the moon's orbit to the ecliptic is 5°8′ 43.42″± 9′ and the maximum and minimum value of this inclination is separated by a span of 173 days. On the other hand the moon exhibits the same phase on the same day of the month at every 18.6 years. Due to these two complexities, the amount of precessional motion for the presence of the moon is determined by the instantaneous position of the moon. Taking into account the combined effect of the moon, the Sun and the planets, the amount of precessional motion is 50.37″ per year. But this amount is not fixed and this value changes between 44.5″ and 56″. The amount of precessional motion in different ages is given in *Table* 3. Due to this slow but

Figure 6. Explanation of precessional motion (Bulging is exaggerated).



Period	Amount of Precessional Motion (per year)	Number of years (per degree motion)
2000 BC	49.391″	72.89
0	49.835″	72.24
1900 AD	50.256″	71.63
2000 AD	50.279″	71.60

Table 3.

steady precessional motion of the equinoxes, the celestial pole changes its position by a considerable amount after sufficiently long time. At present the celestial pole lies very close to the Polaris, the brightest star of the Ursa Minor constellation. But, after about 12,900 years Vega, the brightest star of the Lyra constellation, will be our pole star. This means that in about 14,900 AD. Earth's axis of rotation will be directed towards Vega.

Various Methods of Time Determination

Day – Solar day and Sidereal day

The imaginary line passing through the north point of the horizon, Zenith and the south point of the horizon is called celestial meridian. The crossing of celestial meridian by any celestial body during its westward motion is called upper transit. The time elapsed between two successive upper transits of any celestial body is called 'one day'. If Sun be that particular celestial body, then the time between two successive upper transits is known as one 'solar day' while for other stars it is called one 'sidereal day'. In astronomy, solar day and sidereal day are mostly used.

One solar day has been divided into 24 parts and each part is defined as an hour. So, by definition, one solar day is equal to 24 hours. But, relative to any distant fixed star, Earth takes 23 hours 56 minutes 4.1 seconds to rotate once about its own axis which means that after this time that particular star will be observed in the same direction from Earth. This time is known as one sidereal day and its duration is 23 hours 56 minutes 4.1 seconds. For this reason, on any day any star rises and sets about 3 minutes 55.9 seconds earlier than the previous day.

Month

Month is completely related to the moon. Length of the month can be determined in two ways and depending on that there can be two types of month viz. sidereal month and synodic month. The time taken by the moon to return to a particular point in the sky (say the star Aldeberan) starting from the same point is called 'sidereal month' and is equal to 27 1/3 days. But, from ancient period, the time between two successive new moon has been taken as the length of the month. This month is known as 'synodic month' and its mean length is 29.5305881 days (approximately 29.5 days) although it can vary between 29.3055 days and 29.8125 days due to the variation in the sidereal period of the moon.

Year

We know that Earth revolves round the Sun in an elliptic orbit. As the Earth moves round the Sun, the sunbound line of sight of an observer on the Earth also rotates and the Sun appears to be moving in a circular path in front of the background fixed stars (*Figure* 7). It is known as the apparent motion of the Sun. The time taken by the Sun to make one complete circle before background stars is equal to the time taken by the Earth to revolve once in its orbit and is equal to 365 days 6 hours 9 minutes 10 seconds or 365.2564 days. This time is known as one 'Sidereal year' or 'Nirayana solar year'.

The change of seasons on the Earth depends on the position of the Sun relative to cardinal points. So, taking Vernal Equinox as the reference point, the time taken by the Sun to revolve once along the ecliptic in its apparent motion is called the 'tropical year'. Since the equinoxes move westward, the length of tropical year is slightly less than that of the sidereal year. The length of a tropical year is 365 days 5 hours 48 minutes 46 seconds or

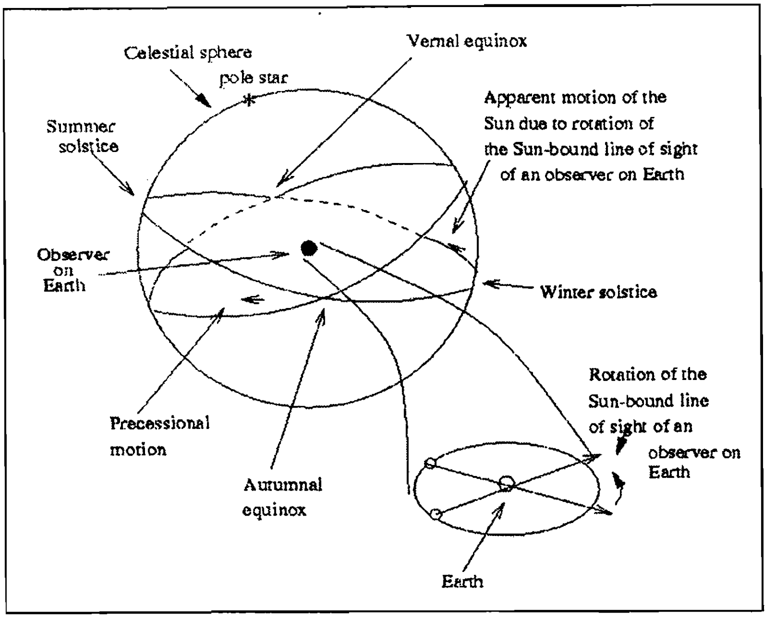


Figure 7. Position of ecliptic and cardinal points in the sky.

approximately 365.2422 days. Since tropical year is calculated taking the precessional motion of the equinoxes into account, it is also called 'Sayana'[1] year. Mathematically speaking,

[1] सायन = स + अयन

1 tropical year = {365.2421 9879 – 0.0000000614 (t-1900)} solar days where t denotes the year in AD.

On the other hand, the time between two successive perihelion passages of the Earth is called 'anomalistic year' whose length is 365 days 6 hours 13 minutes 53 seconds or 365.2596 days.

Precessional of the Equinoxes and Calendar Making

'Panchang' (Indian Almanac) is widely used for performing various religious festivals or rituals in proper time. It has already been stated that the entire zodiac has been divided into 12 equal parts of 30 degree each. Since the entire zodiac covers up 360 degrees, then the Sun stays for about 30 days in each zodiacal sign. If the zodiac is divided into 12 equal parts without considering the precessional motion of the equinoxes (i.e. taking the zodiac as fixed) then this system is called Nirayana system.

In this system, time taken by the Sun to return to the same zodiacal sign from which it started its journey is equal to one sidereal year (365.2564 days). On the other hand, taking one of the cardinal points (usually First Point of Aries) as the starting point and considering the cardinal points as moving (i.e. taking into account precessional motion) relative to the background stars, the division of zodiac into 12 equal parts is called 'Sayana' system. So, in this system, time taken by the Sun to make one complete revolution relative to any of the zodiacal signs is equal to one tropical year (365.2422 days).

Now most of the Panchangs which are in use depend on the old astronomical text 'Suryasiddhanta'. Astronomers in the Siddhantic period believed that in Nirayana system, one tropical year is equal to the time taken by the Sun to make one complete revolution because they failed to realise the importance of the precessional motion. Even those astronomers who noticed precessional motion merely thought that precession is an oscillatory motion and correction in astronomical calculations is not necessary for precession of the equinoxes. At the time of writing of 'Suryasiddhanta' (1400 years ago), the Vernal Equinox was very close to the star ζ– Piscium of Pisces. But due to precessional motion, at present, position of Vernal Equinox has shifted. But still we are making calculations depending on the old Suryasiddhanta and making Panchangs based on it. During last 1400 years, the amount of accumulated error is so much that at present the beginning of the year has shifted by about 23 days. In the year 1865, an article entitled 'The adjustment of the Hindu Calendar in Asiatic Researches' written by P C Ghosh was published in *'Education Gazette'*. It was followed by an article written by Mr Manomohan Banerjee, Zaminder of Telenipara and was published in *'Education Gazette'*. It was pointed out in those two articles that the Panchangs in use are erroneous. Then it was decided to form a committee under the leadership of Sir Asutosh Mukherjee in order to justify the statements of those two articles by comparing with modern astronomical almanacs. But, due to some unknown reason that committee was not constituted. On the other hand without waiting for the formation of the committee, Madhab Chandra Chatterjee, a retired civil engineer, depending on the modern astronomical calculations, published the first modern Bengali Panchang (Bisuddha Siddhanta Panchang) in the year 1890.

As soon as Madhab Chandra published his modern Panchang, a controversy arose. According to astronomical calculations the duration of a 'Tithi' (See *Box* 1) can be 3 hours 10 minutes more or 3 hours 38 minutes less than its mean value of 23 hours 37 minutes. But according to religious scriptures, if any 'Tithi' exceeds by more than 2 hours or diminishes by more than 2 hours 24 minutes than its mean value, then no virtue ('Punnya') can be gained by observing rites in that 'Tithi'. For this controversy, at least on two occasions the publication of Bisuddha Siddhanta Panchang was at stake. Only due to some sympathetic persons it still exists. Although many are aware of the need for correction of traditional Panchangs, yet due to the opposition of followers of the old school, even Government is afraid of reformation. For this reason, famous scientist as well as President of 'Calendar Reformation Committee' set up by Government of India after independence, M N Saha lamented by saying – "The Hindu Calendar which regulates the life of 99% of the 250 million Hindus, is a most bewildering production of the human mind and incorporates all the superstitions and half –truths of

Box 1. Tithi

The important concept of 'Tithi' of 'Lunar day' is found in 'Vedanga Jyotisha' literature where it was loosely defined as the time from moonset to moonset during Sukla Paksa and moonrise to moonrise during Krishna Paksa. It was Siddhantic astronomers who gave a strict meaning to Tithi. According to them, when the longitude of the moon gains exactly 12° or its multiple on that of the Sun, a tithi is completed. The ending of the first tithi is indicated by a difference of 12° in longitude. Similarly, a difference of 24° means the ending of the second tithi and so on. There are 30 tithis in a lunar month. Tithis are shown from Sukla 1 to Sukla 15 (Purnima or full moon) and again from Krishna 1 to Krishna 14 and the Krishna 30 (known as Amavasya or new moon).

medieval times. In theory it uses the sidereal year, the length of the year being still taken as 365.25875648 days, as fixed up by Aryabhata in about 505 AD, under the mistaken impression that the equinoctial points did not precess, but merely oscillated. The real length of the tropical year is 365. 24219879 days, so that the Hindu civil year exceeds the correct length by 0.01656 day nearly. The result is that the solar months, which were definitely linked with stars, are revolving throughout the seasons, and the beginning of the year is now wrong by nearly twenty three days, the result of accumulated error of nearly 1400 years ... In spite of these errors, very few have the courage to talk of reform. We are content to allow religious life to be regulated by the encyclopedia of 'errors and superstitions' which is called the Hindu almanac, and to regard it as a scripture".

It's a matter of regret that most of our Panchang makers, without admitting this error, are still following a dogmatic path. Some of them even argue that use of the length of anomalistic year will yield the same result as that of tropical year. But this opinion is totally wrong because use of tropical year only will give the correct result. Not only that, if we allow to continue these erroneous calculations for 1500 years more, then the festivals will be totally out of seasons and the festival of spring will observed in winter. For this reason, M N Saha commented – "The dates, as given in the Panchangs for religious observances vitiate the fundamental rule of Hindu time reckoning that all festivals should be performed in right seasons".

Epilogue

It is clear from the above discussions that precession of the equinoxes is a natural phenomenon and its role in the correct calendar making is very important. So, for performing various religious and social rituals in proper time, it is important to rectify the errors of the traditional Panchangs in the light of modern scientific calculations.

Suggested Reading

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