METROLOGY OF THE CIRCLE AND THE ROYAL CUBIT: DECIPHERING THE ANCIENT 360 DEGREE CIRCLE DESIGN

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Abstract

Design of the ancient 360-degree circle is proposed to be the result of using a scientific length standard, the Egyptian *Royal cubit*, to define the dimensions of the circle reference frame. The ancient length standard is subdivided into its own sub-units of *palms* and *fingers*, but it is the equivalence to other ancient length units (*inches, feet)* in proportions that match specific circle features that allow underling design aspects to be identified. The available evidence suggests that the original circle design described by Hipparchus, as being based on "***a radius of 3438 minutes"***, should be interpreted to mean that the design circle radius was actually **3438** ***Royal cubits***. From this framework it is possible to observe direct metrological relationships between the design of the *Royal cubit* and the design of the 360-degree circle, as well as the origin of the *inch* and *feet* units. Multiple shared features between the circle and the *Royal cubit* suggest a common design principle was involved, and the evidence suggests that an understanding of electromagnetic physics was in place when the sexagesimal circle was created. If verified, the hypothesis presented here infers that a new frequency standard could be implemented in modern metrology that would provide both the time and length units and allow for complete integration with the 360-degree circle reference frame. This step may also then provide deeper insights into astronomical physics as dimensional features are examined under a suitable length unit.

Historical Setting

For more than 2000 years mankind has been using the circle in its sexagesimal angular arrangement for mathematical and astronomical reckoning. During this period there has not been any conclusive explanation for the specific design of the circle, and despite development of the metric system of measurement in modern times it has proved impractical to replace the circle of 360 degrees with a metric version.

Circle mathematics was transmitted from ancient Babylonian sources to modern society through the scholars of Hellenistic Greece and their successors (Neugebauer)[1]. Historical records traced to Hipparchus (circa 140 BC) reveal that **a circle of radius 3438 *minutes*** was involved with the development of the 360-degree circle, and that the **circle radius was measured in the same units as the angular subdivisions on the circumference**. This information suggests that a fixed unit of length may have been associated with circle design.

The information passed down from Hipparchus (described in Ptolemy's *Almagest*) is extremely valuable evidence that must be considered while developing an understanding of the origins of the circle. The historical information unfortunately does not provide a reason for the choice of the sexagesimal arrangement which results in 3438 *minutes* of angle being associated with 1 *radian* of angle. At this point in history it is quite likely that older sources of the mathematical information were being re-discovered, and the underlying principles were completely unknown. The extent of the problem is summarised by Neugebauer[2], "*But we have practically no concept of the arguments, mathematical as well as astronomical, which guided the inventors of these procedures. Hence, we are very far from any 'history' of Babylonian astronomy and must be satisfied to accept it as a complicated system of admirable elegance and efficiency but without really understanding its development. In short, we probably know as much and as little about Babylonian astronomy as a Greek astronomer of the Hellenistic age knew*".

The influence of the general circle arrangement described by Hipparchus extended to other societies, indicating the widespread use of a central source of mathematical principles and concepts from an early stage in human history. In "Crest of the Peacock", Georges Joseph[3] states the following in relation to discoveries made in Chinese mathematical texts from the Tang dynasty (620 to 900 AD): *"There are also sine tables at intervals of 3˚45' **for a radius of 3438 units**, which are the values given in the Indian astronomical texts Aryabhatiya and Suryasiddhanta. This is the earliest record of a sine table in any Chinese text. **The choice of a radius of 3438** was determined by the practice of dividing the circumference of a circle into 360 x 60 = 21 600 equal parts. If the length of the arc of each of these equal parts is 1 unit, and the value of pi is taken as 3.1416, then the radius of the circle can easily be established using circumference = 2 x pi x r. Then radius = 3438".*

Again, as with the records from Hipparchus, we have an end-result to work with but no description of the scientific basis for the original development of the method, and repetition of the fundamental circle radius in "*minutes"* or "*units*". In simple terms then, since development of the sexagesimal circle took

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[1] *Otto Neugebauer, The exact sciences in antiquity, 1975, Second edition.*

[2] *Studies in the History of Mathematics and Physical Sciences 1, Otto Neugebauer. A History of Ancient Mathematical Astronomy Part One, 1975. Editors M.J. Klein and G.J. Toomer.*

[3] *Georges* Joseph, *Crest of the peacock: Non-European roots of mathematics,1991.*

place in ancient society, scholars have found no fault with the mathematics and have continued to use it, unchanged from its original design, in all fields of science. What has not been accomplished over the past 2000 years, however, is an understanding of why the sexagesimal circle arose in the first place.

The general consensus presented in available scholarly texts (both old and modern) to explain the 360-degree subdivision of the circle, is that it was possibly attributable to the approximately 360 days required for earth to complete one orbit around the Sun. For the *Royal cubit,* knowledge of the earth's dimensions and an ability to accurately measure the distances involved have been inferred as the source of this unit of length. For the sub-units of the *Royal cubit*, specifically *feet*, *fingers* and *palms,* anthropomorphic principles (based on human proportions) have been inferred. There are serious limitations associated with the current hypothesised origins for both metrological systems, and no archaeological or scientific evidence to support the claims.

Unexpectedly, the sub-units of the *Royal cubit* are **not sexagesimal subdivisions** of the primary length unit, and not even decimal subdivisions, and this may explain why links between the circle and the *Royal cubit* have not been identified previously. There is no obvious metrological reason for making such a choice of unusual sub-unit ratios, and it is essentially a red flag amongst the other measurement units. The possible reasons for a non-sexagesimal subdivision of the *Royal cubit* are presented in this article.

This author believes that a repercussion of the move to the *metre* length unit was that scholars lost focus on trying to understand the existing units of measure and their origins, allowing replacement of old units instead with a new set. The only western nation that objected to this change was North America, and to this day the USA still retains use of the ancient *inch* and *feet* units of length measurement. This fact alone makes it still relevant to find an explanation for the original design factors involved in the ancient metrological arrangement.

Before discussing aspects of modern metrology, in order to understand the ancient circle design, it is important to note that archaeological evidence from the ancient societies of Sumeria, Egypt and the Indus Valley (amongst others) attests to the fact that these civilisations had, from around 3000 BC, well-defined standards for length and weights. Some of these units have remained in use to modern times, albeit with some modification from the original unit over time. At the same time, the earliest astronomical measurements were being made and recorded by Babylonian and Sumerian scientists using the 360-degree circle.

Modern Metrology vs Ancient Metrology

Some background to modern metrology is essential to this study, and our current society relies on electromagnetic physics for the definition of the *metre* length standard, and for the measurement and definition of the unit of duration, the *second*. Although the earliest length standards were physical objects, these have rapidly been replaced by more precise laboratory-based methods for defining and maintaining the units.

In terms of applying modern physics to the analysis of circle design origins and the *Royal cubit*, it is our ability to measure and define the speed of light, and to measure properties of electromagnetic radiation (wavelength and frequency), that appear to have some relevance in understanding the ancient metrological units.

The speed of light is $c = 2.99792458 \times 10^8$ m/s, and when this value is expressed in terms of the *Royal cubit*, the value becomes 5.7296×10^8 Rc/s. The potential significance of this value becomes apparent when angular characteristics within the 360-degree circle are considered, foremost of which is the 1 radian sector which subtends the angle of 57.296°.

The *metre* is the distance that light will travel in vacuum in the time of 3.336×10^{-9} s based on the definition of the second and the speed of light. The equivalent expression for the *Royal cubit* produces a time interval of 1.745×10^{-9} s.

It is the observation that these two numbers primarily, 57.3 and 1.745, which have direct correspondence between the circle and the *Royal cubit* that allowed for further examination of the ancient system from a modern metrological viewpoint.

Study Results

This study began by looking for an ancient length unit that may have been attached to the original circle, seeing as we are dealing with a system essentially designed to measure distance. The following assumptions were made as part of this process:

- The circle must have allowed for the measurement and calculation of length and distance; and
- There must have been a standard unit of length in place for the circle to be made practically useful.

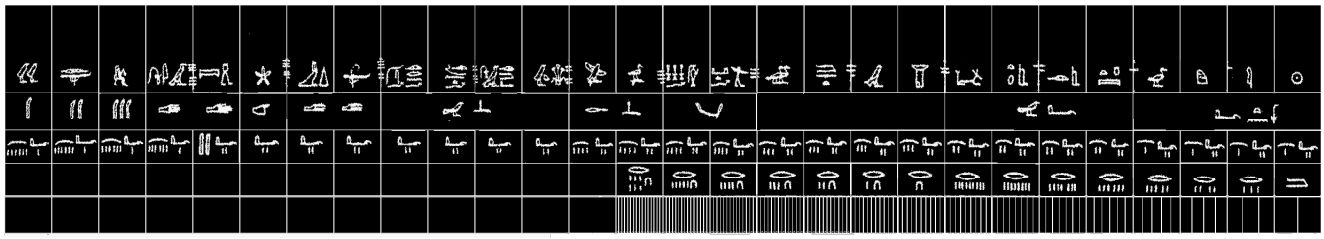
At the end of this process there remained only one candidate length unit, the Egyptian *Royal cubit*. Based on reported measurements of available archaeological examples, the various *Royal cubit* units have lengths in the range 0.52 m to 0.59 m. For this study an equivalent length of 0.5232 m (Stone, 2013)[4] has been associated with 1 *Royal cubit (Rc).*

The critical component of the study involved consideration of modern physics principles which then exposed potential links between the circle and the *Royal cubit*, and a scientific process could be identified in the measurement system. The process required conversion of the speed of light from the normal modern value expressed in metres per second (2.998×10^{8} m.s^{-1}) to a value expressed in *Royal cubits* per second (57.296×10^{7} Rc.s^{-1}).

At this point it was the similarity of the 1 *radian* angle of 57.296° to the value of the speed of light that raised suspicion of a possible link between the two. By studying the dimensions of circles with various radius values, it becomes possible to discern fixed relationships between the circle and the *Royal cubit*. From this it was also possible to discern the likely origins of the sexagesimal subdivision of the circle, and the origin of the various associated length units including *feet* and *inches*.

The 1.745 *feet*, 20.625 *inches* and 28 *fingers* that comprise sub-units of the *Royal cubit* are values that also appear in the circle, especially when the 1 radian sector is analysed. The observed relationships suggest that basic features of the circle in its sexagesimal angular structure may be attributable to application of the electromagnetic equation c = frequency × wavelength. From these relationships it is possible to infer that the *Royal cubit* was based on an electromagnetic definition, and that the specific number of *feet, inches* and *fingers* comprising 1 *Royal* cubit carry the scientific information associated with the definition of the length standard.

Figure 1 shows an example of a *Royal Cubit* rod and its sub-units.



1 Royal Cubit = 523.2 mm = 20.625 inches = 1.745 feet = 28 Fingers

Figure 1: The Egyptian *Royal cubit* and its sub-units

[4] *Mark H Stone. Review Article. The Cubit: A History and Measurement Commentary. Journal of Anthropology, Volume 2014, Article ID 489757, 11 pages. Published January 2014*

For the purely theoretical case of examining the dimensions of a circle that has a radius of 5.7296×10^8 Rc (the radial distance a light signal will travel in the time of 1 second), the 1 radian angle will subtend an arc length of 5.7296×10^8 Rc. The circle angle corresponding to the arc length is 57.296° suggesting the possibility of a direct link between circle design and electromagnetic physics. In addition, a circle with this radius will have a circumference of exactly 360×10^7 *Royal cubits*. This circumference length potentially provides the original reason for the 360 degrees subdivision of the circle, and further sub-division according to sexagesimal principles.

The specific ratios of 20.63 *inches*, 1.745 *feet* and 28 *fingers* which are equivalent to one *Royal cubit* offer a means of identifying the origin of the *Royal cubit* design and its connection with the circle. The basic components of circle mathematics which suggest a connection to the *Royal cubit*, and which therefore present historical evidence to consider while examining the possible origins of the circle and sexagesimal system, are summarised as follows:

- When expressed in *Royal cubits* per second, the modern value for the speed of light becomes 57.296×10^7 *Royal cubits*.s^{-1}. This value is directly proportional to the 1 *radian* angle of 57.296°.
- An electromagnetic signal transmitted from a point source over a time interval of 1s will create a spherical electromagnetic wave front with a radius of 57.296×10^7 *Royal cubits*. At this time interval the full wave front will have a theoretical circumference of 360×10^7 *Royal cubits*. Each 1 arcsecond of arc will be 2.7778×10^3 *Royal cubits*.
- The reciprocal of the speed of light provides the time interval during which light will travel the distance of 1 *Royal cubit*, this being 1.745×10^{-9} s^{-1}.
- Each 1˚ of angle for any circle subtends an arc whose length (L) is traditionally calculated as:

  Arc length L = subtended angle × 1.745×10^{-2} × radius - (1)

  Equation (1) has been used by scholars for many centuries and is still in use in modern society. The number 1.745 is the same as the number of *feet* in 1 *Royal cubit*. The significance of this number in circle mathematics is indicated in Table 1, and it suggests that all arc length calculations are controlled by the speed of light.
- *1 radian* = 57.296˚ (from 360° ÷ 2pi). By subdividing *1 radian* into 20.625 equal sectors, each sector is subtended by approximately 2.8° (the more accurate value is 2.7778°). There are 20.63 *inches* in 1 *Royal cubit*, and 28 *fingers*. The significance of this specific subdivision of the 1 *radian* angle is that it is in accordance with the electromagnetic equation:

  c = λ × f (speed of light = wavelength × frequency, or 57.296 = 20.625 × 2.7778) - (2)
- *1 foot* is equivalent to 0.57296 *Rc*, so 100 *feet* will be equal to 57.296 Rc. The sub-unit ratios of the *Royal cubit* therefore maintain a direct link with the 1 *radian* angle of the circle and its subdivision into smaller units of angle.

Table 1 presents the proposed dimensions of the reference circle that was possibly associated with development of the sexagesimal system and the circle that society has now been using for over 2000 years. The important point to notice in Table 1 is the light speed travel time required for the 1° arc length, being 0.01745 seconds. This value is proposed to be the source of the ratio 0.01745 in circle mathematics, used to calculate any arc length of a circle with known radius (see equation 1). The mathematics relies on the speed of light to calculate all measurements in a circular reference frame. This ratio is only valid when the reference circle has the dimensions shown in Table 1, suggesting that a 1s electromagnetic timeframe may have been the primary definition of the circle reference frame.

In essence, existing circle mathematics is working with speed of light measurements in the background, and no-one is the wiser to it. Equation (1) can be replaced by a similar version in which the time for a light speed signal to travel the radial distance is applied:

1 degree arc length = 0.01745 s × c × 1° (new calculation method using speed of light) – (3)

The mathematics that has been in use for more than 2000 years is simplified in a way that removes the need to use the speed of light value, and this is because the reference circle appears to have been fixed to a 1 s time frame.

Table 1 – Circle Properties in a 1 Second Timeframe

Circle Property	**Length in Royal Cubits (Rc)**	**Length in Metres (m)**	**Light travel time (s)**
Radius	57.296×10^7	29.979×10^7	1.0
Circumference	360.0×10^7	188.4×10^7	6.283 (2pi)
1 radian of arc (57.296°)	57.296×10^7	29.979×10^7	1.0
1° arc length (L = 0.01745 × radius × 1°)	1.00×10^7	0.5232×10^7	**0.01745**

The information presented above provides four unique pieces of evidence regarding circle and *Royal cubit* design origins:

- By subdividing *1 radian* into 20.625 equal sectors, each sector is subtended by approximately 2.8° (the more accurate value is 2.7778°). These specific relationships appear to be applying the electromagnetic equation, c = frequency × wavelength, to subdivide the circle (i.e. 57.296 = 2.7778 × 20.625).
- A circle of radius 57.296 *Rc* (equal to 100 *feet*) will have a 1° arc length of exactly 1 *Rc*, which is equivalent to 1.745 *feet.* This is directly attributed to the workings of equation (1).
- The sub-units of the *Royal cubit* appear to be carrying information regarding the electromagnetic frequency and wavelength used to define the *Royal cubit*.
- The "*inch*" unit is uniquely defined as the 2.8° arc length when a circle radius of exactly 1 Rc is considered, due to the fact that there are 20.63 portions of 2.8° in the 1 radian arc length.

A more detailed examination of the information must be carried out in order to confirm the proposed origins for the circle and *Royal cubit*, and to also find answers to two remaining questions:

- The initial question: why a historical (Hipparchus) circle radius of 3438 *minutes/units*, and what were these units?
- If the circle was based on an electromagnetic frequency standard, what were its properties?

In association with the abovementioned findings, the suggestion that knowledge of the speed of light was involved with development of the circle (and the *Royal cubit*) leads to the obvious inference that the measurement of time was within the capabilities of the society involved with this work. In this regard it is useful to consider the modern situation where the accurate measurement of the duration of 1s is a prime scientific objective that has continued unabated since the earliest mechanical measurements of time were introduced.

Modern metrology uses electromagnetic physics to define the *metre* length standard, resulting in the *metre* being expressed as a function of the speed of light. The *metre* is now the length of the path travelled by light in vacuum during a time interval of 1 ÷ 299792458 of a second[5], or 3.336×10^{-9} s. This value is known as the reciprocal of the speed of light, or 1 ÷ c, where c = 299792458 m/s.

When the *Royal cubit* length is examined in similar terms, the reciprocal of the speed of light is equal to 1.745×10^{-9} s^{-1}. The linear distance travelled by a light-speed signal in the time of 1.745×10^{-9} s is therefore 0.5232 m, or 1 *Royal cubit*. The number of *feet* in 1 *Royal cubit* (i.e. 1.745) would therefore appear to be a direct means of encoding information about the electromagnetic definition of the standard as part of the length unit itself.

In essence then, when analysing the set of data presented by the sub-units and specific length of the *Royal cubit*, we appear to find evidence suggesting that a scientific (electromagnetic) standard may have been in place. The relative ratios provide a means of calculating the speed of light, only available to a scientific society that is capable of recognising the information.

The results of the study suggest that only by consideration of modern scientific knowledge is it possible to identify important links between the *Royal cubit* and the circle, thereby exposing features that might explain the original design of both.

Identifying the Electromagnetic Signal

Since an electromagnetic capability is inferred from the evidence, there must be a means of identifying the properties of the electromagnetic signal and how it was applied. Following the lines of evidence presented earlier, where subdivision of 1 radian according to the sub-unit relationships of the *Royal cubit* suggests that frequency and wavelength values may be involved, the possible characteristics of an electromagnetic signal underpinning circle metrology and the ancient *Royal cubit* length unit have been identified and are summarised in Table 2. The starting points are available as follows:

- 20.625 *inches* - inferred to be associated with signal *wavelength*
- 2.7778° of angle - inferred to be associated with signal *frequency*
- the 1 radian value of 57.296° - inferred to be associated with the speed of light
- Application of the electromagnetic equation c = frequency × wavelength, and
- Modern knowledge of the speed of light and electromagnetic physics.

The values presented in Table 2 are proposed to represent the characteristics of the electromagnetic signal used to define the *Royal cubit* length standard, followed by creation of the circle in its sexagesimal arrangement.

Table 2 – Proposed Electromagnetic Signal Characteristics

Physical Property	**Value**	**Unit**	**Reciprocals**
Speed of light (c)	5.7296×10^{8}	Royal Cubits	1.745×10^{-9} $s.Rc^{-1}$
Source frequency (f)	2.7778×10^{11}	Hz	3.600×10^{-12} s^{-1}
Source Wavelength (λ)	2.0625×10^{-3}	Royal Cubit	Not applicable

If such an electromagnetic source was in fact used to define the *Royal cubit* and circle theory, then there must be a physical example available to science to lend support to the proposed structure. In this

[5] *Claude Audoin and Bernard Guinot, The Measurement of Time. Time, frequency and the atomic clock. 2001*

regard it is extremely interesting to note that the Cosmic Microwave Background (CMB) has a peak wavelength and frequency virtually identical to the electromagnetic signal proposed here as the clock frequency used in the creation of circle theory and sexagesimal mathematics.

The CMB has a thermal black body spectrum at a temperature of 2.725 °Kelvin, which peaks at the frequency of 283 GHz (2.83×10^{11}Hz), corresponding to a microwave wavelength of approximately 1.06 mm when calculated using Wien's Displacement Law: $\lambda \times T = \frac{hc}{4.965\ k}$

$\lambda max \times T = 2.898 \times 10^{-3}$ m°K, where T = CMB temperature (2)

By comparison, the proposed signal frequency associated with the sexagesimal system is closer to 2.7778×10^{11} Hz, while the wavelength (2.0625×10^{-3} *Rc)* is equivalent to 1.05 mm. If the CMB was used as the scientific reference standard to define the *Royal cubit* then it means the ancient length units were not based on a measurement of the Earth's surface dimensions, nor on anthropomorphic principles.

Identifying the Hipparchus Circle Radius

The evidence presented so far has not yet addressed the issue of the origin and significance of the circle radius value of "3438 minutes" as described in historical texts. The ancient texts mention the fact that 3438 *minutes* represented a circle radius and that this was measured in the same units as the angular subdivisions on the circumference. Based on the information presented already in this article, it is proposed that the historical circle radius was **3438 *Royal cubits***.

Table 3 presents a summary of the circle characteristics for the electromagnetic signal travel time of 6×10^{-6} seconds. The result is an exact match for the circle construction methods described in the ancient texts.

Table 3 – Atomic Photon Emission Time Considerations

Circle Dimension	**Proposed Historical Reference Conditions – "Hipparchus Circle"**
Time for Signal Propagation (s)	6.0×10^{-6}
Circle radius (*Rc)*	3438
Circle circumference (*Rc)*	21600
1 radian of arc (*Rc)*	3438
1 degree of arc (*Rc)*	60
1 minute of arc (Rc)	1

The basic structure of the sexagesimal system is exposed in **Table 3** by the simple fact that 1° of arc length on the historical reference circle will be exactly 60 *Rc*, providing the source for further subdivision of the circle in multiples of 60. Each *minute* of angle will also therefore be equal to 1 *Rc* in the 6.0×10^{-6} s reference frame. All numbers in the circle then follow as multiples of 6 and 10 based on this relationship. All features of the sexagesimal number system fall into place naturally within the electromagnetic framework proposed by applying the electromagnetic signal properties as presented earlier in Table 2.

The potential significance of the choice of a 6.0×10^{-6} s reference time is that this is very close to the timeframe in which an atom will release a photon after receiving an energy stimulus sufficient to promote an electron jump between two energy states.

Another aspect associated with use of the *Royal cubit* as the standard length unit is that the radius of the hydrogen atom becomes exactly 1.0×10^{-10} Rc, as opposed to the value of 5.2×10^{-11} m based on the typically cited de Broglie wavelength (and atomic circumference) of approximately 3.3×10^{-10} m. Use of the *metre* length standard to measure atomic dimensions would appear to be producing a more complicated numerical result mathematically when compared with use of the *Royal cubit*.

Discussion

The specific ratios of the *Royal cubit* sub-units (*inches, feet, fingers*) are replicated in the 1 *radian* angle of the circle, and the 1 *radian* angle is proposed to be correlated with the speed of light. The information provides a reasonable amount of evidence to suggest that the circle and the *Royal cubit* were designed to be an integrated metrological system, and controversially, that the basic features of the sexagesimal circle may have been defined scientifically using electromagnetic physics.

Since circle angular relationships are applied in astronomy to measure distances in space, and these specifically require simultaneous measurement of time, the basic physical property which controls the accuracy of such measurements is the speed at which electromagnetic signals propagate through space. As a result, both the measurement of time and the measurement of distance in space are contained within circle mathematics. The underlying integrity of the mathematics is due to it being founded on the fixed value for the speed of light.

It is this scientific relationship between the *Royal cubit* and the circle that explains why the *Royal cubit* was subdivided into smaller units of different dimensions in a **non-sexagesimal** manner. The sub-unit ratios were designed to carry the electromagnetic information upon which the design of the length standard was based, and these automatically transferred to the circle.

From all evidence it would appear that a primary reference circle existed, associated with the definition and measurement of 1s of duration, and this reference frame would have been applied by astronomers. The theoretical dimensions of this circle would not, however, provide a practical daily reference for land surveyors and the general populous in real world terms. It is therefore possible to surmise that a smaller reference circle was created (refer to Table 3) for everyday use, with dimensions that could physically be measured across the earth surface. This is the circle dimension described by Hipparchus.

The evidence also suggests that the ancient metrological system appears to take into account two different length measurement approaches as follows:

a. A direct radial length measurement of the electromagnetic wave as it travels outwards from the source, possibly directly defined by the wavelength of either the electric field or the magnetic field (my guess is that it might be the magnetic component); and
b. A measurement in the circumference of the wave front associated with transverse/tangential stretching of the initial wavelength in order to maintain coherence as the signal travels outwards in time. This circumferential stretching may be directly connected with the electric field. The amount of circumferential stretching of the initial wavelength is easily calculated from the data presented in Table 1 and Table 2 and shows that the initial wavelength of 2.0625×10^{-3} Rc will have increased to 1.296×10^{-2} Rc after 1 s of signal propagation. This value is derived from dividing the 1 s circle circumference (360×10^{7} Rc) by the total number of oscillations of the source that define the 1 s duration (2.778×10^{11}).

Another significant feature of the proposed electromagnetic "clock" signal is that, in the time of 86 400 seconds (the number of seconds in 24 hours), it would provide a count of exactly 24.0×10^{15} oscillations. It is proposed that this may represent the origin of the historical 24 hours per day. Each hour would be associated with exactly 1×10^{15} atomic transitions of the electromagnetic source.

Conclusions

The main conclusion drawn from this study is that the *Royal cubit* and sexagesimal circle were defined by a metrological frequency standard, which also provided the definition for 1 s of duration. The properties of the electromagnetic source can be identified from the specific features of the *Royal cubit* and the circle. From the information presented in this study it is possible to propose that:

- The correct understanding of ancient circle sexagesimal origins can only be made when all length measurements are made in *Royal cubits*.
- The ancient *Royal Cubit* is a metrological standard defined as a reciprocal of the speed of light, in exactly the same way that the *metre* is defined. The *Royal cubit* was the *de facto* length unit referred to in historical texts regarding the fundamental circle radius as 3438 *minutes*. The electromagnetic time definition is 1.745×10^{-9} s, and this definition is reflected in the number of *feet* in 1 *Royal cubit*.
- The reason why the *Royal cubit* itself does not have sub-units in a sexagesimal format is because the *Royal cubit* was defined before the circle was created. Sub-units were created in ratios that reflect the values of the speed of light, and the frequency and wavelength of the electromagnetic source used to define the length unit. Reference circle dimensions were then based on the *Royal cubit* length.
- Due to the electromagnetic physics associated with the reference circle dimensions and angular subdivision, various components of the angular subdivision carry the electromagnetic values associated with the speed of light, frequency and wavelength attached to the length unit. The circle therefore carries information about the length unit used in its creation, and the length unit carries the code of its electromagnetic origins.
- The frequency standard used to define the *Royal cubit,* and from there the circle, is proposed to have the physical properties described in Table 2 of the article. This frequency matches that of the Cosmic Microwave background and it is therefore proposed that the CMB was understood and measured by an ancient society, and the signal was mapped by scientists in order to physically apply the signal to daily metrological use. The fact that all objects in the universe are created within this electromagnetic reference signal infers that dimensional development of all objects, as well as distance relationships, will be controlled in some manner by the frequency and wavelength of the CMB. As a result, all measurements in astronomy should be made using this length unit as well, as seemingly created in ancient times.
- The 1 radian angle is effectively subdivided into 20.625 portions each of 2.7778° of arc according to the electromagnetic equation $c = \lambda \times \upsilon$, and this calculation is reflected in the number of *inches* and *fingers* in 1 *Royal cubit.* The 28 *fingers* of subdivision for the *Royal cubit* is inferred to be the result of referencing the 2.7778° angle and the clock frequency. If extremely accurate physical copies of the *Royal cubit* were available for close examination, then a fractional difference in the measurement of one *finger* might prove this point (i.e. the accurate measurement would show 27.778 *fingers* instead of exactly 28.0 *fingers).*
- The rate of circumferential expansion of the source wavelength with time (1.296×10^{-2} Rc/s) is potentially the core determinant in the expansion rate of the Universe.

The *Royal cubit* and the circle therefore contain evidence to suggest that they are an integrated metrological system based on knowledge of the properties of the CMB. The speed of light expressed in *Royal cubits* per second is proposed as the core determinant in circle theory. It is also obvious that modern metrological standards for length and time have absolutely no connection at all to existing circle mathematics in the pure sense.

Should the step be taken to adopt a new frequency standard equivalent to the CMB peak frequency then the ancient *Royal cubit, feet* and *inch* units would regain metrological significance relative to spherical mathematics and the measurement of 1 second of time. A single frequency standard would be capable of disseminating the 1 s time measurement and of defining the unit of length, while at the same time integrating each of these features with spherical mathematics as originally designed.

In a case of sublime elegance, the *Royal cubit* sub-unit ratios carry the information required to interpret the electromagnetic principles by which the standard was defined, and identify its connection to the circle, enabling this information to be transmitted through history from the time of its original conception. The ancient society associated with the creation of circle mathematics and the *Royal cubit*, and the actual point in time when it was done may never be known, but the information bearing an electromagnetic signature has survived.

The mathematical origins of astronomy are therefore proposed to be based upon fundamental electromagnetic physics, whereby time and distance measurements in a spherical and rotating environment are combined in a single elegant framework. This framework could, and should, be re-instated to its true form. It would appear that, on a theoretical basis anyway, it is possible to carry out this process.

If a metric circle were to be constructed following the same methods as described in this article, it would not be possible to subdivide the circle circumference (188×10^7 m) into a convenient decimal arrangement. The electromagnetic frequency standard currently in use in modern society does not provide both the time and length unit from a single source either, which further complicates the issue when compared with the way the historical circle appears to be integrated with the *Royal cubit*.

The ubiquitous CMB electromagnetic signature represents a dominant electromagnetic structure with a wavelength that is likely to have had a controlling influence on the dimensions of all objects created since creation of the universe. As such it makes sense that all measurements of astronomical objects and distances should be made with a length unit that is commensurate with the physics of the universe.

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