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# Laser, Universe and Arrow of Time

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## Abstract

We have presented a comparison between the universe and the Laser. In many ways, the physics of laser and the universe are analogous. The root of the analogy is the fact that both laser and early universe depend completely on the quantum nature. We have also presented a simple analogous example of the growth of a flower at successive stages of development and shown how the arrow of time may be represented in these cases.

## Keywords

Laser, Universe, Time

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## 1. Introduction

Let us begin our article by reflecting on the truth of the universe, that is, the universe is of four dimensions (length, breadth, height and time). The immediate question is “why Einstein had formulated the theory”. There are various ways to answer it. One way of answering is that—light waves of all frequencies travel with a constant speed in vacuum. It is surprising and unexpected that this speed is independent of relative speeds of the source and observer. This fact led Einstein to formulate special theory of relativity and concluded that space and time are separate entities but constitute the part of the same space-time continuum of a four-dimensional universe. As Einstein writes in his revolutionary paper [1] “Together with the unsuccessful attempts to discover any motion of the earth relatively to the ‘light medium’ suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest”. What they did suggest, he went on, was that “The same law of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good”. Linking of electrodynamics and mechanics was the crux of matter. In the world of electromagnetism governed by the field laws Faraday

and Maxwell, light was propagated at a constant speed which could not be surpassed. But there seemed to be little connection here with Newtonian mechanics, in which the speed of an object might be indefinitely increased by adding more energy to it. What Einstein proposed in his paper was that the velocity of light is a constant and a maximum in the electromagnetic and mechanical worlds and that light would thus travel with a constant velocity that was independent of the bodies emitting or receiving it. Minkowski's contribution to the development of special relativity was in effect a single paper "Basic Equations for the Electromagnetic phenomena in moving bodies" published in 1907 [2]. Minkowski not only gave a new mathematical formulism to the special theory but also enabled Einstein to solve the problems of gravitation by means of general relativity. Thus according to Minkowski an event which takes place in three-dimensional space at a particular time is described as a "world point" described as a "world line". More significantly time is described as a "fourth dimension". Einstein was well aware of the bewilderment which such language created. "The non-mathematician 'he wrote' is seized by a mysterious shuddering when he hears of 'four-dimensional thing' by feeling not unlike that awakened by thoughts of the occult. And yet there is no more common place statement than that the world which we live in is a four-dimensional space time continuum" signifier for a mathematician a fourth variable apart of length, breadth or thickness which must be inserted into any equation concerning events, since these occur not only in space but at a certain instant of time.

The purpose of the present paper is to introduce the topic of the direction of time or arrow of time as discussed by Hawking [3] and to understand it in some environmental and non physics domain. In this paper we are primarily concerned with a familiar topic of a growth of a flower in its successive stages of development commencing from the tender bud which has a greenish hue and proceeding by steps to the mature flower exhibiting a full colour and how the so called arrow of time as discussed by Hawking may be represented and understood. We have also discussed the role of a so called spectral line in understanding this arrow. It is worthy of remark here that one way of looking at a problem is from analogy. In many ways some phenomena in physics appearing in different domains are quite analogous. There are numerous examples to support this. One example is the comparison between laser near threshold and matter near a phase transition as developed by Degiorgio and Scully [4]. Recently we have worked out few analogies which cover specific topics like spatial hole burning, multiple reflection and squeezed states [5], dispersion curves of semi-classical theory of laser and electromagnetically induced transparency [6], analogies between spectroscopic properties of laser and the universe [7]. In this paper we carry the analogies further and introduce additional features so that a worthwhile comparison with the properties of the universe may be made. It is worthy of remark that when a problem is compared with something identical in a different field but which one understands reasonably comparative ideas are created

and this is one way of looking at the problem.

The paper is organized as follows. Section 2 will be a brief review of the topic of arrow of time as discussed by Hawking. The coherent properties of Laser radiation are discussed in Section 3. In Section 4 we have brought under discussion the topics of the quantum theory of radiation, vacuum fluctuation, quantum theory of Laser and quantum cosmology. These topics have been primarily chosen for a worthwhile comparison between laser and the evolution of the quantum universe as shown in **Table 1**. In Section 5 we have presented the specific example of a flower in the successive stages of development commencing from the tender bud which has a greenish tint and proceeding by steps to the

**Table 1.** Laser, arrow of time and the evolution of the universe.

Parameter	Universe	Laser
Entropy	As the universe is expanding (and currently accelerating) entropy increases	Entropy increases
Time	According to Hawking the universe we live in does not appear time symmetric	Laser is not time symmetric
Time	The thermodynamic arrow of time, the psychological arrow of time and the cosmological arrow of time all point in the same direction. These arrows explain the time asymmetry of the universe	Thermodynamic arrow of time is directed along the laser axis
Origin	Origin of the universe took place as a "Big Bang"	Laser action takes place at a threshold condition of oscillation
Origin	For some reason the universe started out in a stable of high order (low entropy)	Laser started out in a state of high order (population inversion)
Temperature	Temperature at a time of $10^{-12}$ sec. after Big Bang is estimated at $10^{150}$ K	Laser output can be described as having an effective temperature of $\sim 10^{180}$ K
Space-time	In special theory an event occurs not only in space but also in time. They are known as world points and linking events are world link	Laser radiation is generally space and time coherent
Vacuum fluctuation	In quantum theory of cosmology the universe can be created from nothing spontaneously by virtue of vacuum fluctuations	The mechanism of spontaneous emission is attributed in connection with quantum theory to all pervading vacuum fluctuations of the electromagnetic field. Laser photon also builds up from vacuum fluctuations
Exponential growth	In the quantum theory of cosmology when the true vacuum bubble expands rapidly the universe can be created irreversibly	In the quantum theory of laser photon grows exponentially in the initial stage as it is created from vacuum

mature flower exhibiting full colour. We have represented thermodynamic arrow of time in these cases and we believe that such examples even as analogy is relevant for science education.

## 2. Arrow of Time

Before we introduce the topic of arrow of time as introduced by Hawking, let us first consider the question: which is the “real” time and which is the “real” dimension. The answer is simple. The real dimension and the real time is that of the observer, and the stationary and the moving observers are each concerned with their own reality. Each man carries with his own space and his own time. The time at which an event takes place is indeed a relative matter. It is now worthwhile to consider the problem of the direction of time in cosmology as discussed by Hawking. There are two things Hawking emphasized. One is that physics is time symmetric; the second is that the universe that we live in certainly does not appear time symmetric. That physics is time symmetric is more accurately shown that [8] any quantum field that has 1) Lorentz invariance, 2) Positive energy and 3) Local causality, *i.e.*  $\mathcal{O}(x)$  and  $\mathcal{O}(y)$  commute (or anti-commute) if  $x$  and  $y$  are space like separated, is invariant under CPT. Here  $C$  means interchange particles with antiparticles,  $P$  means replace left hand by left hand, and  $T$  means reverse the direction of motion of all particles. In most situations, the effect of any  $C$  or  $P$  non-variance can be neglected, so that the interactions ought to be invariant under  $T$  alone. In his work Hawking indicates that the universe that we live in certainly does not appear time symmetric, as anyone who has watched a movie being shown backward can testify: one sees events that are not witnessed in ordinary life. One can identify a number of different “arrows of time” that express the time asymmetry of the universe. The thermodynamic arrow: the direction of time in which entropy increases. The electro-dynamic arrow: the fact that one uses retarded solutions of the field equations rather than the advanced one. The psychological arrow: this arrow of time is the way time appears to flow to the human mind (real time)—the way we experience the unceasing aging of our bodies, remember the past and have no direct knowledge of the future. The cosmological arrow: the direction in time in which the universe is expanding (currently accelerating) from big bang. It is worthy of remark here that we have introduced here in our paper an arrow of time which we call as the local arrow of time. According to Hawking the first arrow of time implies the second and third. The connection between the psychological and thermodynamic arrows can be discussed from an analogy with computers; when a computer records something in the memory, that is, when it records digitally in bits and q-bits (quantum bits), the total entropy increases. Thus computer remembers things in the direction of time in which the entropy increases. Thus it seems reasonable to assume that we remember in the same direction of time that computers do. This means that the psychological arrow of time, our subjective sense of time, is the same as the thermodynamic arrow of

time, the direction in which entropy increases. Entropy increases with time because we define the direction of time to be that in which entropy increases [9]. What was the connection between the cosmological arrow of time and others? Hawking put forth the controversial conjecture that although the three arrows all point in the same direction during the current expanding phase of the universe, he believed that the no boundary proposal (which utilised closed universe doomed to eventually collapse in on themselves) would predict that when the universe began to contract, the thermodynamic arrow of time (and so by the previous arguments the psychological arrow of time as well) would reverse. He proposed that entropy would decrease rather than increase, meaning that things could become more ordered rather than random. Hawking's proposal would also mean that people will grow younger rather than older. We would remember the future and have no knowledge of the past. However Hawking finally admitted that he had been wrong about the reversal of the thermo-dynamical and psychological arrow of time in a contracting universe. Hawking and Collins [10] connected the fact that the overall distribution of matter in the universe is remarkably similar in all directions we observe (isotropic) to the density perturbations in the early universe (which led to the creation of galaxies) and found that the balance to be highly unlikely. They came to the conclusion that we have observed the universe to be isotropic is therefore only a consequence of our own existence. If it were otherwise galaxies would not exist. With these concepts in mind Hawking pondered the problem of the three arrows of time and came to the conclusion that although the psychological and thermo dynamic arrows did not reverse during the contracting phase of the universe, it is only when the three arrows of time pointed in the same direction the intelligent life could exist who could contemplate the problem. In this connection it is worthwhile to mention the work of Hogarth [11] and Hoyle and Narlikar [12] in the early 1960's when they tried to connect the electro dynamic and cosmological arrows. Richard Feynman [13] criticized their work on the grounds that they had implicitly assumed the electro dynamic arrow. They also got the wrong answer in that they predicted retarded potentials in a steady state universe without continual creation of matter. According to Hawking it is generally accepted that we live in a universe which is still evolving. It is now worthwhile to close this section with a remark that the relevant mathematics which concerns the arrows of time are more involved. We shall concern ourselves in the following sections with a more elementary approach to represent arrows of time which we believe is helpful for science education particularly in understanding the arrow of time. We shall discuss few topics like a spectral line, the nature of growth in the successive development of flowers, laser, vacuum fluctuations etc. and see how analogous they are with our evolving universe.

### 3. Coherent Properties of Laser Radiation

In this section we specifically describe the coherent properties of laser radiation

for a possible analogy with the world point and world line in the space time continuum of the special theory of relativity. We must indicate here that the topics set forth in the earlier sections motivated us to draw some analogy with the coherent properties of laser radiation, and to some degree of approximation a spectral line.

A laser radiation is both space and time coherent. A source of radiation may have little time coherence but still has perfect space coherence. Example of such coherent source is light from a distant star.

### **3.1. Spatial Coherence**

If at a particular instant of time the radiation has the same phase across the uniphase wave front it is said to be completely spatial coherent. Laser beam moves in a particular direction is due to this property only.

### **3.2. Temporal Coherence**

If the phase of the light of one uniphase wave front at a particular time is the same with it displaced wave front after it has travelled a distance in time  $t$  and if the phase agrees with all time interval, the radiation is said to be perfectly time coherent. Extreme monochromatically is the manifestation of the property of temporal coherence.

### **3.3. High Intensity**

The usual optical radiation has an intensity characterised by an effective temperature of the order of few thousands of degrees only, on the other hand the laser output can be described as having an effective temperature of  $10^{180}$  K or more.

## **4. Quantum Theory of Radiation, Vacuum Fluctuation, Quantum Theory of Laser and Quantum Cosmology**

The basic facts and principles relating to the special theory of relativity as formulated by Einstein [1] with the three arrows of time articulated by Hawking [3] have been expounded in earlier sections. We have also brought under discussion the topics of spectral line and coherent properties of laser radiation in order to correlate them with the topics of space time continuum and as well as the arrows of time. The correlations are presumably for analogy consideration only. We now consider it worthwhile to discuss the quantum theory of laser and the process of buildup of laser photon from vacuum as formulated by Lamb and co-workers. Laser is basically created inside a resonating cavity and as it emerges out of the partially reflecting dielectric mirror it appears as a unidirectional strong beam of monochromatic radiation coherence. Spontaneous emission is the driving force which acts as the platform for the laser radiation to be built up. The interesting consequence of the quantization of radiation field is the fluctuation associated with the zero-point energy or the so called vacuum fluctuations.



These fluctuations are responsible for many interesting phenomena in quantum optics like spontaneous emission. The mechanism of spontaneous emission—an isotropic perturbation always presents theory to the all pervading zero point fluctuations of the electromagnetic field. The light excites the atoms, the zero point fluctuation de-excites them resulting in re radiation of light.

The role of spontaneous emission is emphasized in the quantum theory of laser by Lamb and co-workers [14] [15]. The buildup of laser photon takes place from spontaneous noise. To do this we show that the average photon number is given by

$$\langle n(t) \rangle = \sum n P_{nn}(t) \quad (1)$$

And it may be shown that the equation of motion for the average photon number  $\langle n(t) \rangle$  is given by

$$\frac{d}{dt} \langle n(t) \rangle = \left( A - \frac{\nu}{Q} \right) \langle n \rangle + A - B \left[ \langle n^2 \rangle + 2 \langle n \rangle + 1 \right] \quad (2)$$

where  $A$  is the linear gain coefficient in quantum theory of laser,  $\nu$  is the laser oscillation frequency in radian/Sec (not Hertz) and  $Q$  is the cavity quality factor. The above equation has been used to investigate the process of build up laser photon from vacuum [16]. We note here that the lone term  $A$  in the equation represents the spontaneous noise originating from vacuum fluctuations.

The accepted explanation for the thermo dynamic arrow of time is that for some reason the Universe started out in a state high order or low entropy. Such states occupy a very small fraction of volume of the phase space accessible to the universe. As the universe evolves in time it will tend to move around phase space ergodically. In this connection it is worthwhile to the Ergodic Hypothesis in statistical physics concerning “phase space”. If a system of  $N$  atoms is enclosed in a fixed volume, the state of the system is given by a point in a  $6N$ -dimensional phase space with  $q$  representing coordinates and  $E$  to be constant a representative point in phase space describe an orbit on the surface  $E(q,p) = C$ , where  $c$  is a constant. The ergodic hypothesis states that the orbit of the representative point in phase space eventually goes through all the points on the surface.

Thus at a later time as Hawking says, therefore there is a high probability that the universe will be found in a state of disorder or high entropy because such states occupy most of phase space. Consider again the example given by Hawking a system of  $N$  gas molecules in a rectangular box which is divided into two by a partition with a small hole in it. Suppose that some initial time, all the molecules are in the left hand side of the box. Such configurations occupy only one part in  $2N$  of the available  $6N$ -dimensional phase space. As time evolves the system will move around phase space on a constant energy surface. At a later time there will be higher probability of finding the system in a more disordered state with molecules in both halves of the box. Thus entropy will increase with time. But if one waits long enough, one will find all the molecules eventually returning

to one half of the box. However, for macroscopic values of  $N$ , the time taken is infinitely large and is likely to be much longer than the age of the universe. This is presumably the consequence of ergodic hypothesis. In general it is very difficult to prove the ergodic hypothesis. In this connection we may also refer to the so called KAM theorem (named after Russian mathematician A. M. Kolmogorov and V. I. Arnold and the German mathematician J. Maser) which states that a non-negligible fraction of orbits in the Phase space of a dynamical system remain indefinitely in a specific region of phase space, even in the presence of small perturbations of the system. This results in a step towards resolving the unsolved problem of the stability of motion of planets. The KAM theorem is also of interest to ergodicity in statistical mechanics, since the majority of orbits lead to ergodic motion going through all available phase space. As the number of degrees of freedom of the system increases, the dominance of ergodicity over stable orbits becomes more pronounced.

In connection with the phenomenon of laser we note that one of the criteria of laser is the population inversion, which is the violation of usual Boltzmann distribution and a highly ordered situation similar to the example given by Hawking regarding all the molecules being located in the left hand side of a rectangular box (divided into two parts by a partition with a small hole in it) at a particular time. We reasonably believe that entropy will increase with time as laser beam propagates through space. This is due to the fact that the concepts of space and time coherency will not be valid for any practical laser after it has travelled a huge distance resulting in an increase in disorder. Thus entropy increases and direction of laser is the direction of the thermodynamic arrow of time. How the entropy increases as the laser beam propagates can be visualised in terms of the distance through which the beam maintains the constant phase relationship. This length is known as the coherence length and is given approximately by the relationship.

$$\ell = c/\Delta\nu \quad (3)$$

where  $c$  is the velocity of light and  $\Delta\nu$  is the bandwidth of the source. Thus the reduction of laser frequency bandwidth significantly increases the coherence length or coherence time. As the laser radiation travels through space, the beam spread increases which are also a measure of increase of disorder (entropy).

Now it is worthwhile to speculate that laser started out in a state of high order or low entropy which is analogous to the evolution of the universe currently expanding (or accelerating) from the big bang. We note here that the temperature at a time of  $10^{-12}$  second from big bang is estimated to be at  $10^{150}$  K (present day microwave cosmic background corresponds to about  $2.7^0$  K). The laser output can also be described as having an unbelievable high value of  $10^{180}$  K or more. The time to achieve lasing action from the time optical (or electrical) pumping is applied on the active medium inside a F P cavity is around  $10^{-9}$  seconds, which depends on the length of the cavity.

That the universe began in a big bang is one of the great theories of modern

cosmology. This theory is presumably a scientific theory supported by numerous evidences. But these still remains an enigma. What caused the big bang itself. For many years cosmologists have relied in the idea that the universe formed spontaneously that the big bang was the result of quantum fluctuations in which the universe came into existence from nothing. Tryon [17] published a paper in Nature where he proposes a model to support the theory that our universe is a large scale fluctuation of vacuum, where “vacuum fluctuation” is to be understood in the sense of quantum field theory. In a recent paper of 2014 Dongsham *et al.* [18] showed rigorously that the birth of the early universe from big bang could indeed have occurred spontaneously because of quantum fluctuations. How Dongsham *et al.* gave a rigorous proof of the idea that the universe could be spontaneously created from nothing can be briefly described as follows. According to them with the Lamda-cold dark matter (ACDM) model and with all available observation such cosmic microwave background, abundance of light elements, it has been widely accepted that the universe was created in a big bang. However there are still some puzzles, such as problems of flatness, the horizon, the monopole and the singularity [19]. In particular, the inflation theories which suggest that the universe experienced an exponential expansion period were proposed to solve puzzles of the early universe [20] [21] [22]. In quantum cosmology the universe is described by a wave function rather than the classical space time. The wave function of the universe should satisfy the Wheeler-Dewitt equation (WDWE) [23].

With the development of quantum cosmology theory, it has been suggested that the universe can be created spontaneously from nothing where nothingness means there is neither matter nor space or time [24], and the problem of singularity can be avoided naturally. Although the concept of the universe created spontaneously from nothing has emerged for a long time, a rigorous mathematical foundation for this is still missing. According to Heisenberg uncertainty principle, a small empty space also called a true vacuum bubble can be created by quantum fluctuations of the metastable false vacuum.

But if the small bubble cannot expand rapidly, it will disappear soon due to quantum fluctuations. In this case the early universe would disappear before it grows up. On the other hand if the small bubble expands rapidly to a large enough size. In 2014 paper Dongshan *et al.* obtained analytical solution of the WDWE of the true vacuum bubble. With the de Broglie-Bohn quantum trajectory they prove that once a small true vacuum bubble is created, it has the chance to expand exponentially when it is very small, that is  $a \ll 1$  where  $a$  is the radius of the bubble.

The exponential expansion will end when the size of the true vacuum bubble is very large, that is,  $a \gg 1$ . It is also shown that the quantum potential of the bubble is the driving force for the exponential expansion and it also plays the role of cosmological constant.

This explicitly shows that the universe can be created spontaneously by virtue of a quantum mechanism.

We now feel it appropriate to use **Table 1** to include all the considerations set forth in earlier sections so that a summary of the comparisons between laser radiation and the evolution of the universe may be presented. In **Table 2** of the following Section 6, we show specifically how the arrow of time may be represented in the successive stages of development of flowers (as analogy).

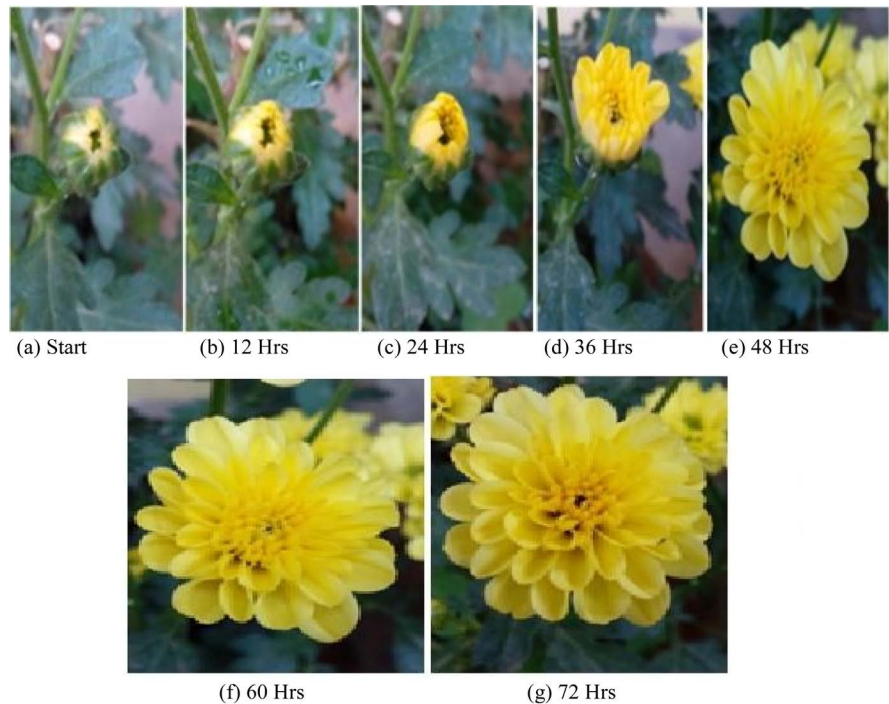
## 5. Successive Stages of Development of Flowers

It is quite instructive of examine the flower of a particular plant in the successive stages of development commencing from the tender bud which has a greenish tint and proceeding by steps to the mature flower exhibiting full colour. We may represent thermodynamic arrow of time in these cases at least as analogy, and which we believe is relevant for science education. For the purpose of illustration we have reproduced the photographs of few specimens of flowers at different stages of growth occurring at different times. It is worthwhile to note that we could have selected numerous other examples for the purpose of our illustration, but the consideration set forth in the present case is also applicable in these examples (**Figure 1**).

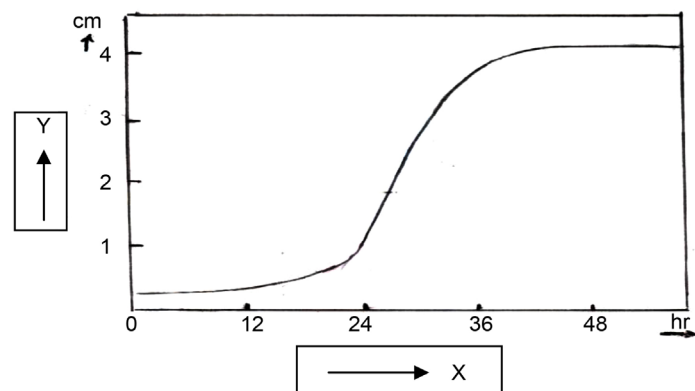
**Figure 1** shows the photographs of a flower chrysanthemum at successive stages of development. The photographs have been taken with the help of a smart phone after every twelve hours to investigate its nature of growth in time. As may be inferred from the photographs, the linear growth of the flower takes place from some non-zero value and after some time becomes maximum and remains constant. The situation is well illustrated with the help of **Figure 2** where we have plotted the linear dimension of the flower (in cm) against time. For every twelve hours the measurements have been made. As may be inferred from the figure the growth of the flower initially indicates exponential growth from some non-zero value, after which there is a rapid growth in linear dimension

**Table 2.** Summary of the characteristic features in the successive development of flowers (events).

Quantity	Event	Remark
Entropy	Entropy increases as the flower grows in size at different time	Arrow of time is directed along the direction of the increase in disorder
Symmetry	Successive stages of growth is asymmetric in Nature	The universe that we live in does not appear time symmetric
Build up process	The flower initially builds up from a tender bud (non zero value) indicating some sort of Fluctuation	That the universe is build up spontaneously from vacuum fluctuation is shown in a recent publication [19]
Growth	Irreversible, grows exponentially in the initial stage	The theory [19] indicates that the true vacuum bubble expands rapidly and the universe can be created irreversibly



**Figure 1.** Photograph of Chrysanthemum (*Dendranthema grandiflora*) flowers at successive stages of development.



**Figure 2.** Build up of linear dimension of a flower Chrysanthemum (*Dendranthema grandiflora*) at successive stages (12 hr Interval of development).

and it yields steady state value after 72 hours. It is worthy of remark that this topic of graphs are quite common in biological specimens. We use the middle part of the growth curve to represent the arrow of time, which we designate as local arrow of time. It is quite interesting to use the following equation to represent the growth of a flower at successive stages of development (or any biological specimen). It is of the form:

$$I_n(t) = I_n(t) = \frac{I_n I_0 \exp(2) a_n t}{I_n - I_0 + I_0 \exp(2 a_n t)} \quad (4)$$

where  $I_n$  is the linear growth of the flower at its maximum  $I_0$  is the linear growth

of the specimen at a time before onset of threshold growth. It must be emphasized that  $I_0$  is always finite. This is similar to the parameter  $I_n(0)$  in the semi classical theory of laser. We treat the equation as empirical as it is not derived rigorously like the intensity equation of motion and its solution in the semi classical theory. Now we include all the considerations set forth in this section in a tabular form so that some of the characteristic features of the arrow of time may be visualized.

## 6. Summary and Conclusion

We have presented a comparison between the universe and the laser. Some topics which are quite analogous are included in **Table 1**. It must be emphasized that the characteristic features as shown for laser and the universe are already well established in the literature. As may be inferred from **Table 1** in many ways, the physics of the laser is analogous to that of the evolution of the universe. The root of the analogy is the fact that both the laser and the early universe depend completely on the quantum nature of the theory. We have also presented a simple example of the growth of a flower in the successive stages of development and show how the arrow of time may be represented in these cases.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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