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The Inflaton Spacetime Model: Making Sense of the Standard Models of Particle Physics and Cosmology

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Abstract

We know that the inflaton and dark energy cause accelerated expansion of space, but we don't know what they are. We are pretty sure that spacetime is not nothing, but we don't know what it is. In this paper, spacetime is modeled as an expanding set of self-reproducing quantum states. The roles of the inflaton and dark energy are played by spacetime itself. The model reproduces all of the phenomenology of the standard model of particle physics and the standard cosmology with cosmological constant and cold dark matter.

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Awareness is growing that spacetime, or the vacuum, is neither nothing nor empty, and that it is probably discrete in some sense. But what is it? There has never been a model of spacetime that recognizes these realities. This lack leaves physics in a position of trying to develop theories that explain natural phenomena without any idea of what is going on at the most fundamental level. While excellent theories have been developed anyway, such as the standard model of particle physics, we are now experiencing a frustrating lack of progress on many important questions.

One such question is concerned with periods of accelerated expansion of the universe. There is compelling evidence that the universe expanded by some enormous factor in an unbelievably short time soon after its birth. This phenomenon, called *inflation*, is thought to have been driven by a scalar field called the *inflaton*. Today, evidence has been found that the universe is still, or again, expanding at an accelerating rate, although much slower than during inflation. The unknown energy driving the current acceleration is called *dark energy*. No one knows what either the inflaton or the dark energy is, and it is unknown whether the inflaton and the dark energy are related.

This paper describes a model of spacetime in which *accelerated expansion is an inherent property of spacetime*. No separate inflaton and dark energy are needed. *Spacetime itself is both the inflaton and the dark energy*. Spacetime is made up of discrete quantum objects, or states, called *points*, which are *self-reproducing*. The model leads directly to the standard model of particle physics and to the standard inflationary big-bang cosmology. I shall refer to it as the *inflaton spacetime* model.

The inflaton spacetime model answers many questions that are currently puzzling physicists. It explains the cosmological constant problem and the weakness of gravity, gives accurate predictions for the masses of the electron and the W boson, tells what the Higgs field is and predicts that the Higgs boson will probably not be found even though it does exist, explains why neutrino mass and flavor eigenstates differ, leading to neutrino oscillations, provides a candidate particle for the dark matter that seems to surround galaxies, and predicts a tiny probability for proton decay.

The inflaton spacetime model is not a replacement for the standard theories. It does not supersede the models of the electromagnetic, electroweak, and strong forces found in the standard model of particle physics, or the theory of gravity found in Einstein's General Relativity, but because it is a discrete theory, it avoids the infinities and need for renormalization found in those theories. It supports the standard cosmology including the big bang, inflation, cold dark matter, a cosmological constant, and a flat universe. These theories are highly successful and there is no need to throw them out. What the inflaton spacetime model contributes is the model of spacetime that has been missing, thereby opening the door to further progress in the standard models and beyond.

In quantum field theory, the formalism of the standard model, spacetime is only a background in which fields and particles exist and interact. In General Relativity, spacetime is continuous. In contrast, the inflaton spacetime model is *background independent*. Spacetime points are discrete quantum objects and particles are excited points. Nothing else exists.

A surprising conclusion of the inflaton spacetime model is that the four basic forces—gravity, electromagnetic, weak, and strong—are *latent in spacetime*, but are hidden by the symmetry of spacetime until that symmetry is broken by the presence of particles. Another major revelation is that the principal forces are symmetry and the law of spin and statistics. An important concept is that spacetime is a directed medium, and especially that time is a local phenomenon: time at a given point of space does not have to be the same as global time or the observer's time. This concept provides enough new degrees of freedom that the inflaton spacetime model can explain the standard model without resorting to strings, loops, or higher dimensions. The model does exhibit supersymmetry at the point level, but only limited supersymmetry at the particle level.

Postulates of the Model

In addition to quantum mechanics and its postulates, the inflaton spacetime model postulates an expanding set of spacetime points, based on a recursive definition of a point. The usual objection that such a set of points "has no justification in fundamental physics" is invalid here, since we are trying to expand the boundaries of fundamental physics. A discovery that spacetime is self-reproducing is no stranger than having to accept that the universe is governed by quantum mechanics.

The inflaton spacetime model is based upon quantum mechanics and the following three additional postulates:

1. Spacetime is a field composed of discrete quantum states or objects called *points*. These quanta carry quantum numbers called *spin* and *relative position* or *relative coordinates*. These are simply intrinsic quantum numbers of the quantum objects called points. They are independent of any particular spacetime model. Thus, coordinates need not be defined in any particular spacetime. They are simply numbers—completely random at first, as we will see. They can take on any real values, and in general, their values will vary from observation to observation, a lot at first, then less as time goes on. As quantum observables, coordinates have continuous spectra—they take values in a continuous spacetime. As a result, it is common to think of points as existing in this continuous spacetime. This is an illusion. The spacetime of all possible point coordinates has only a potential or virtual existence. It is never observed. Only real points can be observed. Where there is no point, there are no coordinates. Nothing can exist or happen there. It is the void, nothing. Thus, although it seems continuous, spacetime is mostly nothing, just as atoms, which seem solid, are mostly empty space. The continuous spacetime does have uses. The wave functions of points exist here. So do the fields of quantum field theory, which are wave functions. Thus, quantum field theory is defined in a continuous background spacetime, but this is at best a low-energy approximation to the real spacetime of discrete points, which exists in itself, independent of any background space. Although quantum field theory is a powerful tool for dealing with particles and their interactions, it is usually easier at the point level to work with quantum mechanics. The inflaton spacetime model uses some concepts and results from quantum field theory, but is based primarily on quantum mechanics, adhering to the standard Copenhagen interpretation.

2. A point is the characteristic function of a set of points. The characteristic function of a set is a two-valued function. A function has three elements: (1) a domain, (2) a range, and (3) a relation, mapping, or rule of correspondence between the domain and the range. The domain of a point is a set of preexisting points, and its range is two-valued: the function takes the value true when applied to any point in its domain and the value false otherwise. Any point that is true on some domain exists as a spacetime point. Its coordinates are unspecified.

3. There is at least one point. The existence of one point implies the existence of at least two points, since the point that is postulated to exist must have a domain, and its domain must have at least one member.

The Big Bang

The last two postulates call for an expanding spacetime. As noted, the existence of one point implies that there are at least two. Given a set of two points, take the subsets of this set. There are $2^2 - 1 = 3$ nonempty ones, and each defines another point. A set of three points has $2^3 - 1 = 7$ nonempty subsets, and a set of 7 points has 127, and so on. The number of points rapidly becomes astronomical. In other words, starting with two points, one gets an expanding set of points—a very rapidly expanding set.

In the inflaton spacetime model, this is the *big bang* at the beginning of the universe. Instead of an expanding set of points, which brings in the notion of time a little prematurely, we can look at each of the stages of the expansion we have just described as an alternate layer of spacetime, so spacetime is seen as a superposition of many, many layers. Readers familiar with the theory of sets may recall Cantor's paradox. The question, "What is the cardinality of the set of all sets?" leads to the conclusion, which Cantor proved impossible, that this set has as many members as subsets. The existence of two alternative ways of looking at spacetime is precisely Cantor's paradox. It arises because of the recursive or self-referential definition of a point. The set of all sets is the universe, or spacetime, and it is a foliation of many layers, each of which has a different cardinality. Alternatively, from a different reference frame, it is a process in a state of continual expansion. In the inflaton spacetime model, these are two *complementary* (in the sense of Bohr) descriptions of the universe. They are both correct. It is well-known that the introduction of a notion of time will often resolve a paradox of self-reference. In this case, it makes our universe possible.

Orderings of Spacetime

Now let us examine this spacetime as a mathematical space. Does it have any structure?

First of all, as we have seen, there is a natural ordering that looks like time. The progression from N points to $2^N - 1$ can be considered to define an instant of time. But how much time? How long an instant? That is not defined. We can look at spacetime as existing all at once and at time as a meaningless construct. Or we can look at spacetime as expanding in time, which is the way we see it as human beings. These are two different reference frames.

This time ordering is only a partial ordering. The characteristic function of a particular set of points is clearly later in time than the points in its domain, but less can be said about its time relationship to points not in its domain. The relationship "later" is meaningful, however, since given any point, there is some set of points that it can be shown to be later than. However, it cannot be assumed that the $2^N - 1$ points that arise from a universe of N points are created simultaneously. This is not required. It is an important spacetime characteristic that while the global arrow of time points in the direction of the expansion, the local arrow of time can point in a different direction at each point, and the local creation time of a point can differ from the global creation time. *In fact, local time at a point is simply another intrinsic quantum number of a point.*

As it extends in time, the universe expands. This expansion is spacelike, but there is no natural ordering, no natural geometry. Thus, as a mathematical space, spacetime is partially ordered, but the ordering is very weak.

On the other hand, every possible complete ordering of the points of spacetime defines a different universe, with a different history and perhaps different physical laws. Do all of these universes exist? In the inflaton spacetime model we assume that there is only one real universe. If it is in a state where there can be different possible outcomes of an observation, its state is described by a quantum mechanical wave function, which assigns a probability to each possible outcome. Upon observation, one possible outcome is realized, a phenomenon called *collapse of the wave function.* As in the standard Copenhagen interpretation, we do not attempt to model any mechanism that might cause this collapse or choose the outcome.

Expansion and Structure of Spacetime

At each step in the expansion of spacetime, the number of points expands from N to $2^N - 1$. The succession of such steps is timelike, while the expansion in the number of points looks spacelike. In other words, we have a space of points that gets bigger with time. At each time step, a copy of each of the N points existing at the previous time step is created, along with many new points representing all possible combinations of the N points. Physically, all points are structureless and identical. Except that they can have different intrinsic quantum numbers, they are *indistinguishable*.

It is natural to ask, "How many seconds does each time step represent?" "How many centimeters are there between points at any given time?" According to this model of spacetime, these questions have no definite answers. The number of seconds in each time step and the number of centimeters of distance between points are undefined.

It is important to understand the meaning of *undefined*. It does not mean that these quantities are zero, although they could be. It also does not mean that they are random, although they could be, or at least appear to be. "Undefined" means that *these quantities could be anything*. As will become clear later, sometimes some independent requirement will give a value, or a range of possible values, to an undefined quantity. Sometimes a value will be selected by the collapse of a wave function.

Let's call the time increment Δt and the space increment Δx. There is clearly a reference frame in which both of these quantities are zero. This is the reference frame of an observer who is outside of time. We can't see this frame, but it is an important frame because whatever happens in any other reference frame must not contradict what happens in this one. The universe must be *relativistically invariant*, so that the laws of physics have the same form regardless of the reference frame.

Now let's look at spacetime from a reference frame in which Δt and Δx are undefined and could be nonzero. Take Δt first. The universe as a whole needs to be atemporal, because there is a reference frame in which there is no time. The only way that Δt can be nonzero while overall there is no time is for the universe to take a step backward in time for every step forward. It doesn't matter which way it goes first; we can even assume that it takes the forward and backward steps simultaneously. Thus, *universal time is always zero*.

Each time the universe takes a step, either forward or backward, it expands, N points becoming $2^N - 1$. Therefore, after it completes each pair of steps, one forward and one backward, *one direction will always have more points*. We'll call this direction *forward in time*. This asymmetry is all we need to explain why, when matter and antimatter annihilated in the early universe, there was plenty of matter left over, but no antimatter.

To make thinking about this universe easier, we can look at it as two universes: one going forward in time and one going backward. The two universes are collocated and coupled, yet separate. From now on, when we speak of *global* time or the *observer's* time we will mean time in the forward universe.

Now let's look at Δx. How do we describe the position of a spacetime point? What numbers do we give for its coordinates? We are used to thinking in terms of a continuous spacetime, in which we can specify the position of something precisely. We can't do that in the early universe. The position of a given spacetime point within the virtual background spacetime is—that's right—*undefined*. It could be anywhere. To an observer located at one point trying to measure the position of another, it would appear to be vibrating madly. Recall that at each new time step, an image of each previously existing point is created, along with many new points. *The observer sees each new image of a given point at a different location.* It's as if the spacetime points fill up the nothingness between them by racing about madly. This activity is called *quantum fluctuations of the vacuum*. An alternative way for points to fill up space would be for them to have some size or extension, but this does not seem to be the way spacetime works. The smallest particles seem to be pointlike (the inflaton spacetime model does not support string theory).

Notice that we have made an assumption here that time advances a fixed amount at each time step while the spatial positions of points vary randomly. In reality, both time and position could be random. However, special relativity allows us to absorb the time randomness into the position randomness so that we lose no generality by considering time to be regular. We use this assumption throughout this paper.

Spin and Statistics of Points

Not only is the position of a given spacetime point undefined, but its *orientation* in space is also undefined. Thus, for the same reason that it appears to be vibrating madly, it also appears to be *spinning*. We have said that points have a quantum number called spin. Spin is independent of any spacetime model, but when we look at points in the usual three-dimensional spacetime model, spin turns out to be an intrinsic angular rotation.

We know that the wave function of a system of indistinguishable quanta must be either symmetric (keep the same sign) or antisymmetric (change sign) under an exchange of any two quanta. Along with the uncertainty principle, which implies that spin can only change by multiples of $\hbar = h/2\pi$, where h is Planck's constant, this leads to the conclusion that pointlike objects can only have values of spin that are equal to $n\hbar$ or $n\hbar/2$, where n is an integer. For example, particles that have symmetric wave functions have integer spin, $n\hbar$, obey Bose-Einstein statistics and are called *bosons*. Their wave functions are such that the amplitude to find a pair of them in the same quantum state is higher than the amplitude to find them in different states. Particles that have antisymmetric wave functions have half-integer spin, $n\hbar/2$, obey Fermi-Dirac statistics, and are called *fermions*. The amplitude to find a pair of fermions in the same quantum state is always zero. This is known as the *Pauli exclusion principle*. The attraction of bosons and the repulsion of fermions are examples of *forces* that are actually manifestations of the law of spin and statistics.

How about spacetime points? Are they fermions or bosons? Since there is no reason to choose one way or the other, we expect that there is some probability for them to be in either state. In quantum mechanical terms, we assume that points are *mixed states*. On any observation of the first creation of a point or its subsequent images, we assume that we will observe the point to be in either the fermion state or the boson state with probabilities given by a parameter called the *mixing angle*, θ_F. Using Dirac notation:

$|\text{point}\rangle = \sin\theta_F|\text{fermion}\rangle + \cos\theta_F|\text{boson}\rangle.$

This means that the probability that a point is a fermion is $\sin^2\theta_F$ and the probability that it is a boson is $\cos^2\theta_F = 1 - \sin^2\theta_F$. For *maximal mixing*, $\sin^2\theta_F = 1/2$ and the odds are 50% that a given point will be a fermion and 50% that it will be a boson at any time step, or time tick. This condition probably prevailed at the time of the big bang, although we really have no way of knowing. We can say that θ_F is not constant, but decreases with time. As we'll see shortly, there are good cosmological reasons to think that θ_F is very small today, and that almost all points are bosonic.

Hereafter we will assume that fermionic spacetime points have spin 1/2 and bosonic points have spin one, where we are now using *natural units* in which $\hbar = 1$.

We now have a field of points that are sometimes fermions and sometimes bosons. Thus, the inflaton spacetime model has *supersymmetry* at the point level. Fermionic points and bosonic points form a doublet and can turn into each other. However, because spacetime points are indistinguishable, this situation is identical to having two separate spacetime fields, one fermionic and one bosonic, except that the fields are *coupled* as a result of mixing. In the remainder of this paper I will treat the fermionic and bosonic spacetime fields as separate fields, so we now have forward-time and backward-time fermionic and bosonic fields, coupled together. By making this *choice of gauge*, we break the supersymmetry between fermions and bosons, and it does not extend to particles. Thus, the inflaton spacetime model does not agree with theories that predict that supersymmetric partners should exist for all of the standard model particles.

The basic quantum state for a spacetime point is identified by its position or coordinates. Remember that these are just intrinsic quantum numbers. As a quantum observable, the position of a point has a continuous spectrum, giving the illusion that points exist in a continuous spacetime, but this spacetime is only virtual. There are only a finite number of points, so most of virtual spacetime is empty. The quantum state of a point is also described by its spin.

There is no limit on how close together bosonic spacetime points can be. We are accustomed to thinking of spacetime as consisting entirely of bosonic points: between any two points there is always another. But given the tendency of bosons to be found together, if all points were bosonic, spacetime would soon consist of only one point! We would be back to $\Delta x = \Delta t = 0$ again. So, because we are allowing Δx and Δt to be greater than zero, some points must be fermionic.

There is a limit to how close together fermionic points can be. If they get too close together, that is, too close to the same quantum state, the amplitude for them to get closer drops to zero. Because of the Pauli exclusion principle, they appear to repel each other. Although no actual force is involved, this effect is known as *degeneracy pressure*.

Although we are treating the fermionic and bosonic fields as separate fields, we know that they are really one field and that a given point is sometimes a boson and sometimes a fermion. Therefore, the two fields are *coupled*—they interact. The result is that as the bosonic points seek each other out and gradually tend to cluster together, they carry the fermionic points with them.

So far we have seen that spacetime consists of bosonic points and fermionic points, and that there is coupling between the two kinds of points. The bosonic points try to pull everything together while the fermionic points resist getting any closer together than some minimum distance. The effect on the fermionic spacetime points of the interaction between the fermionic spacetime field and the bosonic spacetime field looks somewhat like *gravity*. The fermionic points are drawn together. Like degeneracy pressure, there is no real force, but the effect looks like the force of gravity, and in fact, it is. Later we will show that the same effect is responsible for the real gravitational attraction between particles or larger objects. For points, it makes it possible to think of them as effectively having *mass* and *momentum*, even though intrinsically, they do not have mass or momentum, only relative position (potential energy) and spin.

Because some points are fermionic and resist being closer together than some minimum distance, we see that we can't really ever have $\Delta x = 0$ except when there is only one point. The universe will expand, no matter what. However, the universe preserves this symmetry *on the average* by expanding equally in all directions from every point. Thus, there is no center of the universe.

So far I have not said anything about the dimensionality of spacetime. Why does the universe have three space dimensions and one time dimension? In the inflaton spacetime model, the space dimensionality of spacetime is *undefined*. It could be anything. Quantum mechanics requires us to consider space to be a quantum superposition of spaces, each having a different dimensionality, and each having some probability of being observed. Spaces of zero, one, and two dimensions cannot contain observers, but what about higher-dimensional spaces? In more than three dimensions, the degeneracy pressure that keeps spacetime from collapsing to a single point is not felt. The fermionic points can go right through each other, so they do not interact and the space dimensions higher than three simply collapse. Moreover, it is known that gravitational structures are not stable in more than three space dimensions. Thus higher-dimensional spaces collapse to a condition in which spacetime is stable, that is, to three dimensions, and that is all that we observe.

The Early Universe

Let's go back now to the moment of the big bang and look at the very first points. Can we say what their location was? Can we say where the big bang occurred? Absolutely not. It is completely undefined. As more points are created, their positions can be defined in some relative sort of way, but they are still largely undefined. Thus, these early points seem to be vibrating with enormous energy. Because they respond to something like gravity, they seem to have mass, and so their vibrational energy looks like thermal energy and the temperature of the early universe seems very high. Hence the hot big bang picture of the early universe.

Although the position quantum numbers of points are undefined, the values they can take are limited by the requirement that the universe look the same to all observers. In three dimensions, this confines the positions of points to a three-sphere. Since there can be as few as two or three points in an essentially infinite space, at first the three-sphere is very large. As the expansion proceeds, there are more and more spacetime points and gravity gradually draws the fermionic points together so that they have less and less room in which to move, that is, the three-sphere shrinks. The fermionic points cannot collide because the exclusion principle keeps them from hitting each other, but the distance they can move in one increment of time decreases. This decrease in velocity represents a decrease in kinetic energy and therefore a decrease in the temperature of the early universe. Moreover, the possibility of specifying the location of a particular point relative to other points improves.

Eventually spacetime reaches a point where there are so many fermionic points that they can't get any closer together because the degeneracy pressure won't let them. At this time each fermionic point acts like it is in an infinite potential well or a little box. It occupies some minimum volume of space, and each new fermionic point that is created adds that much more space to spacetime. The bosonic points distribute themselves uniformly. Since there is no preferred direction or center point, they are attracted to the nearest fermionic point, and the fermionic points are uniformly distributed. The vacuum is now effectively frozen except for quantum fluctuations. However, its final approach to this condition, far from being gradual, resembles a sort of crash or collision in which the vacuum gives up its energy in a shower of particles, as we will see a little later.

When spacetime freezes into its final structure, except for the usual possibility of quantum fluctuations, it is a relatively uniform lattice of fermionic points embedded in a sea of bosonic points. Each fermionic point is as close as it can get to its neighbors and occupies a volume of spacetime with diameter equal to the average separation between adjacent points, which is our old friend Δx. Later we'll show that it's probably equal to about 10^{-33} cm, the Planck length, although the model does not give a definite value. The time dimension Δt would then be about 10^{-43} second. Spacetime is effectively frozen. It does not change its structure with further decreases in temperature, even down to absolute zero. The observed position of each point within its little volume of space changes with each observation, the vibrational motion called quantum fluctuations of the vacuum, or *zero-point energy*.

Let's look at this more closely. Recall that fermionic points have no intrinsic mass, momentum, or kinetic energy, since they are only observed at time ticks, when they are stationary. They have only spin (1/2) and potential energy (relative position). Their energy levels relative to an observer are determined by their relative positions: closer means lower energy. Thus, when they are as close to each other as they can get, they form a *Fermi gas*, a cloud of fermions in which every energy level is occupied by a fermion. Since they have no momentum, fermionic points do this *trivially*. There is no other configuration they can assume, and because each energy level corresponds to a position, this Fermi gas forms a relatively uniform lattice. This is now the permanent configuration of fermionic spacetime—a lattice held together by gravity, a result of coupling to the bosonic spacetime field. The lattice is not rigid; the point positions fluctuate quantum mechanically.

In the fermionic lattice, every position that is occupied by a fermionic point can be co-occupied by other fermionic points as long as they are not in the same quantum state as the original occupant. This means that at any position there can be as many as two positive-time fermionic points, one with spin up and one with spin down, since these are different quantum states. There can also be spin up and spin down negative-time points at the same position, for a total of four points. There can be independent quantum fluctuations of the precise positions of all four points within the little volume of space corresponding to one lattice "position". These points do not form bound states with each other.

For now, let's just look at spin up, positive-time fermionic points. In the fermionic lattice there is one and only one of these points at each occupied spacetime position. However, because these points are indistinguishable, the lattice will look the same whether the points are stationary, with each point always occupying the same position, or moving, with any particular point possibly occupying different positions at different times. Quantum mechanics tells us that both possibilities may be observed. If we look at the effective velocity of a fermionic point as a quantum observable, we can conclude that one of its eigenvalues must be zero. In other words, a fermionic point can be stationary. Points can also move, so we might guess that another of their velocity eigenvalues is the speed of light. Any velocity state can be formed as a mixture of $v = 0$ and $v = c$ states, so these two must be all of the eigenvalues. Notice that we do not need any mechanism by which points move. All we need is quantum mechanics, which says that because spacetime looks the same whether any given point moves or not, both possibilities have nonzero probability.

All of this will be important in later discussions. Returning now to the expansion, what we have described so far is the phenomenon of *inflation*, a period of very rapid expansion that makes the universe flat and homogeneous. In terms of the number of points, the inflationary expansion of spacetime actually continues forever, since there are always more and more new points. However, at the moment when spacetime freezes, a phase transition occurs (this is the crash I spoke of earlier) in which all the mass that will ever be created is created, and physical inflation ends. Subsequently, matter and the volume of space occupied by it undergo a much slower matter dominated expansion according to the laws of general relativity.

Inflation

According to inflationary cosmology,[1][2] when the expanding infant universe had cooled below a certain temperature, a scalar field called the *inflaton* was displaced from the minimum of its potential energy density. This resulted in a state called a false vacuum in which the vacuum appears to have an energy density. Such a vacuum has a large negative pressure, resulting in a gravitational force that is negative, or repulsive. As a result, the expansion accelerates and spacetime grows exponentially, doubling in size each 10^{-34} second. This continues until the inflaton field completes a phase transition to a true vacuum state and the energy or mass that was in the vacuum precipitates as a shower of particles, which first appear as coherent oscillations of the inflaton. These are unstable and decay into lighter particles and radiation. The universe reheats and the expansion becomes matter and radiation dominated and slows down to the kind of expansion we see today.

In the inflaton spacetime model, the inflaton field is not a matter field: it is spacetime itself. The vacuum has masslike behavior, but the pressure for expansion comes from the enormous number of new fermionic points being created. To make this picture more precise, let's set up an observation post on one fermionic spacetime point and measure the distance between our position and that of our nearest neighboring fermionic point. Repeated measurements will show that we are measuring a random variable. At first we perceive the mean value of this variable, which we define as the *mean free path* of our point (it's as far as we can go, on the average, without possibly hitting another point) to be nearly infinite, since there are few real points in the infinite virtual background space. The number of real points increases rapidly, and simultaneously the points are drawn together by gravity, so the mean free path of our point, and indeed of all points, decreases.

After a few iterations, the expansion from N points to $2^N - 1$, which if θ_F is constant applies to the fermionic points as well as to all points, results in a truly enormous number of new points at each step and represents an essentially infinitely rapid *potential* expansion of the universe. However, the expansion is limited by symmetry principles, which are embodied in the theory of General Relativity. Fermionic points behave as if they both have mass and feel gravity. As we've seen, they ultimately form a relatively uniform lattice. The average distance between points actually starts out very large and gets smaller as the number of fermionic points rapidly increases, but just for a moment, let's assume that it is constant and equal to its final value. This will give us a clearer picture of the inflationary nature of the expansion and the end result will be the same. If this distance is constant, the volume of the universe is proportional to the number of fermionic points and the point density remains constant as the universe expands. The very high rate of creation of new fermionic points represents some virtual pressure p, and because we are dealing with the vacuum, which is completely devoid of matter at this epoch, the pressure p and the energy density ρ are related by the vacuum equation of state, $\rho = -p$. This condition is called de Sitter space, and General Relativity says that it expands according to:[1]

$R \propto e^{Ht}$,

where H is the Hubble factor, H = (dR/dt)/R, and R is not the radius of the universe, but a scale factor relating distances at different times.

In other words, General Relativity shows that the expansion rate cannot approach infinity, but must have an exponential character. Therefore, something must limit the production of fermionic points, and the only possibility is that the mixing angle θ_F is a function of the mean free path of fermionic points, which we'll call a. Then $\theta_F = f(a)$, so when a decreases, θ_F also decreases. This is simply the Pauli exclusion principle at work again. Just as it limits how close together fermionic points can be, it also reduces the amplitude for more fermionic points to be created when there is less room for them. As θ_F decreases, $\sin^2\theta_F$ also decreases, so $\cos^2\theta_F$ increases, which means that as the universe expands and fewer fermionic points are produced, more bosonic points are produced. Eventually, after inflation ends and the expansion becomes much slower, almost all new points will be bosonic.

Phase Transition

Now let's look at the phase transition that ends inflation. Recall that a is the mean free path of a point. We can define a scalar field $\phi = 1/a$. The value of the field is assumed to be the same for all points, *including all of the new points created at a given instant of time*. The value of the field starts out near zero and gradually increases as spacetime expands, until it reaches the value $1/a_o$, where the gravitational pressure is equal and opposite to the degeneracy pressure. The potential energy density of this field is almost entirely gravitational until a approaches a_o, a number that we'll identify with the Δx we spoke of before.

Until a gets close to a_o, the degeneracy pressure is negligible, so the spacetime points don't feel each other's presence very much. As a approaches a_o, the degeneracy pressure begins to resist the gravitational forces and the field's potential energy density drops sharply. As a decreases to a_o and beyond, the potential energy density rises sharply again as the degeneracy pressure strongly resists further contraction of the spacetime lattice. The value of a "hits bottom" (the crash I spoke about earlier), rebounds, drops again, and repeats, oscillating about $a = a_o$ as first gravity and then the degeneracy pressure dominates the potential energy. These oscillations are interpreted as particles, in much the same way that photons are oscillations of the electromagnetic field. Later we'll see that the process I've described here classically is really a quantum process, but the result is similar: the process ends in oscillations that represent particles.

During the early stages of inflation, quantum fluctuations make it likely that the value of the mean free path, a, will be slightly different in different parts of the universe. Large differences are unlikely because there is nothing to distinguish one part of the universe from another. In the phase transition at the end of inflation, all of the fermionic points are drawn together rapidly and strongly, so that after inflation, a is the same everywhere and the universe is almost perfectly homogeneous except for the small quantum fluctuations that make up the zero-point energy. However, the differences in a going into the phase transition cause the transition to take slightly more or less time in different areas, resulting in slightly smaller or larger oscillation amplitudes, respectively, in different areas. These differences represent primordial density perturbations, which subsequently grow gravitationally and seed the large-scale structure we see today in the universe. Therefore, the inflaton spacetime model is like other inflationary models in predicting a homogeneous, isotropic, flat universe with density perturbations that seed large-scale structure. The current observations of the cosmic microwave background confirm these predictions of inflationary models.

Notice that while the field ϕ is a scalar field that controls inflation, ϕ is not the *inflaton*, the field that both drives and ends inflation in most inflationary models. It is not a matter field and it does not drive inflation. That is the job of the point production process of spacetime itself. However, the particles produced in the phase transition are the same as those of the standard scalar-field-mediated inflationary scenario. These particles decay into light particles and radiation, reheating the universe and beginning the radiation and matter dominated expansions of the standard big-bang model.

The standard way to specify a particle theory is via its Lagrangian. For a spatially homogeneous field that has no kinetic energy, only potential energy, the energy density and pressure are related by:

$\rho = V(\phi)$, and $p = -V(\phi)$,

where $V(\phi)$ is the potential energy density. In the inflaton spacetime model, we need a term in the potential energy density $V(\phi)$ to represent the pressure of the expanding number of points, and we need two other terms: one to represent the coupling of the fermionic spacetime field to the bosonic spacetime field and another to represent the coupling of the fermionic spacetime field to itself. Classically, the potential should have a minimum at $\phi = 1/a_o$, but quantum mechanically, this is not necessary. Thus we can write:

$V(\phi) = V_0(\phi) + V_1(\phi) + V_2(\phi)$,

The $V_0(\phi)$ term represents the increasing number of fermionic points. The $V_1(\phi)$ term acts like a gravitational potential, which is a good model for the way in which the fermionic points seem to attract each other. Because of their coupling to the bosonic spacetime field, they are swept towards each other as if they had mass and were attracted by gravity.

The $V_2(\phi)$ term models the degeneracy pressure, which is only felt by the fermionic points when they are almost at the same position ($\phi = \infty$). This term is zero until the points are at the same position, where it becomes infinite. $V_2(\phi)$, which represents the degeneracy pressure and tends to decrease ϕ, opposes $V_0(\phi) + V_1(\phi)$, which represent the increasing number of points and the effect of gravity, both of which tend to increase ϕ. Thus, if $V_2(\phi)$ is positive, $V_0(\phi)$ and $V_1(\phi)$ are both negative.

During most of the inflationary period, $V_2(\phi)$ is not felt and $V_1(\phi)$ is small compared to $V_0(\phi)$. Then $\rho = V_0(\phi)$ during inflation. The form of this function is not important as long as it is sufficiently constant to give enough expansion to make the universe very flat before the end of inflation.. It does decrease sharply near the end of inflation as the Pauli exclusion principle reduces the amplitude for new fermionic points to be creased, as we have already noted.

We'll discuss the form of the other two terms of the potential energy density later, under "Back to Inflation."

It is significant that the inflation-controlling field is a field that describes the *structure of spacetime*. *The bosons represented by the oscillations in a at the end of inflation are resonances or resonance modes of the fermionic spacetime lattice.* In fact, the structure of spacetime in general is determined by an ensemble of such fields. One of these, as we will see later, is the electroweak Higgs field, which turns out to be a field representing several structure parameters of the fermionic spacetime field.

After Inflation

At inflation's end, the oscillations of the inflation-controlling field are damped as the inflationary bosons, which are unstable, decay to lighter particles and radiation, reheating the universe. New spacetime points continue to be created, and the universe continues to expand, but the new points are added at the minimum of $V(\phi)$, so there is no oscillation and no new matter created. By saying that new points are now created at the minimum of $V(\phi)$, I mean that the existing fermionic points are as close together as they can be, on average, so you might think that no more fermionic points could be created (the Pauli exclusion principle). However, the quantum fluctuations in the positions of individual points guarantee that there is always room for a few more points, so spacetime continues to expand. The expansion is now much slower than the inflationary expansion, but it is still ultimately an accelerating expansion because, ignoring the presence of matter for the moment (see below), the density of fermionic points and the amplitude to create new fermionic points remain constant. Thus, the number of fermionic points grows by a fixed (very small) percentage at each time tick. This is like compound interest, which as everyone knows, leads to an accelerating expansion of one's bank account. Bosonic points can be produced in any quantity, of course, so after inflation, most new points are bosonic.

If we observe the universe today, we see that it appears to be very flat. Parallel lines never meet, at least as far as we can see. The circumference of a circle is 2π times its radius. The angles of a triangle sum to 180°. Inflationary theory predicts this based on the huge expansion during the inflationary period. If the universe was curved to begin with, it was very, very flat by the time of the phase transition.

In the inflaton spacetime model, there is no matter before the phase transition, and nothing to cause spacetime to be curved except for the point creation process, which results in de Sitter space. De Sitter space is curved, but it is *conformally flat*, which means that the metric is the flat metric times the square of a nonzero differentiable function. After inflation this function is so close to one that the difference cannot be detected, so spacetime is essentially flat. As I explain below, the matter created in the phase transition does not change this, no matter how much matter is created.

After the phase transition, the universe continues to expand at what would be an accelerating rate except for the gravitational attraction of the matter, which slows the expansion rate. However, this slowing is only temporary, because as the universe expands and the matter density decreases, the point creation process eventually dominates over the gravitational attraction of the matter and the expansion rate again accelerates, driving the universe ever closer to flatness. Thus, unlike other inflationary models, in the inflaton spacetime model the universe does not just drift after the phase transition. Instead, it is continually driven to flatness.

The expansion of spacetime with matter is governed by the equations of General Relativity for a matter and radiation dominated universe, except that the flatness of spacetime as a whole, and its continuing accelerating expansion, create effects that require the inclusion of a *cosmological constant* in the expansion equations.

Points where matter or energy is located (see "Particles and Reheating") are decoupled from spacetime as a whole (see "Gravity"). The effect is to make gravity for particles and energy much weaker than the gravity that makes the fermionic spacetime points come crashing together at the end of inflation. This is a good thing, for if it were not so, the large-scale structures seeded by the primordial density fluctuations would not look like the galaxies we see today. Instead the universe would be filled with mainly black holes, which would form very quickly after the end of inflation

A suitable cosmological model for the universe is a Friedmann-Robertson-Walker (FRW) model with zero curvature (k = 0). The equation describing the expansion is:

$$H^2 = 8\pi G\rho/3c^2 + \Lambda/3,$$

where H is the Hubble factor (the ratio of the rate of change of the scale factor of the universe to the scale factor itself), G is Newton's constant, ρ is the energy density of the matter in the universe, c is the velocity of light, and Λ is the cosmological constant. Usually this equation is divided by H^2 and expressed as:

$$\Omega = \Omega_m + \Omega_\Lambda = 1,$$

where the value of 1 is expected for a flat universe. Recent measurements indicate that Ω_m is approximately 0.3 and Ω_Λ is approximately 0.7. Not enough matter is observed to produce a matter value of 0.3, so it is thought that much of the matter in the universe is *cold dark matter*. We will revisit this concept later. As for the cosmological constant, the inflaton spacetime model predicts that it has whatever value is necessary to produce a sum of 1 in the above equation, since as we saw above, spacetime is inherently flat. This is true regardless of the amount of matter, since all matter is created in the phase transition at the end of inflation, when the universe is almost perfectly flat, that is, $\Omega = 1$. Since Ω_m only decreases as the universe expands, it must always be less than one and the flatness of the universe adds whatever cosmological constant is required to make $\Omega = 1$. Thus, the cosmological constant problem—the question of what could be the source of the energy represented by Ω_Λ—does not exist in the inflaton spacetime model.

Recent measurements also show that the universe is indeed expanding at an accelerating rate, as predicted by the inflaton spacetime model.

I will close this section on inflation by estimating the effective or virtual vacuum energy density driving inflation. During that period,

$H^2 = 8\pi G\rho/3c^2$,

so $R \propto e^{Ht} = \exp[(8\pi G\rho/3c^2)^{1/2}t] = \exp[(8\pi GV_0/3c^2)^{1/2}t]$.

Let's assume that V_0 is constant during inflation and see how large it would have to be to give enough inflation to fit current observations. Usually, it is accepted that Ht needs to increase by 70 or more during inflation (70 *e-folds* of inflation), which lasts about 10^{-32} s. Hence we need $10^{-32}H > 70$ or $V_0 > 2.62 \times 10^{64}$ (g cm^2/s^2)/cm^3. This can be compared with the Planck density, which is 4.63×10^{114} (g cm^2/s^2)/cm^3.

In the inflaton spacetime model, the average distance between fermionic points starts out very large and inflation ends when the vacuum reaches the Planck density, meaning that the average distance between fermionic points after inflation is the Planck length (but see "Vacuum Energy Density"). Most inflationary models predict that galactic distance scales were smaller than the Planck length before inflation. This is a problem, since spacetime is believed to be structureless at sub-Planckian scales. In the inflaton spacetime model, all scales start out larger than the Planck length and stay that way. The minimum distance, that is, the Planck length, is established only at the *end* of inflation.

Two other problems of conventional inflation models are: 1) they have difficulty producing primordial density perturbations that are as small in amplitude as those observed in the cosmic microwave background radiation (CMBR), which are at the 10^{-5} level, and 2) they predict more large-angle power in the CMBR than is observed. The inflaton spacetime model may be free of these problems. The end of inflation in the inflaton spacetime model is more of a crash than a smooth transition to the minimum of the inflaton potential. This may produce density perturbations that are both smaller in amplitude and shorter in wavelength.

Particles and Reheating

Particles can be real or virtual. Virtual particles are usually gauge bosons, or force-carrying particles. They are not directly observable and, in fact, they are not particles at all but manifestations of the law of spin and statistics, as we have seen. Real particles, such as the inflation-produced particles we have just encountered, can be described as processes involving spacetime points, that is, these phenomena are *excitations or resonances of the vacuum*. Fermions are resonances of the fermionic spacetime field and bosons are resonances of the bosonic spacetime field. Most of the spin and other quantum numbers of a particle are carried by the spacetime point, not by the resonance.

Because particles are processes and not things, it takes time to detect them or make measurements on them. As a result, there is a limit to the precision with which we can measure their properties. This is the origin of the *uncertainty principle*, of which one of the consequences is that a precise measurement of a particle's position destroys all information about its momentum or velocity.

A spacetime point where there is no particle would be said to be in its *ground* state, or state of lowest energy. Where there is a particle, the spacetime point would be said to be in an *excited* state. In the ground state the position is a random function of time and the ground state energy is the zero-point energy.

To characterize real particles, we'll go back to the end of inflation and look at what actually happens when the inflation-produced bosons are created, that is, when the value of the parameter a oscillates about its mean value a_o. The position of a given fermionic point is random, but its wave function, a spherical wave packet that is significant over the spherical volume around the point's average position and near zero elsewhere, is dimensionally modulated like a rubber ball expanding and contracting radially. These oscillations are *coherent*: the oscillations for individual points are in phase over the whole universe. The modulation energy is superimposed on the zero-point energy.

Oscillations of a field are considered *quanta of the field*, or *particles*. The oscillations in the wave functions of the points represent bosonic particles. These oscillations in the parameter a soon decay into lighter particles and radiation. Globally, the continuing expansion will damp the oscillations. Locally, the energy represented by oscillations in the amplitude of the point wave function, that is, in the size of the point cell, can simply be absorbed into the point along with its zero-point or ground state energy, so that each particle-bearing point is in an energy eigenstate that is above the ground state. For example, a particle of mass m in an infinite spherical well of radius r has a ground state energy equal to $E = \hbar^2\pi^2/2mr^2$ and a first symmetrical energy eigenvalue equal to twice this amount. For a point, there is no intrinsic mass but there is also no distinction between its mass and its energy, so we can substitute $m = E/c^2$ and find that the zero-point energy is $\pi\hbar c/\sqrt{2}\,r$. With this model, a point could have twice this energy and the energy above the zero-point energy would represent a particle whose rest energy, or mass, is equal to the zero-point energy. The decay of the inflation-produced bosons is then seen as the decay of the oscillations in the parameter a as the resonance energy is absorbed into the points. Since physical changes don't occur instantaneously, the decay occurs with a time-dependent probability, that is, with some *decay width*. The resulting particles are stable because the only way for a point to give up the particle energy and revert to its zero-point energy would be for the particle energy to be absorbed in its entirety by an adjacent point, in which case the particle would move, but not disappear.

For the inflaton spacetime model I adopt the point in an infinite spherical well as the basis for the lepton model, that is, the model of electrons and neutrinos. Later I will show that spacetime is a superposition of spacetimes with different structures, and that mesons, baryons, and heavy leptons are resonances in these alternate spacetimes. The discussion here will be limited to light leptons and photons, but similar processes occur to generate the other known particles.

The Schrödinger particle in an oscillating infinite spherical well has been studied,[3] and it has been shown that if the oscillations in the radius of the well are high in frequency, the energy of the particle simply increases to a higher but constant level, while if the oscillations are at a low frequency, the energy of the particle follows the oscillations up and down. In other words, a point will absorb the oscillation energy if the frequency is high enough and will not absorb the energy if the frequency is too low. In the inflaton spacetime model, the end of inflation is modeled quantum mechanically because the potential is not bounded from below, so there is not just one frequency of oscillation as in most classical inflation models, but a wide spectrum of oscillation frequencies. The energy of these oscillations is quantized so that it must be exchanged in quanta equal to $\hbar\omega$. Thus, if $\hbar\omega > mc^2$, where m is the zero-point energy of the point, absorption is possible. This limits the amount of energy that a stationary point can absorb to form an electron. However, points moving at the speed of light can have any energy and therefore can absorb any frequency provided that the oscillations are coherent throughout spacetime. Such points form neutrinos and photons. Because oscillations of any energy can be absorbed into points, forming particles, the particle creation process continues until the postinflation oscillations have completely decayed. The light particles and radiation created in this process then begin to interact like normal particles, raising the temperature of the universe and beginning the radiation and matter dominated parts of the hot big bang scenario. This thermalization process is called *reheating*.

Notice that it is the spatial confinement of the stationary (v = 0) fermionic spacetime points that gives them an effective mass and gives electrons mass. If we simply say that $r = a_o$, where a_o is the postinflation expectation value of a and r is the radius of the point well, an electron would have a mass on the order of the Planck mass, which is 23 orders of magnitude larger than its actual mass. This would be true if all fermionic points were stationary and confined to a well of dimension a_o. We saw earlier that fermionic points actually have two velocity eigenstates: stationary and moving at the speed of light. Mixtures of these two states make it possible for points and particles to move at any speed. The vacuum expectation value of the electroweak Higgs field determines the proportion of stationary to relativistic fermionic points, and causes the effective size of a stationary point well to be much larger than the Planck scale, as explained later in "Masses and Coupling Constants." As a result, the electron mass is quite small. The effective well size is an invariant of spacetime and therefore the electron mass is the same for every electron.

In the inflaton spacetime model the local time need not correspond to the global time. This results in a gauge invariance that makes it possible for the particle energy at a point to be converted to phase modulation. The energy of an excited point consists of equal parts zero-point energy and particle energy. This allows us to choose any gauge as long as the total energy remains the same. Because we are talking about very small space and time fluctuations in local reference frames in a flat universe, we can apply special relativity, which says that the interval $dx^2 + dy^2 + dz^2 - c^2dt^2$ between the observer and any point is invariant. Thus, we can choose a reference frame, or gauge, in which the particle half of the point energy is represented by oscillations in the local time rate. This turns out to correspond to the usual quantum mechanical view, in particular the Schrödinger equation. It is also appealing from the point of view that the oscillations of the radius of the point well are absorbed as internal oscillations in the local time rate. We will model the particle energy as a classical harmonic oscillator.

We have noted earlier that it is not required that all of the spacetime points created at a given stage of the universe be created at the same time. Recall that at a given point, fermionic or bosonic, each new stage of the universe is marked by the creation of a new image of that point. This happens on average every Δt seconds. The actual time of creation can vary at each point, but the bosonic points, being bosons, will tend to synchronize. As they do so, a phenomenon similar to gravity occurs as a result of the coupling between the fermionic and bosonic spacetime fields, and the bosonic points tend to drag the fermionic points with them, so that eventually the creation times of all points are synchronized. This is global time. However, when a point contains a particle, we can choose a gauge in which the particle energy is manifested in a local creation time that is modulated in a stable fashion that does not decay with time. As long as the maximum deviation of a point's creation time from the universal time is less than Δt, this phenomenon can be modeled as a classical harmonic oscillator, as follows.

The presence of a particle—energy or mass—at a point causes the point's creation times to be phase modulated, so that they differ from the global creation times. The bosonic spacetime field tries to restore synchronization, but because there is energy present and no place for it to go, the system can reach a stable state in which the creation time t' of the particle point oscillates around the global creation time t:

$$t' = t + T\sin(Et/\hbar + \phi) = t + T\sin(\omega t + \phi) ,$$

where E is the particle energy, T is a constant, $\hbar = h/2\pi$, where h is Planck's constant, and ϕ is an unknown phase angle. As long as $T < \Delta t$, where Δt is the time increment between global creation times, the system acts like a harmonic oscillator—like a mass on a spring—in its ground state, with the synchronization-restoring action of the bosonic field serving as the spring. E must be at least as large as the ground state energy of the system for such a system to be stable. Such a system can serve as a model for an electron, if the point is at rest, or a neutrino, if the point is moving at the speed of light.

It is natural to ask whether higher-energy states could be muon or tau particles. Because T would be greater than Δt for these states, distortion would introduce higher-frequency energy, so the energies of these higher states would be much larger than those of the simple harmonic oscillator. Unfortunately, this does not account for the fact that the muon mass is 200 times that of the electron and the tau mass is nearly 3500 times larger than the electron mass. Similarly, making the restoring force of the harmonic oscillator go to infinity at $T = \Delta t$ or $\Delta t/2$ does not provide the required spread of energy eigenvalues. Later we will offer a different model for muons and tau particles.

Using this model for a stationary electron, what can we say about the wave function of such a particle? The amplitude to detect the electron depends on $(\omega t + \phi)$, since the probability of detecting the particle depends on how much its creation time differs from the global creation time at the time we observe the point. One possibility is the real harmonic oscillator, $A\sin(\omega t + \phi)$. However, this choice is not relativistically invariant. A better choice is the complex harmonic oscillator, $Ae^{i(\omega t + \phi)}$. This encapsulates the same phase information but its squared magnitude is A^2, which is constant.

This harmonic oscillator model for a stationary electron has the underlying point's creation time modulated sinusoidally at frequency ω where, from quantum mechanics, $\omega = mc^2/\hbar$. Thus, the wave function includes a phase difference between the local time at a particle point and the global time of the universe, which is the local time at every point that does not contain a particle. This will be important when we discuss gravity.

Notice that this wave function is independent of x. We have specified a stationary electron, one with zero momentum. The uncertainty principle tells us that when we know the momentum of a particle exactly, we lose all knowledge of the position.

This wave function is not yet the answer we seek, since the integral of A^2 over all space is infinite instead of 1. In quantum mechanics, any particle with well-defined momentum and energy can be represented by a plane wave, that is, by a wave function of the form $A(k)\exp\{i(kx - \omega t)\}$, where the momentum and energy are specified by the wave number k and the frequency ω. The parameters k and ω obey a dispersion relation:

$\omega(k) = [c^2k^2 + (mc^2/\hbar)^2]^{1/2}$.

For a stationary particle, $k = 0$ and $\omega = mc^2\hbar$.

The probability of detecting such a particle is A^2, which is independent of x, so definite momentum still means no knowledge of position. To localize a particle in space we need to construct a *wave packet*. From basic quantum mechanics we know that that this leads to a wave function for the free electron—the general solution to the Schrödinger equation—that is the sum (expressed as an integral over k) of an infinite number of complex harmonic waves of the form $A(k)\exp\{i(kx-\omega(k)t)\}$, that is, a moving, spreading wave packet. The contribution of the inflaton spacetime model is that it reveals the basic spacetime mechanism that leads to this conclusion.

Renormalization

In the inflaton spacetime model, spacetime is not continuous, but quantized. A finite number of fermionic points of zero size cover all of spacetime. The position of any point is *undefined*; it could be anywhere. Between spacetime points there is nothing. When we attempt to observe this quantum vacuum as if it were continuous, each point appears to vibrate madly in the sense that successive measurements of its position relative to any other point give different values.

In quantum field theory, infinities arise in calculating probability amplitudes because in some of the terms there are integrals with limits of zero distance or infinite momentum, and these integrals become infinite when these limits are inserted. Some theories have been found to be *renormalizable*, which means that they can be made finite by canceling one infinity against another. However, not all theories are renormalizable. In particular, General Relativity is not renormalizable. This has foiled attempts to combine General Relativity and quantum mechanics into a theory of quantum gravity.

The inflaton spacetime model has an answer to this problem. It implies that although the distance goes to zero or the momentum goes to infinity, it does so with *zero probability*. To find the value of the desired amplitude, the troublesome limit must be treated as a random variable. The value of the integral is therefore a random variable and we cannot say what its value is. We can only talk about its expected value, its variance, and other statistical measures. To find its expected value we multiply by the probability density function of the random limit and integrate over this limit. As a result of this additional integration, the expected value of the troublesome integral is finite.

Gravity

If there were no resonances in the spacetime structure, it would consist of just a lattice of fermionic points held together by a sea of bosonic points (once the fermionic points are as close together as they can get). The structure would be stable because it is symmetric. If there were an identifiable center, the bosonic points would gravitate towards it, but there is none. The structure is completely isotropic.

However, this does not mean that every point has a fixed position. The points are *indistinguishable*. Therefore, quantum mechanics allows them to change places at will, as long as the structure remains the same. Therefore, the bosonic points still seek each other out and try to drag the fermionic points with them, but the result is no net change in the structure.

Now let's introduce a particle somewhere in spacetime. One point is now distinguishable, but the structure is still symmetric, so the particle just stays where we put it.

However, if we now introduce a second particle, everything changes. By making two points distinguishable, we break the symmetry of spacetime between the particles. This exposes the bosonic flow—the basic tendency of bosons to get together. And because the fermionic spacetime field is coupled to the bosonic field, the resonances—particles—move towards each other. We see no change in spacetime. The only observable effect is that the resonances seem to attract each other.

The laws governing gravity were discovered by Newton and refined by Einstein based on symmetry principles. As Einstein showed, the effect of matter on spacetime is mathematically equivalent to curvature: matter curves spacetime. If $m = 0$, that is, if there is no matter, there is no apparent curvature and spacetime appears flat. Einstein's General Relativity applies only to the spacetime defined by matter, and only to the gravitational interactions of matter and energy. Einstein did not know that there is an underlying spacetime in which the gravitational force is inherent. As the inflaton spacetime model shows, this latent force is hidden by a symmetry: the indistinguishability of spacetime points. Matter breaks this symmetry, exposing the underlying tendency of the bosonic spacetime field to shrink and drag the fermionic field with it.

Infinite curvature is not possible in this discrete spacetime model. We'll see that maximum curvature occurs for $m = m_{Pl}$. Many efforts to model gravity quantum are frustrated by infinities resulting from the need to accommodate zero distances, hence infinite momentum. Renormalization to get rid of these infinities is not possible for General Relativity. In the inflaton spacetime model, there are no infinities and there is no need for renormalization, because zero distance only occurs with zero probability.

In most interactions not involving cosmological distances, Newton's law gives the gravitational force between two objects. Newton's law says that the gravitational force between two particles of masses m_1 and m_2 is $-Gm_1m_2/r^2 = -\hbar cm_1m_2/m_{Pl}^2r^2$, where G is Newton's gravitational constant and is equal to $\hbar c/m_{Pl}^2$.

Now recall that a particle is characterized by a phase or creation-time difference between a point and the rest of the universe. The creation time of the particle point is modulated at a frequency determined by the particle mass. Thus, the particle point is only in phase with the rest of the universe for a proportion of time equal to the ratio of the particle mass to the mass corresponding to the universal creation time clock. This phase difference represents a *partial decoupling* of the particle from spacetime. It is as if particles only feel the gravitational forces that are latent in spacetime if they are in phase with the global creation time clock. From Newton's law, it looks as if the coupling factor can be represented as the ratio of the particle mass to the effective mass of a stationary point, and that the stationary point mass can be modeled as the Planck mass after inflation is over. Thus the gravitational potential energy between any two particles of masses m_1 and m_2 is $-(m_1m_2/m_{Pl}^2)(\hbar c/r)$. We can interpret the first factor as the coupling between two fermionic particles and the fermionic spacetime field, and we can interpret the second factor as a massless gauge boson. Since gravity is always attractive, the gauge boson should have spin 2. Thus, gravity can be modeled quantum mechanically as an exchange of a massless, spin-2 boson, which has been given the name *graviton*. Such gauge bosons are virtual bosons. They are never observed, and the inflaton spacetime model reveals why: they are actually the law of spin and statistics at work.

For this same reason, Newton's law is only an effective theory. It does not hold down to $r = 0$. Gravity is really not a force, but the law of spin and statistics. Newton's law might lead one to think that the four points at each fermionic lattice position would be tightly bound together by infinite gravitational forces, while in fact, they only tend towards the same position statistically. Thus, they are actually free to fluctuate quantum mechanically in position, independent of each other. Gravity only looks like a force at distances much larger than the Planck length.

Now let's see how we can derive Newton's law based on the inflaton spacetime model and some results from quantum mechanics and quantum field theory. As inflation ends, the rate of fermionic point production is drastically curtailed (see "After Inflation"). The ratio of bosonic spacetime points to fermionic spacetime points approaches infinity. As a result, the probability amplitude for an interaction, or *scattering*, between a fermionic point and the bosonic field approaches a limiting value of 1. Thus, the probability amplitude for an interaction between any two fermionic points via the bosonic field approaches the same value. Another way to express this is to say that the gravitational coupling between fermionic points is 1. Notice that there are two interactions involved in a gravitational interaction between two fermionic points: each point interacts separately with the bosonic field. Therefore, the spin of the virtual gauge boson "exchanged" by the fermionic points, that is, the graviton, is 2. (Later we'll see that this is unlike the electromagnetic interaction, which is a direct interaction between fermionic points and therefore corresponds to a spin-1 gauge particle, the photon.)

According to quantum field theory, the amplitude for a scattering interaction is proportional to the Fourier transform of the potential.[4] Then the potential energy between any two fermionic points is proportional to the inverse Fourier transform of the interaction amplitude. Let $V_F(q)$ be the Fourier transform of the potential V(r), where q is the momentum transfer or change as a result of the interaction and r is the initial distance between the interacting points. In the case of points, q is an effective momentum change, since points have no intrinsic momentum. Points have no intrinsic mass, but act like they do, so they can be said to have an effective mass. They have no intrinsic velocity or momentum, but from one time instant to the next they can move and therefore can be said to have an effective momentum that exists between time ticks. The effective momentum change q is always negative (the points always move towards each other), and is directed along the line between the points so that we can treat this as a one-dimensional problem. Then:

$$V(r) = (1/2\pi)\int_{-\infty}^{\infty} V_F(q)\exp(iqr)dq,$$

From nonrelativistic quantum mechanics, the Born approximation for distinguishable fermions says that, to first order, the scattering amplitude iM is:[5]

$$iM = -(i/2\pi)V_F(q)\delta(\Delta E),$$

where we have divided the three-dimensional form by $4\pi^2$ to get the one-dimensional form. The delta function just expresses the conservation of energy, which is trivial for points, so this factor is equal to 1. From the inflaton spacetime model,

$iM = 1$ for $q \leq 0$

$iM = 0$ for $q > 0$.

Therefore, $V_F(q) = 2\pi i$ if q is zero or negative and $V_F(q) = 0$ otherwise. We then have:

$$V(r) = i\int_{-\infty}^{0} \exp(iqr)dq,$$

This evaluates to:

$V(r) = -1/r$.

This result is for natural units ($\hbar = c = 1$). In standard units,

$V(r) = -\hbar c/r$.

This is the gravitational potential between any two fermionic points. To get Newton's law, we multiply by the coupling factor for particles as explained earlier in this section. Thus, the gravitational potential between two particles of masses m_1 and m_2 is

$-(m_1m_2/m_{Pl}^2)(\hbar c/r) = -Gm_1m_2/r$,

where G is Newton's gravitational constant and is equal to $\hbar c/m_{Pl}^2$. Once again, I emphasize that this only holds at distances r that are much greater than the Planck length.

Back to Inflation

If the maximum mass is the Planck mass, then by our definition of mass as proportional to the modulation frequency of the local creation time, the maximum modulation frequency is the inverse of the Planck time, and the creation time interval Δt is the Planck time. This implies that the granularity of spacetime is the Planck scale, that the space interval Δx and the minimum point separation a_o at the end of inflation are equal to the Planck length, and that the potential energy between two fermionic spacetime points is the Coulomb potential, $\hbar c/r$, where r is the separation between the points. We can consider fermionic spacetime to be made up of independent pairs of points, each subject to this potential.

With this knowledge we can say something more about the potentials $V_1(\phi)$ and $V_2(\phi)$ that govern the process of inflation. $V_1(\phi)$ is the energy density corresponding to a potential energy of $-\hbar c/a$ per point pair and a point density of $1/a^3$, where the parameter $a = 1/\phi$ is the mean free path of a point. $V_2(\phi)$ is the energy density corresponding to a potential energy of $\delta(a)$ per point pair, where $\delta(a)$ is the Dirac delta function.

We now have enough information to estimate the wave function of a. Let's make things as simple as possible and consider just two fermionic points, and we'll find the wave function of the distance between them. We know that the potential energy between the points is:

$V_1(a) = -\hbar c/a$,

and

$V_2(a) = \delta(a)$,

and we are now using potential energies, not energy densities..

Let's assume that the interaction between these points has a stationary state and is governed by the Schrödinger equation in one dimension. Thus:

$-(\hbar^2/2m)y''(a) + V_1(a)y(a) = Ey(a)$, where y(a) is the stationary state wave function of a, y'' is the second derivative of y with respect to a, m is mass, and E is energy. Points don't have intrinsic mass, of course, but they behave as if they have an effective mass. To satisfy the V_2 requirement, we will require that our solution y(a) be zero at a = 0.

This equation has a solution:

$y(a) = a\exp(-amc/\hbar) = a\exp(-a/a_o)$,

where $a_o = \hbar/mc$.

Then $m = \hbar/a_o c$ and $E = -\hbar c/2a_o = V_1(a_o)/2$.

If a_o is the Planck length, as we concluded above, then the mass m is the Planck mass and the energy E is half the Planck energy. In this stationary state, the energy is above the potential energy, the difference being the zero-point energy. This is not the whole energy story, of course, because we have simplified the system down to two points and one dimension. As explained above in "Particles and Reheating," we can consider each point to be like a particle in an infinite spherical well. If the well has a radius equal to the Planck length, the zero-point energy is $\pi/\sqrt{2}$ times the Planck energy (in three dimensions).

The distance a_o is the location of the peak of the wave function, that is, the most likely value of a. However, a_o has a continuous spectrum, so we have not shown that a_o is the Planck length, but only inferred this from gravitational evidence.

In our description of the end of inflation, a, the average separation between points, hits bottom at $a = a_o$ and oscillates around this point. The solution we have just derived also has oscillatory modes, which we can derive by mixing stationary modes. We will not show the derivation here. However, the oscillatory solution has an amplitude that is much greater than a_o, while we need an oscillation amplitude of the order of a_o. To solve this problem, we need to expand the two-point model to take account of all of the other points closing in on the point assumed stationary. We have assumed that at any time, there is just one average value of a that applies to all points in the universe. Therefore, as soon as the moving point passes a_o and turns around, it sees another point that it must avoid, so instead of a large oscillation amplitude, it acts as if it is trapped in a potential well of expected dimension $2a_o$ and its oscillation is confined to that small volume of space. In reality, of course, the dimensions of the well have quantum fluctuations, since the positions of all points are random variables. This complicates any attempt to calculate the exact energy of a point.

With what we now know about the potential acting on points, we can make a few assumptions and get an idea of the time evolution of the mean free path a during inflation. Assume that, as a evolves from some initial value a(0) to its final value a_0, we can consider each point to have a virtual mass corresponding to a Compton wavelength of a, that is, $m = \hbar/ac$. Then by Newton's law, the force between two points is $f = -Gm^2/a^2$, so the acceleration is $-Gm/a^2 = -\hbar^2/(m_{Pl}^2 a^3)$, where m_{Pl} is the Planck mass. The acceleration is d^2a/dt^2, so we have a second-order differential equation that we can solve to get:

$a^2 = a(0)^2 - 2a_o ct.$

We have assumed that a_o is the Planck length, 1.616×10^{-33} cm. If a(0) is much greater than a_o, then $a = a_o$ when $t = a(0)^2/2a_o c$. For $a(0) = 10^6 a_o$, $t = 2.7 \times 10^{-32}$ s. If a(0) is greater, say 1 cm, t can be very large, even larger than the age of the universe, but we have ignored the role of the tremendously rapid point production in driving a to a_o, so our analysis would only be valid for small a. For all practical purposes, only the end stages of inflation really matter, and we see that a goes from a million times its final value to its final value in a very short time, even ignoring point production.

Electromagnetism

The spacetime of the inflaton spacetime model possesses other local symmetries in addition to the rotational symmetry that leads to the important concept of spin. One of these that is not found in continuous spacetime models is *local time reversal invariance*. This is different from the global time reversal invariance that is commonly referred to as time reversal invariance in particle physics. Remember that spacetime is a combination of forward-time and backward-time fields. Thus, *local* time at an individual point can be positive or negative with respect to *global* time, or the observer's time. (Overall, of course, universal time is zero because the universe takes a step backward every time it takes a step forward.) In other words, we can have either $\Delta t(\text{point}) = \Delta t$ or $\Delta t(\text{point}) = -\Delta t$, where Δt is the observer's time step discussed earlier. A measurement of the time direction of any point would result in one of these two eigenvalues.

Let us now consider the effect of this local symmetry on the statistics of fermionic points. A wave function for two indistinguishable fermions is antisymmetric under an exchange of the fermions, that is, exchanging the fermions multiplies the wave function by -1. A consequence is that the wave function vanishes if we try to put the two fermions into the same state. The probability of finding two fermions in the same state is zero—fermions obey Fermi-Dirac statistics. Boson wave functions are symmetric under an exchange of two bosons, and the probability of finding two of them in the same state is not zero, but is greater than the probability of finding them in separate states. Bosons obey Bose-Einstein statistics.

Two forward-time fermionic points obey Fermi-Dirac statistics, as expected, and they cannot occupy the same position (unless they have opposite spins). If we reverse the local time direction of one of the points so that it becomes a backward-time point, the points are no longer identical and can occupy the same position. If the points are at different positions, there are two possibilities:

1. Forward-time point at x_1 and backward-time point at x_2.
2. Forward-time point at x_2 and backward-time point at x_1.

These are related by a local time reversal transformation applied to both points. Now, applied to time, the names forward and backward are arbitrary. If we were able to occupy and examine a single point we would not be able to tell whether it is a forward-time point or a backward-time point. If we have two points with opposite time directions we cannot say which is forward and which is backward, only that they are opposite. Therefore, for any pair of opposite-time-direction points, a form of local time reversal invariance applies. The physics is completely unchanged if we exchange the points, so possibilities 1 and 2 above are indistinguishable states in the quantum mechanical sense: they are the *same* state.

This means that there is only one state in which the two points are at different positions. However, there are two states in which they can be at the same position: both at x_1 or both at x_2. The probability of finding them at the same position (2/3) is higher than the probability of finding them at different positions (1/3). This is just what happens for indistinguishable bosons. In other words, *two opposite-time fermionic points obey Bose-Einstein statistics and seem to attract each other like bosons*. This attractive "force" is not the same as gravity; it is an additional force: *electromagnetic attraction*.

If we now reverse the local time direction of one of the points, this effect is reversed in time. The points attract each other *backward in time,* that is, they repel each other. This "force" is not the same as degeneracy pressure; it is an additional force: *electromagnetic repulsion*.

The electromagnetic force is a close relative of gravity. Gravity results from the coupling of the fermionic spacetime field to the bosonic spacetime field, which attracts itself. In the case of electromagnetism, the fermionic field attracts or repels itself as if it were itself bosonic. The two forces are both components of the same bosonic attraction. Gravity depends on the phase of the wave function and electromagnetism is independent of the phase.

What happens if two fermionic points with opposite time directions meet? This is permitted, even though they are fermions, because they are not in exactly the same state. Two fermions with opposite spins can also occupy the same position. In such cases, the fermionic points do not form a bound state, so they remain fermions and repel any additional fermions that come along. So we have fermionic points with opposite local time directions attracting each other and pairing up (on the average) while remaining fermionic. In the inflaton spacetime model, the result of this behavior is a symmetrical fermionic spacetime field in which each occupied position has a combination of a positive-time point and a negative-time point. Thus, fermionic spacetime is *time-neutral*.

When there are no particles present in spacetime, all points are indistinguishable and none of this spacetime activity is observable. When particles are present, the symmetry of spacetime is broken, and the result is the electromagnetic force.

A *matter* particle is a resonance or excitation of a positive-time or forward-time fermionic point. An example is the electron, which by convention, is negatively charged. *Electromagnetic charge is simply a number proportional to the local time rate of a point or particle.* An *antimatter* particle or *antiparticle* is a resonance of a negative-time or backward-time point. Antiparticles are oppositely charged but otherwise identical to particles. Richard Feynman correctly described antiparticles as particles going backward in time. Time reversal reverses charge, turning a particle into an antiparticle.

Like their underlying spacetime points, particles with opposite charges attract and particles with equal charges repel. However, when a particle and an antiparticle meet, the result is different from the meeting of two fermionic points. There can be only one resonance at a position, so when a particle meets an antiparticle, they annihilate and the resonance is coupled into the bosonic spacetime field as two photons moving in opposite directions with the speed of light. In effect, local time $t(x) = 0$ for the combined resonance, and we know from special relativity that when the local time of an object stands still, it means that the object is moving at the speed of light. Here we actually get two real photons moving in opposite directions at the speed of light.

Thus, like gravity, the electromagnetic force is latent in spacetime. With one particle present, nothing happens, but the latent force becomes a *potential* force. With two or more particles present, the force is real. In the Standard Model, the electromagnetic force is carried by gauge bosons—virtual photons—that are not observed. They are not observed because the force is actually a result of the law of spin and statistics. *Transitions* between electromagnetic states result in real photons propagating through space as radiation in the form of light, radio waves, etc.

We can examine Coulomb's law of electrostatic force in the light of the inflaton spacetime model as we did Newton's law for gravity. Coulomb's law says that the repulsive potential energy between two electrons a distance r apart is $\alpha(\hbar c/r)$, where α is a coupling constant. We interpret α as the boson-like coupling of the fermionic spacetime field to itself and $\hbar c/r$ as a massless gauge boson, which we know as the photon.

A reason has long been sought for the similar forms of Newton's and Coulomb's laws. The inflaton spacetime model shows why they are similar. Both forces are manifestations of the bosonic self-attraction of the law of spin and statistics. For this same reason, Coulomb's law, like Newton's law, does not hold down to $r = 0$. At close range, we don't see a force, but only statistical tendencies.

The coupling constant α is proportional to the square of the electric charge e. The probability of an electromagnetic interaction between two points or particles is e^2. As we will see when we discuss the electroweak force, e is equal to the weak coupling constant g times the sine of the Weinberg angle. The value of g is related to the vacuum expectation value of the electroweak Higgs field.

The inflaton spacetime model also reveals why gravity is so much weaker than the electromagnetic force. A particle is a resonance of a spacetime point characterized by creation-time phase modulation. The resulting phase difference decouples that point from the bosonic spacetime field by a factor of m/m_{Pl}, where m is the mass of the particle. Thus, the gravity component of the bosonic self-attraction is very weakly coupled to particles. The electromagnetic component of the bosonic self-attraction is not affected by this phase difference.

Actually, for fermionic *points*, gravity is far stronger than electromagnetism, since the coupling constant for gravity is 1 while α is about 1/137. The smaller value of α may reflect the fact that the electromagnetic interaction is a *direct* interaction between fermionic points, which are *not* dense in spacetime, while the gravitational interaction is *indirect*, via the bosonic spacetime field, which *is* dense at the present epoch for all practical purposes. The direct-indirect difference also explains why the virtual gauge bosons that mediate these forces in quantum field theory have different spins. The photon has spin 1 (direct) while the graviton has spin 2 (indirect). Also, recall that there can be four points at each "position" in the fermionic lattice: two points and two *antipoints*. This is only possible because gravity is much stronger than electromagnetism for points, so the electromagnetic repulsion of like charges is overcome by the attraction of gravity.

The laws of electromagnetism were first written down by Maxwell. It is also now known that they can be derived from another local symmetry. The wave function of a particle is oscillatory because a particle is a point whose local creation time is phase modulated. The wave function is a complex-valued function of positions and time. It has a magnitude and a phase. *The phase of the wave function is the phase of the local time at a point with respect to the unmodulated local time at the point.*

The electromagnetic force between two charged particles does not depend on the phase of the wave function. Remember that it is gravity that is affected by the decoupling effect of the phase modulation, not electromagnetism. Electromagnetism is the part of the interaction between particles that depends only on the time directions or charges of the underlying points. The phase independence is reflected in the fact that the probability of finding the particle is the square of the magnitude of the wave function, a real number, as it must be. As a consequence, the wave function can be given an arbitrary phase rotation at each individual spacetime point without changing any probabilities or observed behavior. This is a local U(1) symmetry. It requires the electromagnetic potential to behave in a certain way. This symmetry is exploited in the standard model to derive the laws of electromagnetism, and it is often said that phase independence requires the presence of a potential, that is, a force between charged particles. The inflaton spacetime model shows that the potential is latent in the underlying spacetime behavior, while the symmetry principle reveals the laws that it must obey.

The phase of the wave function is not only a function of time. In the relativistic universe, space and time are coupled. Thus, a change in the spatial position of an object—either a translation or a rotation—is accompanied by a change of the phase of the wave function.

Notice that the pairing of forward-time and backward-time fermionic points provides a natural structure for the production of virtual particle-antiparticle pairs in otherwise empty spacetime, as is known to occur in the phenomenon called *vacuum polarization*. In reality, these virtual particle-antiparticle pairs are *unexcited point-antipoint pairs*.

The physical effects of local or global time reversal are complex. Both experiment and theory indicate that time reversal invariance is violated in some interactions. Earlier we saw that one direction of time always has more points and we defined this as the forward-time universe. However, for the simple case of two opposite-time fermionic points, local time reversal symmetry applies, resulting in the electromagnetic force.

Vacuum Energy Density and the Cosmological Constant

One of the major conundrums of modern cosmology is that the vacuum energy density today is zero or nearly so, while the quantum fluctuations of the vacuum, which are thought to have a wavelength equal to the Planck length, should contribute an energy density that is most logically estimated as the fourth power of the Planck mass, which is enormous. The idea that spacetime is filled with virtual particle-antiparticle pairs that constantly go into and out of existence unobserved but contribute to the vacuum energy also leads to estimates of the vacuum energy density that are in conflict with reality. The inflaton spacetime model, with its discrete spacetime, gives the right answer for the vacuum energy density—zero or nearly zero.

Let us first consider the virtual particle-antiparticle pairs. The existence of these objects is not in question. They cause vacuum polarization and they must be accounted for when computing interaction amplitudes. But what are they? They are simply unexcited point-antipoint pairs, which as we have seen, are everywhere in spacetime. The vacuum does not acquire any observable energy by virtue of being made up of such pairs.

The only observable contribution to the vacuum energy comes from the quantum fluctuations of the vacuum—that is, the zero-point energy—which is the energy resulting from the position indeterminacy and apparent random vibration of each spacetime point within its small volume of virtual space. If the diameter of this volume is the Planck length, 10^{-33} cm, then the particle-in-a-well model gives a zero-point energy for this system that corresponds to a particle having $\pi/\sqrt{2}$ times the Planck mass, $m_{Pl} = (\hbar c/G)^{-1/2}$, where G is Newton's constant. This leads to an energy density equal to about twice the fourth power of the Planck mass *for an individual point*.

In the inflaton spacetime model, each point's position uncertainty is an independent random variable. To find the vacuum energy density over large distances, areas, or volumes, the individual point energies must be summed. However, because these fluctuations are statistically independent, there is an *averaging* effect—the square root of the sum of the energies must be divided by the number of points in the region of interest. This results in a reduction of the resultant energy density by the number of points. In any large space region, and especially in the entire universe, the number of points is very large, so the vacuum energy density in these regions is virtually zero. This effect, noise reduction by averaging, is well known in the fields of instrumentation and communications. It will only work if spacetime is discrete.

It might appear that energy somehow disappears here, and that the vacuum does not respect energy conservation. This is not the case. The zero-point energies of all of the points are still there, but it is only their vacuum expectation value that counts, and this is near zero.

To find the zero-point energy in any volume of space, the single-point energy is multiplied by the number of points in the volume, and then divided by the same number to account for averaging. Thus, the vacuum energy in any volume of space is about the Planck energy, independent of the volume, provided that the individual point fluctuations are statistically independent. This amount of energy spread over any significant volume, such as the universe, gives an energy density that is very nearly zero. Actually, the individual point energies are not entirely independent since, being fermions, the points interact when they get too close to each other. This would make the vacuum energy in any volume of space larger, perhaps equal to several times the Planck energy, but still too small to be observed when spread over the entire universe.

Vacuum energy density is often equated with the cosmological constant Λ, and indeed, they have the same effect. The cosmological constant Λ is thought to combine with visible and cold dark matter to make the universe flat. In the inflaton spacetime model, the cosmological constant is actually a result of the inherent flatness of spacetime and not of the vacuum energy density, which is nearly zero over large distances. The other effect attributed to the cosmological constant, a small acceleration of the present expansion rate of the universe, is shown by the inflaton spacetime model to come from the expansion of spacetime as a whole, which continues to accelerate after inflation, but this acceleration is very small. Let's examine these points in more detail.

In the inflaton spacetime model, the number of spacetime points expands at an enormous rate. An initial inflationary period ends with a phase transition in which all matter is created. Elementary fermions (leptons and quarks) are excited fermionic spacetime points, that is, points that remain above their vacuum or ground state energy after the phase transition. After the phase transition and the mutual annihilation of particles and antiparticles, relatively few points are left with particles. Spacetime as a whole continues to expand, although much more slowly than during the inflationary period. At first the rate of expansion decelerates because of the gravitational attraction of the matter, but eventually it begins to accelerate as the matter density decreases and the accelerating expansion of the point creation process dominates. In this state of accelerating expansion the universe is continually driven to flatness. Thus, spacetime is always essentially flat regardless of the amount of matter in it. So, the cosmological constant is observed partly as an exotic form of energy—the accelerating expansion of the number of fermionic points—and partly as geometry: spacetime as a whole is essentially flat.

The Speed of Light and Massless Particles

The fastest possible speed in the inflaton spacetime model is $c = \Delta x/\Delta t$ = one space unit per time unit. This is the speed of light.

In an earlier section, we saw that some spacetime points travel at the speed of light. A massless particle, such as a real photon, is energy carried by such a point, that is, a difference between the creation time of the point and the global creation time. For a massless particle, this difference exists at any given position at only a single time point. For a massive particle, the creation time difference can remain at a position for more than a single time increment Δt. In other words, rest mass is energy localized at a point.

Because the presence of a particle at a point is signaled by a difference between the global and local creation times, the creation time interval with a particle present can be shorter or longer than the global creation time interval Δt. This means that for a particle to move one space unit per time unit when the time unit is less than Δt, the instantaneous speed can exceed the speed of light unless the space unit is also smaller than the global space unit. This is not a problem for bosons like the photon, since bosons can land anywhere, even on top of other bosons. However, it can be a problem for fermionic particles, which are restricted by the spacetime lattice to a fixed average space increment. Most massive fermions can simply occasionally remain at a point for an extra creation time interval to avoid exceeding the speed of light. However, neutrinos never remain at a point for more than one creation time interval. They are the fermionic analog of the photon. With the inflaton spacetime model as we have described it up to this point, a neutrino would travel at the speed of light on average, but would travel at less than this speed half the time and would exceed the speed of light half the time. Either a mechanism is needed to compensate for the possibility that neutrinos will instantaneously exceed the speed of light, or we must accept and explain this possibility. To compensate, for example, we could say that neutrinos actually travel at slightly less than the speed of light most of the time. This means that neutrinos would have mass. Recent experimental results seem to confirm that they indeed have mass. On the other hand, as we shall explain later, a neutrino that sometimes exceeds the speed of light can be useful in explaining the observed absence of right-handed neutrinos in nature.

This is a good place to point out the difference between gauge photons and real photons, and between gauge gravitons and real gravitons. Gauge particles, as we have seen, are really the law of spin and statistics at work. They are virtual particles, never observed. Real particles, on the other hand, transmit energy through space. Real photons are excited bosonic spacetime points. They travel at the speed of light; in fact, they are light, that is, electromagnetic radiation. Real gravitons we have not met before, and they are not actually particles. They are distortions of the fermionic spacetime lattice. They carry energy away from such systems as inspiraling binary star systems, and they propagate through space at the speed of light. For many years the existence of such gravitational radiation was controversial, but it is now accepted as real and experiments are under way to detect it. In the inflaton spacetime model, there is no doubt that gravitational radiation exists.

Weak Isospin

When we first introduced the inflaton spacetime model, we showed how the undefined spatial orientation of individual points leads to the concept of spin. Actually, the local spacetime of each point is four-dimensional, with time as the fourth dimension. In the inflaton spacetime model, local time is independent of global time and the local time axis has an undefined orientation with respect to the global time axis. Thus, the four-dimensional local spacetime of each individual point has an undefined orientation with respect to the global spacetime, so the spin of individual points is really four-dimensional.

We can model local spin as a pair of three-dimensional spins: one entirely spatial and the other involving time. The first is ordinary spin and the second is what is called *weak isotopic spin* or *weak isospin*.

In reality we never see points, we only see particles, and in fact, we observe that there are two kinds of electrons: those with spin only, and those with both spin and isospin. Those with spin only are called *righthanded* or *helicity +1/2* and those with spin and isospin are called *lefthanded* or *helicity -1/2*. Helicity is related to the spin in the direction of motion of the particle. Actually, helicity and handedness are not the same. We can change the apparent helicity of an electron simply by overtaking and passing it. This will cause it to appear to stop and then reverse its direction of motion, which reverses its helicity if its spin direction remains the same. To be correct, we can only speak of probabilities. An electron with negative helicity is in a lefthanded state with probability (1/2)(1 - v/c), where v is the electron's velocity and c is the velocity of light. In practice, however, most authors choose to ignore this confusing point and treat helicity and handedness as if they were the same. I will follow this practice.

Spin is defined in x-y-z space and can be described by three angular momenta defining rotations in the x-y, y-z, and z-x planes. Similarly, isospin is defined in x-y-t, y-z-t, or x-z-t space. We are going to be concerned not only with angular momenta, but also with rotations or angular differences between the local coordinates at a point or particle and the global or observer’s coordinate system. Since the choice of coordinates is somewhat arbitrary, when we look at any individual point or particle we can choose the direction of motion of the point or particle as the local z-axis, and we can choose the observer’s z-axis (ours) so that it lies in the same direction. Then we only have to consider differences in the x-y-t space. With this choice, isospin can be described by three angular momenta defining rotations in the x-y, x-t, and y-t planes. Spin has components J_x, J_y, and J_z describing the angular momenta around the x, y, and z axes (with angular momentum vectors directed along the x, y, and z axes). Weak isospin, or just isospin, has components I_1, I_2, and I_3 defined similarly.

The uncertainty principle prevents simultaneous knowledge of all of these components. The total spin J and one spin component, and the total isospin I and one isospin component can be known simultaneously. Usually the components chosen are J_z and I_3, the spins around (directed along) the z and t axes. For fermions like electrons and neutrinos, J = 1/2 and $J_z = \pm 1/2$, and either I = 0 or I = 1/2 and $I_3 = \pm 1/2$. Righthanded electrons have $J_z = +1/2$ and I = 0. Lefthanded electrons have $J_z = -1/2$ and $I_3 = -1/2$. Lefthanded neutrinos have $J_z = -1/2$ and $I_3 = +1/2$. There are no righthanded neutrinos.

If a particle has isospin it cannot have the same spin as a particle with spin only. Because the x-y plane is shared, isospin rotations change spin. But spin is quantized such that electrons can only have either spin +1/2 or spin -1/2. Therefore, one helicity value identifies spin-only or righthanded electrons and the other helicity value identifies spin-with-isospin or lefthanded electrons. Choosing the x-y plane as the plane shared by spin and isospin is consistent with characterizing spin as helicity with the z direction being the direction of motion.

Weak isospin is a local SU(2) symmetry. When applied to a fermionic spacetime point, a weak isospin rotation can turn a stationary point (local t = t(x) = global t) into a point moving at the speed of light (local t = t(x) = 0, since according to special relativity, a clock moving at the speed of light relative to an observer appears to that observer to stop). Conversely, a weak isospin rotation can turn a point moving at the speed of light into a stationary point. Thus, this symmetry has two eigenvalues. Observation of a fermionic point, were it possible, would always result either in a stationary point or a point moving at the speed of light. Quantum mechanics also permits points to be in a mixture of these two eigenstates, so they can appear to be moving at any velocity. Since points are indistinguishable, none of this activity is seen when there are no particles present.

If the points have particles, an electron can be turned into a neutrino by an isospin rotation. Thus the lefthanded electron and its neutrino are an SU(2) doublet: the laws of physics consider them the same particle. The neutrino has the same helicity as its electron—lefthanded. There are no righthanded neutrinos, and the righthanded electron is considered a singlet.

Notice that a weak isospin rotation represents a rotation of the local time axis with respect to the global time axis. Time-axis anomalies or mismatches represent charges. Points or particles that are affected by isospin rotations are said to have weak charge, which is different from electromagnetic charge. There are three kinds of weak charge, each corresponding to one of the three isospin rotation planes.

It is puzzling that there are no righthanded neutrinos, since there is no reason why spacetime points should not all have isospin. If there are lefthanded and righthanded stationary fermionic points, there should be lefthanded and righthanded fermionic points moving at the speed of light. Both lefthanded and righthanded bosonic points and bosons moving at the speed of light are known to exist. Why are fermionic points different?

The answer may be that fermionic *points* are not different, but fermionic *particles* are. The reason is related to our earlier observation that, in the inflaton spacetime model, a neutrino might exceed the speed of light half the time, even though its average speed is equal to the speed of light. Suppose we are riding a photon on a parallel course with a neutrino. We would see the neutrino alternately fall behind us, then pass and go ahead. Every time it passes us, we see its helicity change. If neutrinos really alternate helicities in this way, *a righthanded neutrino can be the same particle as a lefthanded neutrino!* When it is lefthanded, the neutrino travels at less than the speed of light and therefore has mass. When it is righthanded, the neutrino is a tachyon, a faster-than-light particle. Such a particle cannot be changed into a stationary particle (an electron) by an isospin rotation. This may explain why the righthanded electron is an SU(2) singlet and we don't see righthanded neutrinos. They exist—every neutrino is righthanded part of the time and lefthanded part of the time—but when righthanded, neutrinos are sterile and don't interact with anything.

The Electroweak Higgs Mechanism

When applied to the fermionic spacetime points, the weak isospin rotations set up potential energy that affects the fermionic spacetime field through its coupling to the bosonic spacetime field, which attempts to move all points into the same state. Thus, two fermionic points with different isospin rotation angles will try to get into the same state, as bosons do. This can be viewed as the exchange of virtual particles or *gauge bosons*. In fact, it is not an exchange of particles nor is it a real force. It is Bose-Einstein statistics at work, that is, it is the law of spin and statistics. However, it is useful to think of fermionic points as exchanging virtual particles. There are three kinds of these virtual particles, one for each kind of weak charge. This is consistent with the general rule that when there is a local symmetry involving N particles, there will be $N^2 - 1$ gauge bosons. However, these bosons are supposed to be massless, while the bosons that mediate the weak force are known to be massive.

To explain why these gauge bosons are massive, the Standard Model[6] postulates the existence of a scalar field ϕ that is an SU(2) doublet consisting of two spin-zero fields ϕ^+ and ϕ^0 which are related by an SU(2) rotation (like the electron and the neutrino) and are both complex fields:

$\phi^+ = (\phi_1 + i\phi_2)/\sqrt{2}$

$\phi^0 = (\phi_3 + i\phi_4)/\sqrt{2}$.

The nature of this field is unknown. It is assumed to exist because it gives the right answers. The inflaton spacetime model allows us to identify this field, verifying that it does indeed exist. That particle physicists could postulate the existence of such a field without knowing whereof they were speaking is testimony to the power of symmetry principles in physics.

The field ϕ is called the electroweak Higgs field. In the inflaton spacetime model it is similar to the field that controlled inflation, which was a measure of the mean free path of a fermionic spacetime point. In other words, that field was a structural parameter of fermionic spacetime, a measure of the interval or separation between points in x-y-z space.

The electroweak Higgs field is also a kind of interval or separation between points, but in x-y-t space. It represents the four degrees of freedom in which the local spacetime orientation can differ from the global spacetime orientation.

We have seen that points can be stationary or moving at the speed of light. Let's call these 0 points and c points, respectively. The field ϕ^+ is a charged field characterizing the 0 points (local t = global t). It consists of ϕ_1 and ϕ_2, which are the phase differences or rotations between the local x-t and y-t planes and the global x-t and y-t planes. These fields are charged because the time axis is involved.

The field ϕ^0 is an uncharged field consisting of $\phi_{3,}$ which represents the c points (local t = 0) and ϕ_4, which is the local x-y phase difference from the global x-y orientation.

The potential energy of the field ϕ has a minimum, just like the potential energy of the inflaton. In the standard model, the effective potential is written as:

$V(\phi) = \mu_2{}^2\phi^\dagger\phi + \lambda_2(\phi^\dagger\phi)^2$,

where $\phi^\dagger$ is the Hermitian conjugate of ϕ and:

$\phi^\dagger\phi = (\phi_1{}^2 + \phi_2{}^2 + \phi_3{}^2 + \phi_4{}^2)/2$.

If λ_2 is positive then $\mu_2{}^2$ is negative. Just as for inflation, this potential is for a scalar particle field and doesn't accurately depict degeneracy pressure, so it isn't ideal for the inflaton spacetime model. However, the basic concept is valid: the potential $V(\phi)$ has a minimum that is not at $\phi = 0$ but at $\phi^\dagger\phi = -\mu_2^2/2\lambda_2 = v^2/2$. In the standard model, v is called the *vacuum expectation value of the Higgs field*. (That the conventional choice of symbol for this quantity is v is unfortunate because of the potential for confusion with velocity. I will try to be careful to make it clear what is meant whenever I use the symbol v.)

The field ϕ evolves to $v/\sqrt{2}$, where its potential energy is minimized. At this point the fields ϕ_1, ϕ_2, ϕ_3, and ϕ_4 can have any values as long as $(\phi_1^2 + \phi_2^2 + \phi_3^2 + \phi_4^2)/2 = v^2/2$. In other words, we are free to choose a gauge, and in the standard model the choice is $\phi_1 = \phi_2 = \phi_4 = 0$ and $\phi_3^2 = v^2$. This choice is possible because the SU(2) symmetry allows any arbitrary choice of the four fields to be rotated into this form.

With this choice of gauge, *ϕ_3 is now the average energy associated with a fermionic spacetime point*. It is a measure of the ratio of 0 points to c points. If all points are c points, v is zero. If all points are 0 points, or stationary points, v is approximately the Planck energy. In other words, the value of ϕ_3 averaged over some volume is a measure of the density of 0 points in that volume. Because an energy of zero is lower than the Planck energy, the field ϕ_3 feels a potential energy that tends to make all points c points, or speed-of-light points. However, if *all* fermionic points are c points, by the uncertainty principle no point has a well-defined position, and spacetime looks something like a Bose-Einstein condensate. In other words, the fermionic points don't behave like fermions, they behave like bosons. Therefore, at least *one* fermionic point *must* be a 0 point. In other words, the potential energy of the Higgs field has an infinite wall, or delta function, at $\phi_3 = 0$, so the field feels degeneracy pressure similar to what we saw in the inflation process.

It has been determined experimentally that v = 246.222 GeV, which implies that there is one stationary fermionic point (with energy of the order of $\pi/\sqrt{2}$ times the Planck energy, 1.2211×10^{19} GeV, and zero velocity) for about every 1.1×10^{17} relativistic points (with zero energy and velocity c, the velocity of light). Various combinations of these eigenstates form points that move at less than the speed of light, so that resonances of these points are massive. Thus, fermions can have mass precisely because the Higgs field has a vacuum expectation value that is not zero.

Let's look at this important point in more detail. Mass is defined as a measure of inertia or resistance to acceleration. Resistance to movement and having a known or fixed location are really the same thing. For an elementary fermion (lepton or quark), mass can be calculated as the inverse of the precision with which the location of a stationary particle can be known. The vacuum expectation value of the Higgs field is a measure of the ratio of speed-of-light fermionic points to stationary fermionic points, which turns out to be about 10^{17}. This ratio limits the precision with which a stationary point can be located. If the vacuum expectation value of the Higgs field were equal to the Planck energy, all points would be stationary, electrons would have the Planck mass, and nothing could move. If the vacuum expectation value were zero, all points would move at the speed of light, only neutrinos would be possible, and nothing could stand still. Because the potential energy of the Higgs field has a delta function at $\phi_3 = 0$ and the field settles at a value of v closer to zero than to the Planck energy, the electron has a very small mass and things can move relatively freely in spacetime. Later, in “Masses and Coupling Constants,” we will calculate the electron mass based on these principles.

When we "gauge away" the fields ϕ_1, ϕ_2, and ϕ_4 and the field ϕ_3 acquires a vacuum expectation value, the local SU(2) isospin symmetry is said to be *spontaneously broken*. The Goldstone theorem says that we create three massless bosons, one for each of the zero fields. These combine with the three massless gauge bosons of the local SU(2) symmetry to form three massive gauge bosons. There is also a massive Higgs boson corresponding to fluctuations or oscillations of the field ϕ_3 around its vacuum expectation value. If we knew the frequency of these oscillations we would know the mass of the Higgs boson.

The Higgs boson has not been detected, but is thought to be detectable. In earlier versions of this work, I too thought that the Higgs boson was detectable. Now, however, it seems clear to me that the Higgs bosons may not be detectable at all, although they are most definitely there. More later.

The Electroweak Force

In the standard model, the Weinberg-Salam theory of the electroweak force requires that the vacuum has a symmetry described by the SU(2)×U(1) group of transformations. The weak isospin SU(2) symmetry treats the lefthanded electron and neutrino as a doublet and requires three massive charged bosons: W^1, W^0, and W^2. The U(1) symmetry treats the electron as a singlet and requires one massless boson: the B photon. These particles are never observed. What are observed, albeit indirectly, are combinations or superpositions of these particles: the W^- boson, the W^+ boson, the Z^0 boson, and the electromagnetic photon, γ. The weak force is mediated by the W^-, Z^0, and W^+ bosons, evidence for all of which has been observed in weak interactions. The electromagnetic force is mediated by the photon.

When an electron or neutrino undergoes a weak interaction, the phase of its wave function changes. This phase change represents a rotation of the particle (actually, the point of which it is a resonance) in one of the isospin planes. An interaction causing a rotation in the x-y plane can viewed as an exchange of a W^0 particle. Similarly, rotations in the y-t and x-t planes can be viewed as an exchange of W^1 and W^2 particles, respectively. A rotation through an angle α in any of these planes changes the phase of particle wave functions:[7]

Rotation Plane	Particle Exchanged	Phase Change e_R	e_L	ν_L
x-y	W^0	0	$-\alpha/2$	$\alpha/2$
y-t	W^1	0	mix	
x-t	W^2	0	mix	

Two of the rotations mix the electron and neutrino states, that is, they can turn one type of particle into the other. The W^1 and W^2 particles are charged, because they represent time anomalies. The W^0 particle is not charged. All three are virtual particles. These are the gauge bosons of the local SU(2) symmetry made massive by the spontaneous breaking of this symmetry.

The W^+, W^-, Z^0 and γ (photon) particles are mixtures of these three states and the B, as follows:

$W^+ = (W^1 + iW^2)/\sqrt{2}$

$W^- = (W^1 - iW^2)/\sqrt{2}$

$Z^0 = W^0\cos\theta_W + B\sin\theta_W$

$\gamma = B\cos\theta_W - W^0\sin\theta_W$,

where θ_W is the Weinberg angle.

The W^+, W^-, and Z^0 are massive. The W^1, W^2, and W^0 bosons are left massless by the electron-neutrino SU(2) symmetry, but acquire mass during the spontaneous breaking of the symmetry. In the standard model they are said to take up the three Goldstone bosons created by gauging away the fields ϕ_1, ϕ_2, and ϕ_4. The Goldstone bosons become the longitudinal polarization states of the gauge bosons. In the inflaton spacetime model, things are simpler. The vacuum expectation value v of the Higgs field gives a measure of how far apart the stationary fermionic points are at any instant, and since any charge-changing weak interaction must involve one of these points, the range of the weak force is inversely proportional to v. If v were zero the range would be infinite and the gauge bosons would be massless. But v is not zero, and this makes the weak interactions short-range, consistent with the exchange of massive bosons.

The mass of the W bosons is proportional to v, that is, $m_W = gv/2$. The proportionality constant g is related to the distribution of stationary fermionic points about an arbitrary point and is about two-thirds, so that $m_W = 81$ GeV. We will estimate m_W based on the inflaton spacetime model in the next section.

There seems to be some confusion among physicists on the way in which the Higgs field makes fermions such as the electron massive. As we have seen, it is the vacuum expectation value of the Higgs field that does this by making the distance between fermionic 0 points finite. Somehow, physicists have acquired the idea that mass results from coupling of the other particles to the Higgs particle such that the Higgs boson exerts drag on the other particles, causing them to move at less than the speed of light. This picture is incorrect. The Higgs bosons have nothing to do with mass. Mass is determined by v. We will say more about this in the next section.

As mentioned above, the photon and the Z^0 are seen as combinations of the W^0, which is now massive, and the B photon, which comes from the U(1) symmetry that governs the electromagnetic force. The photon remains massless in all of this because the Higgs field is neutral. Like the photons that mediate the electromagnetic force, the W and Z bosons are virtual and are never observed directly. They are part of the symmetry-imposed laws that must be obeyed by weak interactions. Thus, once again, the inflaton spacetime model exposes the underlying spacetime behavior while the standard model applies symmetry principles to deduce the physical laws. The weak coupling between weakly interacting particles is, once again, the law of spin and statistics in disguise.

Masses and Coupling Constants

For an elementary fermion (lepton or quark), mass is the inverse of the precision with which the location of a stationary particle can be known. For a composite particle such as a baryon, mass is mostly binding energy (gluons), the masses of the elementary constituents (quarks) contributing very little to the baryon mass. For a massive gauge boson, mass is the inverse of the range of the force carried by the particle.

The Electron. In the standard model, the mass of the electron is given by:

$m_e = G_e v/\sqrt{2}$,

where m_e is the electron mass, G_e is a coupling constant of unknown origin, and v is the vacuum expectation value of the Higgs field. Since we know v and m_e experimentally, we know that the value of G_e is 2.935×10^{-6}. We would like to calculate G_e starting from the inflaton spacetime model, or if an exact calculation is beyond us, at least show that the inflaton spacetime model gives answers that are of the right order.

According to our particle model, we need to find a G_e such that the zero-point energy of a stationary spacetime point is equal to the electron rest energy. This is because the first excited state of a point in an infinite potential well has energy equal to twice the zero-point energy. Half of this is the zero-point energy and the other half is the electron rest energy.

The energy of a point in an infinite potential well is proportional to the width of the well. Our analysis of inflation and gravity led us to infer that the granularity of postinflation spacetime is about the Planck scale, that is, the spacetime points after inflation are about the Planck length apart, or $l_{Pl} = 1.6160\times10^{-33}$ cm. This means that a rough estimate of the effective width of the well confining each point is about $2l_{Pl}$. The volume of the well is proportional to the cube of its width, so the energy is proportional to the cube root of the well volume.

Because of quantum effects, an exact calculation of the effective well volume, and therefore the point energy, would be difficult. However, we can conjecture, based on our estimate of the well width and the assumption that the well is spherical, that the zero-point energy of a single point is of the order of $\pi/\sqrt{2}$ times the Planck energy, where $E_{Pl} = 1.2211\times10^{19}$ GeV.

This would be a good estimate if all points were stationary, but the vacuum expectation value of the Higgs field, v, tells us that there is only one stationary point for about 1.1×10^{17} relativistic points with approximately zero energy. This implies two things: first, the average energy per arbitrary point is v = 246 GeV, and second, the energy of each stationary point is spread over a volume of about 10^{17} point wells. Since we don't know where in this volume the stationary point is located, by the uncertainty principle the effective energy of a stationary point is reduced by the cube root of the ratio of the vacuum expectation energy v to the original point energy $(\pi/\sqrt{2})E_{Pl}$ (that is, the cube root of the volume ratio). Thus, we have:

$m_e = [v/(\pi/\sqrt{2})E_{Pl}]^{1/3}(v) = 0.513\times10^{-3}$ GeV.

The measured value is $m_e = 0.511\times10^{-3}$ GeV.

W Boson. According to the standard model, the mass of the W boson is:

$m_W = gv/2 = 81$ GeV,

where g is an experimentally determined coupling constant. We would like to calculate m_W based on the inflaton spacetime model, or at least show that the inflaton spacetime model gives a reasonable approximate answer.

In a charge-changing weak interaction, an electron and a neutrino (or antineutrino) change identities, exchanging a W boson. How far does the W boson have to travel, on average, in such an interaction? Let's say a neutrino turns into an electron. To complete the interaction, an electron must be found to change into a neutrino. What is the expected value of the distance to the nearest electron, given that there is one stationary point for every 1.1×10^{17} points? In a weak interaction, the momenta of the entering particles determine the direction of travel of the W boson, so we are looking for the distance from a random starting point to the first stationary fermionic spacetime point in a predetermined direction. A reasonable guess is that the distance has a Gaussian distribution around the starting point, the average distance to the first stationary point being the standard deviation of this distribution. The standard deviation would be equal to the range, or Compton wavelength, of a particle with a mass equal to v. In three standard deviations, the probability of finding a stationary point should be close to 1. If we then estimate the expected range or Compton wavelength of the W boson as three standard deviations then our estimate of m_W is $v/3 = 246/3 = 82$ GeV, close to the measured value of 81 GeV.

Higgs Boson. The electroweak Higgs boson is the only standard model particle that has not been seen experimentally. Its mass is not predicted by the standard model. The most likely value based on all experimental data gathered to date is said to be about 89 GeV with a large uncertainty of +38 and -28 GeV. This is in a mass range that has already been excluded by accelerator experiments. Other estimates place the Higgs mass between 114 and 170 GeV or so. The upper end of this range also appears to have been excluded.

As explained above, in the inflaton spacetime model Higgs bosons are not really particles but fluctuations in the local value of the electroweak Higgs field, which is a scalar field that represents the average energy of a fermionic spacetime point, imputing an energy of approximately the Planck energy for a stationary point (0 point), and zero for a speed-of-light point (c point). The fluctuations occur as spacetime seeks the vacuum expectation value v of the Higgs field by changing stationary points to speed-of-light points and vice versa, thereby ensuring that the ratio of speed-of-light points to stationary points is approximately E_{Pl}/v, where E_{Pl} is the Planck energy.

The vacuum expectation value v represents the average energy of a point when the Higgs field is at the minimum of its potential energy. It reveals the ratio of 0 (stationary) points to c (velocity of light) points. It is uniform throughout spacetime to an extraordinary degree. For example, every electron, no matter where or when it is observed, has exactly the same mass within experimental accuracy.

Spacetime is like a plasma of negative charges embedded in a sea of positive charges. In spacetime, stationary points are embedded in a sea of velocity-of-light points. Just as a plasma acts to equalize the distribution of negative charges, spacetime acts to equalize the distribution of 0 points to maintain the value of v. If there are too many stationary points in a local area, so that $\phi_3 > v$, interactions between points occur that change 0 points to c points, and conversely. Such excesses and deficiencies can occur in the forward-time spacetime, the backward-time spacetime, or both.

Such fluctuations occur constantly, but we do not see them unless there are particles involved. When a 0 point changes to a c point and a particle is present, we see, for example, an electron change to a neutrino. At another point, a matching pair of particles is created: an electron and an antineutrino. Thus, the excess 0 point at one location is moved to another location that had a deficiency of 0 points. These interactions *between particles* are seen as an exchange of $W^{\pm}$ bosons.

Earlier in this paper, we estimated that the average distance between fermionic spacetime points after inflation is approximately the Planck length. We've also estimated that there are about 10^{17} c points for every 0 point. For a rough estimate of the density of 0 points, let's assume that each point, 0 or c, occupies a volume equal to the cube of the Planck length, about 10^{-33} cm. Then there is one 0 point for every 10^{17} point volumes, or approximately $10^{17}(10^{-33})^3 = 10^{-82}$ cm^3. Thus, there are about 10^{82} 0 points per cm^3! In other words, there could be a deficiency or an excess of millions of 0 points in a very small volume of space and the percentage change in the vacuum expectation value of the Higgs field would be so small as to make the fluctuation unobservable! The bigger the volume of space, the less likely it is that any variation in v will be detectable, but even at subnuclear scales, say in a volume of $(10^{-15}\ cm)^3$, there are 10^{37} 0 points on average, and an excess or deficiency of, say, 10^7 points is only a variation in v of 10^{-28} GeV. Our conclusion, then, is that the vacuum expectation value of the Higgs fiend is essentially independent of when, where, or over what volume it is measured. The fluctuations of the Higgs field are exceedingly small in amplitude. It therefore seems that Higgs bosons are exceedingly scarce, so scarce as to make it highly unlikely that the LHC will see them above the background processes.

What can we say about the Higgs mass? Since we don't know the shape of the potential energy, we can only make a very rough estimate. Just because it seems reasonable to me, let's assume the potential is triangular, that is $V(\phi_3) = A\phi_3$, where A is some constant, and there is an infinite barrier at $\phi_3 = 0$. The wave function for the field is then proportional to the Airy function. The first energy level, which represents the expectation value plus the Higgs mass, is proportional to the first zero of this function, or -2.338. We can't calculate the energy directly, since we don't know what A is, but if we can find a similar number for the expectation value, which we know is 246 GeV, we can use a simple ratio to estimate the energy. The mean value for this wave function differs from the first zero by 1.57. Dividing 2.338 by 1.57 and multiplying by 246, we get a value for the minimum energy of 366 GeV. Thus, we can speculate that the Higgs mass might be somewhere in the neighborhood of 366 - 246 = 120 GeV. Both the LHC and the Tevatron are capable of exploring this region, but as we have seen, it is unlikely that there are many Higgs bosons to be found.

Quarks, Baryons, QCD, and the Strong Force

We have shown that fermionic spacetime consists of a quantum lattice with two pairs of points in each lattice cell. One pair consists of a forward-time point and a backward-time point or antipoint, and the other pair is a similar pair with opposite spins. Thus, each position in spacetime holds a *point quad*. These points do not form bound states, and do not annihilate.

Since spacetime points are indistinguishable, quantum mechanics requires that we take into account all possible ways in which such point quads and individual points can be formed. For most purposes, we can think of any given point as having a certain spin and time direction. However, this need not be the case. Just as points are mixtures of fermionic and bosonic states, we also must consider them mixtures of spin up and spin down states, and of forward-time and backward-time states. *Points are completely indistinguishable.* The points of a given point quad do not have to be the same four points at every instant, and points do not have to remain at one position. We have already seen that some points move at the speed of light. A spacetime of stationary and relativistic points is indistinguishable from a spacetime in which all points are stationary, so we must consider both.

Similarly, a point at a given position can be a mixture, or superposition, of point states of the same type, each with a certain probability of being found at that position, as long as the probabilities add up to 1. A "point" can also be a superposition of n points that are *never* at the same position. In particular, we can have superpositions of n points, where n = 2 and n = 3 are especially important.

Any possible spacetime arrangement must be considered, as long as it is indistinguishable from the basic spacetime of point quads. Just as it forces us to consider radiative corrections in QED, quantum mechanics says that there is some probability that all possible position-occupancy patterns will occur. Of course, we see none of these different patterns unless there is a resonance (particle), because indistinguishable means just that.

Superpositions of n points at different positions are like *multiposition* points, or *points that have more than one position*. However, there are restrictions. There cannot be just one n-position point. A mixed state of n points must involve *n point quads* if spacetime is to remain indistinguishable from its canonical configuration in which each point occupies one position and there is a point quad at every position. To be as general as possible, one can think of an n-position point as just one point of an alternate vacuum in which every point is a mixed state of n single-position, or *pure*, point states.

Because there are many different indistinguishable patterns in which the fermionic spacetime can be organized, the inflaton spacetime vacuum is actually a superposition of many vacua. Each value of n defines a different vacuum. Many of these vacua are never observed because no particles exist in them. Only those in which particles exist are observed.

In a normal quantum mechanical superposition, wave functions of quantum mechanical entities are added with coefficients equal to the complex amplitudes for observing those entities. The squared magnitudes of the amplitudes are the probabilities for observing the corresponding entities, and the probabilities have to add up to one. In the inflaton spacetime model, we can have forward-time and backward-time points in the same superposition, and the local time rate can differ from the global time rate. In this case, the notion of probabilities runs into trouble—some of them can be negative. For points, it makes more sense to speak of time rates or charges.

Let's consider a superposition of three points. In the following example, the magnitudes of the entries are time rates. A value of 1/3 means that when the mixed point is observed, the point at that position will be observed on 1/3 of the local time ticks. A minus sign indicates a forward-time point and a negative charge. The time rate at each point is the magnitude of the electric charge in units of e. The notations up and dn indicate spin up or spin down.

Points (Positions)		
1	2	3
2/3up	**2/3dn**	**-1/3up**

The "local" time rate for this mixed point (if we can use the word "local" for a multiposition point) is the sum of the rates shown. One way to think of this is that for every observation of the forward-time point, one of the backward-time points will also be observed, so "local" time for the mixed point does not advance. Thus, the net "local" time rate is 1 and the charge is e. To the global observer, this looks like a spin-up composite object with a charge of e and three components that all exist at once.

A resonating multiposition point is a *multiposition particle*. If the bold entries in the above table represent resonances, we see that *a resonance of an n-position point can occur if it covers all n positions and all n points, if the charges add up to an integer (0, ±1, ±2), and the spins add up to a half-integer*. The bold entries in the above example would make a proton, and the partial resonances represented by the individual entries are quarks. Since they are only partial points, they are never found separately. Baryons and mesons are all multiposition particles like the proton.

Spacetime still has the structure to produce particle-antiparticle pairs when it is made up of superpositions of n points. There are nine other points in the same three point quads that are not shown in the above table. Three of these points would have the occupancy probabilities to form an antiproton resonance.

We can get all of the baryons in this way, and applying the same principles to two-point superpositions gives the mesons.

To summarize, in the inflaton spacetime model, hadrons (baryons and mesons) are resonances of what we can call multiposition points, which are superpositions of pure point states. *Thus, quantum mechanically, hadrons are point particles!* The subpoints in a multiposition point are in effect tied together, and their resonances are what we know as quarks. Because a multiposition point is a single entity, a resonance of such a point is a single particle, and its charge is quantized in multiples of e, the electronic charge. The subresonances appear to have quantum numbers (charge, spin, mass, etc.) that add up to those of the overall resonance. In particular, they have fractional charges. They can never be observed in isolation, however, because their behavior is only possible for a subresonance of a multiposition resonance.

Because the subresonances or quarks are parts of a single resonance, their total angular momentum must add up to the angular momentum of the particle they make up—a proton, for example. This means that they must orbit around each other, forming a single object with a single spin. Since they can go no faster than the speed of light, their maximum distance from each other is limited. As they approach the speed of light at this maximum distance, it takes more and more energy to accelerate them further. It would take an infinite amount of energy to accelerate them to this maximum distance, so it is impossible to separate them further. Thus, quarks are confined within hadrons by a *strong force* that gets stronger as the separation between quarks increases. In the standard model, quantum chromodynamics (QCD) is the theory of this strong force.

QCD makes accurate predictions based on a local SU(3) symmetry that rotates different quark "colors". Only colorless quark combinations are permitted, that is, combinations whose colors add up to white. In the inflaton spacetime model, quarks are subresonances of resonances of spacetime points that are quantum-mechanical superpositions of two or three basic spacetime points at different positions. Each of the two or three quarks making up a hadron is said to have a different “color” as a result of having a different point at a different position underlying it. The zero-color requirement is a least-action, stationary action, or minimum energy requirement. The points in a superposition are entangled. To satisfy the minimum energy condition, their positions must bear a particular relationship to each other. It seems a safe conjecture to say that this means that there must be geometric symmetry. Of course, these are quantum mechanical systems, so we can’t speak of exact positions but only of wave functions of positions. Geometric symmetry would say that on any observation the two quarks in a meson would always be diametrically opposite each other on a circle—that is, the wave function is circular — while the three quarks in a baryon would be symmetrically placed on a sphere—the wave function is spherical. The quarks are interchangeable, of course; hence the SU(3) symmetry.

In the case of baryons, it is obvious that a symmetrical arrangement of a red quark, a green quark, and a blue quark yields a white, or colorless, object. But mesons are made up of a quark and an antiquark of the same color. Where do the three colors come from? In fact, it was the experimental fact that the production rate of mesons was three times what was expected that led to the idea that there had to be another three-valued degree of freedom in the wave function. For mesons, the circular wave function lies in a plane that can be considered a superposition of three eigenplanes, say xy, xz, and yz. Thus, there are three ways to make a given meson out of a quark and an antiquark, so quarks must come in three colors.

The notion that zero color means geometric symmetry leaves open the possibility that colored hadrons may someday be produced in accelerators if the collision energy is high enough to knock the quarks into a lopsided configuration.

Proton Decay and Grand Unification

Is the proton stable? Grand unified theories (GUTs) predict that it can decay. For example, the two up quarks (charge 2/3) in the proton can exchange a Y particle (a new gauge boson predicted by GUTs) and turn into a positron and an anti-down quark. The proton then decays into a positron and a pion, which is an n = 2 particle consisting of a down quark and an anti-down quark.

In the inflaton spacetime model this interaction is possible, but very unlikely. The proton can exist in a number of states distinguished by the spin directions (up or down) of its constituent quarks. If the proton's two up quarks have opposite spins (possible) and happen to find themselves in the same position momentarily (possible but highly unlikely), they are indistinguishable from a positron and an antidown quark at that position at that moment. Thus, the proton can decay. The virtual Y particle they are said to interchange would have a range less that the Planck length and therefore would have a mass greater than the Planck mass, 10^{19} GeV. This would result in a proton lifetime orders of magnitude greater than predicted by GUTs, which set the Y mass at 10^{15} GeV or so. This puts the inflaton spacetime model's prediction in line with current proton lifetime measurements (proton decay has never been seen).

GUTs are out of favor these days partly because of their proton lifetime error. They also predict magnetic monopoles, which haven't been seen, and a lot of new Higgs fields. The proton error can be excused as an error in interpreting the theory and the monopoles would have been dispersed by inflation, so these aren't serious problems. What about the Higgs fields? Actually, the inflaton spacetime model has at least one new Higgs field. It is the field that assigns to any point at any time the value n of the vacuum to which the point belongs (in which n points share n positions). The n = 1 vacuum can be thought of as the electron vacuum. In this vacuum only electrons and neutrinos can remain after their antiparticles have been annihilated. If this were the only vacuum the universe would be negatively charged, clearly a higher energy state than a neutral universe. To make the universe neutral requires some protons, so there must be some points with n = 3. This can be thought of as the baryon vacuum. Baryon interactions require pions, so n = 2, the meson vacuum, is necessary. Thus, the new Higgs field has a potential that has a minimum when there is some mixture of vacua, and it has some vacuum expectation value at this minimum potential.

If there is one new Higgs field, there may be more. It thus begins to appear that the inflaton spacetime model may be compatible with grand unified theories such as the SU(5) theory of Georgi and Glashow.[8] Clearly these theories are worth another look.

Three Generations of Leptons and Quarks

Consider the following spacetime pattern, in which three points share three positions in such a way that a resonance can occur at one of the positions:

		Points		
		1	2	3
	1	**-1/3up**	**-1/3up**	-**1/3up**
Positions	2	-1/3up	-1/3up	-1/3up
	3	-1/3up	-1/3up	-1/3up

This pattern is forbidden in QCD because it doesn't meet the symmetry requirements. In the inflaton spacetime model, if points are indistinguishable, there is no reason why three points can't share three positions in this way, subject to the restriction that the points are in adjacent or nearly adjacent point cells of the lattice so they don’t exceed the speed of light at any time. This pattern is like a little eddy in spacetime, and it can happen in two ways. First, the points can simply move from position to position, in which case the only possibility for a particle resonance would be an electron or neutrino moving from position to position. Second, these three points can be quantum mechanical superpositions of each other. The pattern would look the same, but now a particle resonance could remain at a single position while the point located there is a mixture of pure points. What we are seeing here is a symmetry principle, but it is not the color symmetry of QCD, which applies only to multiposition resonances. *It is a dual symmetry.* The bold point pattern is indistinguishable from a single point at position 1 with local time rate -1. Notice that the spins of the component subresonances do not add as they do in QCD. *This symmetry requires that if three points are going to mimic a single point resonating at some position, they must all have the same spin, and their charges must add up to ±1.* The resonance corresponding to this point pattern would be identical to a single-point resonance except that its mass would be different. This pattern results in a much heavier resonance than in the single-point case because there is a great deal of binding energy involved. In fact, this resonance is a tau particle, while the single-point resonance is an electron.

The model for the muon is similar. It consists of just two points sharing two positions with charges -2/3 and -1/3. Clearly the electron pattern has no binding energy and therefore is the lightest lepton. The muon pattern involves two points and has some binding energy. The muon is heavier than the electron. The tau pattern has the most binding energy, even more than the proton, because the points involved are bound to resonate at a single position rather than three. In fact, the tau particle is almost twice as heavy as the proton and seventeen times as heavy as the muon.

So far, we have shown how the three generations of leptons, that is, the electron, muon, and tau particles, come to exist in the inflaton spacetime model. The corresponding neutrinos are the same resonances moving at the speed of light (but see the next section). We have also seen how the first-generation quarks—the up and down quarks—come to exist. The second and third quark generations are formed by applying the same principles to the muon and tau spacetime point patterns. Because the muon and tau patterns look like electron patterns from the outside (i.e., -1 resonances at a point), they can form superpositions of states according to the ±1/3, ±2/3 scheme to generate other hadrons that result in the second and third generations of quarks.

Neutrino Oscillations

When we discussed weak isospin and neutrinos, we saw that the neutrino can be seen as a particle whose speed oscillates sinusoidally around the speed of light. This is a classical picture that results from our choice of a gauge for our particle model. Quantum mechanically, the neutrino is a mixed state, having a 50% probability of being in a lefthanded state that travels at less than the speed of light and therefore has a mass, say m, and a 50% probability of being in a righthanded state that travels at more than the speed of light and has an imaginary mass im. The righthanded state does not participate in the weak interaction and therefore does not interact with other matter. It is *sterile*. That the neutrino is a mixture of two states with a mass-squared difference ($2m^2$ in this case) would imply that neutrino oscillations can occur. In this case, oscillations would occur between an active neutrino state and a sterile state. In fact, experiments show that active neutrinos do oscillate, but only to other active states and not to a sterile state.

The Super Kamiokande experiment provided proof that muon neutrinos oscillate with tau neutrinos, but apparently not with electron neutrinos, at least not very often. Sterile neutrinos seem to be disfavored by the data, so the effect described in the preceding paragraph can't account for the experimental results. In fact the oscillation with the sterile righthanded state would probably be much too fast to be seen in experiments. Now an experiment at the Sudbury Neutrino Observatory seems to have verified that electron neutrinos also oscillate, probably with muon or tau neutrinos. A sterile neutrino is disfavored. This electron neutrino oscillation is thought to explain the solar neutrino deficit, that is, why only about a third to a half of the expected number of solar neutrinos are actually observed. How does the inflaton spacetime model explain active neutrino oscillations?

As we said in the preceding section, electron, muon, and tau neutrinos are the corresponding lepton resonances moving at the speed of light. This sounds simple, but the reality is more complicated. Let's say an electron neutrino is created in a weak interaction. It is observed as a fermionic spacetime resonance moving at the speed of light. Is it a single point moving at the speed of light and resonating, or does the resonance move from point to point? It's impossible to say, so we must assume that both cases are possible. If the resonance moves from point to point, how can it be guaranteed that all of the points it touches are in the n = 1 spacetime? Recall that spacetime or the vacuum is a mixture of different vacua parameterized by an integer n. It is the n = 2 spacetime that gives us muons, and it is the n = 3 spacetime that gives us tau particles.

Nothing guarantees that an electron neutrino resonance will always occur on an n = 1 point, so we have to conclude that an electron neutrino must be a mixed state, that is, a resonance of a mixture of n = 1, n = 2, and n = 3 points, because spacetime itself is such a mixture. The ideal pictures of the electron, muon, and tau neutrinos, that is, resonances of n = 1, n = 2, and n = 3 points, respectively, moving at the speed of light, represent eigenstates of the system. However, these eigenstates are not the same as the electron, muon, and tau neutrino eigenstates. The electron, muon, and tau neutrino eigenstates are *flavor* eigenstates, while the n = 1, n = 2, and n = 3 eigenstates are *mass* eigenstates. Remember that the mass increases with n because of binding energy.

So here is the situation. For neutrinos, the flavor eigenstates are not the same as the mass eigenstates, and the flavor eigenstates are mixtures of the mass eigenstates (and vice versa, of course). This, with the mass squared difference, meets the conditions for neutrino oscillations in the most popular model. I won't go into the mathematics here because the current literature presents it very well. The inflaton spacetime model reveals the physical mechanism responsible for the neutrino oscillations that have been experimentally observed, and verifies that the most popular model is correct. The mixing angles and mass differences are being measured to better and better accuracy as time goes on.

Dark Matter

In the inflaton spacetime model, spacetime is a combination of fermionic and bosonic fields, which are coupled as a result of mixing, that is, as a result of each point's having some probability of being either a boson or a fermion on any given observation (time tick). The coupling gives the fermions some bosonic behavior: they feel the force of gravity. Now we want to consider some fermionic behavior that is imparted to the bosonic points as a result of the same coupling.

Fermions obey Fermi-Dirac statistics: there is zero probability that any two identical fermions can occupy the same position. The apparent force that keeps them apart is called *degeneracy pressure*. As a result, they form a lattice or Fermi gas, and because they are indistinguishable and spacetime looks the same whether they move or not, there is some probability that they do move. They have two velocity eigenvalues, zero (not moving) and the speed of light, c (moving). The vacuum expectation value of the electroweak Higgs field determines the ratio of 0 points to c points at any time tick. Over time, fermionic points can be mixtures of these two states, so they can have any velocity between zero and c.

How does the coupling to the fermionic field affect the bosonic field? In the absence of the fermionic field, the bosonic field would assume a minimum-energy configuration in which all bosonic points would be in the same quantum state and move at the speed of light. However, as a result of the coupling to the fermionic field, the bosonic spacetime field feels a kind of friction derived from the degeneracy pressure felt by the fermionic field, so on any time tick some of the bosonic points will not be able to move. Therefore, like the fermionic points, which have two velocity eigenvalues, zero and c, the speed of light, the bosonic points also have two velocity eigenvalues, 0 and c. The bosonic spacetime field has its own version of the Higgs field, which settles to some vacuum expectation value that determines the ratio of bosonic 0 points to bosonic c points.

The bosonic and fermionic fields differ when it comes to the ability of points or particles to move at velocities between 0 and c. Particles are points that are in a resonant state, above their ground state or zero-point energy. At the end of the inflationary period of the early universe, when the oscillations in the mean free path of the fermionic points decay into particles and radiation, some of the fermionic and bosonic points absorb this energy and resonate, forming particles. Particles are modeled as excited points whose excess energy above the ground state is vested in a creation time that oscillates around the global or observer's time ticks.

As explained earlier, fermionic spacetime is a lattice of point quads. Each quad consists of spin up and spin down forward-time points and spin up and spin down backward-time points. It doesn't matter which four points are in any point quad as long as they are the right kinds. The points need not have any special relationship to each other because, whether they do or not, spacetime looks the same. Thus, as spacetime takes a step forward in time and a step backward, the forward-time and backward-time images of a given point do not have to remain at the same position. It simply doesn't matter. When a point moves, there will always be a point of opposite type at its new position, guaranteeing that spacetime remains time neutral and charge neutral. A point or particle moving at an arbitrary velocity can therefore be modeled as a mixed state of 0 and c velocity eigenstates.

Bosonic spacetime does not form a point quad lattice. Points can have any position. For spacetime to remain time neutral, there must be a guarantee that when a bosonic point moves, it will not remain in any position for more than one time tick unless it is paired with an opposite-time point wherever it lands. In other words, speed-of-light bosonic points are acceptable by themselves, but to guarantee time and therefore charge neutrality, stationary bosonic points must be paired—every stationary forward-time bosonic point must be paired with a stationary backward-time bosonic point. The two points form a bound state—they are tightly coupled electromagnetically. Moreover, they must always have the same position. The position of such a pair can only change through quantum fluctuations, which means that it can move, but very slowly. In the bosonic spacetime field, neither points nor particles can be in a mixed state of 0 and c eigenstates. Only pure velocity eigenstates are possible. This is because the 0 eigenstate is a bound pair of forward-time and backward-time points, so it cannot mix with points in the c eigenstate, which are single, unpaired points. The degeneracy pressure affects only the paired, stationary points. Thus, the inability of the 0 and c velocity eigenstates of bosonic points to mix splits the bosonic spacetime field into two separate fields. The quanta of one are extremely sluggish and feel degeneracy pressure, while the quanta of the other all move at the speed of light.

Why don’t fermionic points form bound states? Any stationary point has an electromagnetic charge, so stationary bosonic points will immediately pair up, with opposite charges bound together by electromagnetic attraction. But any fermionic point is completely surrounded by oppositely charged points, so the net electromagnetic force on it is zero. Bosonic points, on the other hand, are mostly c velocity points, which are massless and chargeless, so those that are stationary are strongly attracted to any oppositely charged points that happen to be nearby.

The Sloton. A bosonic resonance can be a forward-time or backward-time resonance or both. A resonance or particle is identified by a creation-time difference between a point and the global or observer's time. If the resonance is of an unpaired forward-time bosonic point, it is a photon and the resonating point moves at the speed of light. It is indistinguishable from a resonance of an unpaired backward-time point moving in the opposite direction. Therefore, the photon is its own antiparticle.

If the forward-time and backward-time points of a stationary bosonic point pair resonate, they do it as a single unit because they constitute a bound state, and the resonance is a stationary particle with zero charge and zero spin. No such particles are known to exist. However, they are possible in the inflaton spacetime model because the forward-time and backward-time components of a stationary point are collocated, so they can resonate synchronously. This particle cannot move at all, except for quantum fluctuations of its position, which means that it can move, but very slowly.

The resonance of a bosonic stationary point pair is a particle that is related to the photon, since it is something like a bound state of a photon and an antiphoton. The photon has spin J = 1, and therefore should have three helicity states: J_3 = +1, 0, and -1. The photon and its antiparticle (itself) account for the +1 and -1 states. The 0 state is not known to exist because the photon always moves at the speed of light. If a photon were to have zero helicity it would have to be standing still. But this is just what the new particle does! Thus, we can conclude that here we have *the previously unknown zero-helicity state of the photon, which exists only in combination with its antiparticle* (the photon and the antiphoton are indistinguishable physically, but in the inflaton spacetime model they are different particles). The particle and antiparticle do not annihilate because they form a single resonance of a stationary bosonic point pair, and points do not annihilate like particles do.

Now we can suggest a name for our new particle. I will refer to it as the *sloton*, for "slow photon." It is a massive boson, has zero charge, acts like a zero-spin or scalar particle, interacts only gravitationally, and feels degeneracy pressure. It is very cold, that is, slow-moving, because it moves only by quantum fluctuations of its position, and it is obviously very heavy. It is a good candidate for the dark matter that is known to form massive halos around galaxies and clusters.[1] In fact, it is thought that these halos formed first, and galaxies formed within them. This would indicate that at the end of the inflationary period, when all particles were formed, there were quantum fluctuations in the sloton density that grew gravitationally to form large regions of greater and lesser sloton density.

Sloton Gravity. The sloton has very peculiar gravitational properties. It is a boson, so over time it will gravitate towards other slotons, but it does this very slowly, as if subject to friction. *It does not interact gravitationally with other types of particles*! Recall that gravity is the result of the bosonic spacetime points tending towards the same state (Bose-Einstein statistics) and dragging the fermionic spacetime points with them. This only happens if the points are indistinguishable. A bound state of a bosonic point and a bosonic antipoint is *not* indistinguishable from a single bosonic point. Thus, there is no gravitational attraction between these two types of points, and therefore, there is no gravitational attraction between slotons and other particles. At *long distances*, a sloton and a baryon or lepton will *seem* to gravitate towards each other because, as explained in "Gravity" earlier in this paper, gravity acts throughout spacetime but is unobservable until it is revealed by the presence of particles. Even the presence of a sloton will reveal that a baryon is attracted towards the region of space around the sloton. However, it is not attracted to the sloton itself. It just seems that way. At close range, it becomes obvious that there is no attraction between slotons and normal particles. Observationally, slotons would obey Newton's law when interacting with each other, but with other types of particles, their interaction would seem to obey Newton's law at long distances and decrease to zero at zero distance. If we look at gravity as an exchange of gravitons for ordinary matter, it would appear that dark matter particles exchange some other force carrier. Of course, in both cases it is the law of spin and statistics at work (along with the coupling of the fermionic and bosonic spacetime fields). A group of researchers has recently published a paper[9] that suggests that dark matter particles interact through a new force mediated by a new force carrier.

Dark Matter Halo Density Profiles

The existence of dark matter is inferred from measurements of the rotation velocity of gas and isolated stars far outside the luminous cores of galaxies. Here the rotation velocity at a distance r from the center of the galaxy, according to Newton's law, should be given by $v^2 = GM/r$, where G is Newton's constant and M is the mass of the luminous galaxy. Outside the luminous core, there should be almost no matter, so M should be constant and v^2 should fall off as 1/r. In fact, *v^2 falls off much more slowly*. Measurements indicate that the velocity is nearly constant, implying a linear increase of mass with radius. Since no matter can be seen that would account for this increase of mass, it is attributed to a halo of *dark matter* surrounding the galaxy.

Dark matter researchers seek to predict the mass density profile of dark matter halos via computer simulations and then confirm these predictions by observing actual galaxies. At large distances there is fairly good agreement. Some recent measurements seem to confirm the mass density profile seen in simulations of the model called *collisionless cold dark matter*. For small r, near the center of the galaxy, the collisionless cold dark matter simulations indicate that the halo density becomes very high near the core of the galaxy (a *cuspy* halo). Some observations appear to confirm this, and others find that the core density appears to flatten out near r = 0. A major problem with the cold dark matter model is that the simulations show much more clumping or fine structure in dark matter halos than is actually observed. The simulations assume that dark matter particles attract each other according to Newton's law. Observations consist of measurements on the visible, baryonic matter in galaxies. The dark matter density profile is then computed from these measurements, assuming that baryons and dark matter particles also attract each other according to Newton's law.

Two researchers have recently found that the observations and the simulations can be reconciled if it is assumed that interactions between the dark matter and the baryonic matter do *not* obey Newton's law.[10] They propose a modified gravitational potential between dark matter and baryons that obeys Newton's law at large distances but goes to zero at close range.

Does the sloton of the inflaton spacetime model have the right properties to be the dark matter? It is very cold, and it is collisionless in that it does not interact with normal matter at close range. We have seen that the sloton appears to interact gravitationally with baryonic matter according to the kind of law proposed in [10], which gives a better fit to the observational data than the standard cold dark matter model for many galaxies. The sloton is not collisionless with respect to itself, because slotons feel degeneracy pressure. This means that while its core density can be very high, as predicted by the simulations, it can never be infinite because of the degeneracy pressure, which tends to keep slotons apart. Because of this degeneracy pressure, sloton density profiles should not be very clumpy or fine-structured; this agrees with observations.

Annihilation. A last word about degeneracy pressure as felt by slotons: Degeneracy pressure for slotons is not the same as for fermions. It is a rather weak force that tends to keep slotons apart *on the average*. It is more of a bulk effect than an individual particle effect. Thus, a sloton will be repelled by a large cloud of slotons, but if two slotons get close enough, gravity will overcome the degeneracy pressure and pull them together. Since a sloton is its own antiparticle, two slotons that collide will annihilate into photons or leptons, in the same way that matter and antimatter annihilate into photons. (It is the resonances or particles that annihilate, not the underlying points. Points do not annihilate.) This means that if the sloton is the dark matter, we might be able to detect gamma rays or leptons from dark matter annihilation. In fact excesses of both gamma rays and leptons have been detected in our galaxy, and there is strong suspicion that these may be products of dark matter annihilation.

Fate of the Universe

Is the universe open, closed, or flat? Will it expand forever or eventually collapse in a "big crunch"? Current observations indicate that the universe is flat and that the expansion is accelerating. This would seem to indicate that the universe will expand forever, eventually becoming cold and dead—the dreaded *heat death*.

The inflaton spacetime model says that the universe is certainly open logically, as a set of points. There is no end to the generation of new points by the big bang process. Geometrically, the inflaton spacetime model says that the universe is flat. This is common to all inflationary models and is confirmed by observations of the cosmic microwave background radiation.

The inflaton spacetime model also says that the spacetime defined by the presence of matter is only a subset of an overall spacetime that is flat and expands at an exponential rate. The matter spacetime is very loosely coupled to the overall spacetime and therefore expands at a rate that is primarily determined by General Relativity except for its observed asymptotic flatness and the acceleration of its expansion. These two observed characteristics are usually ascribed to a cosmological constant or *dark energy*. The inflaton spacetime model reveals that they are inherited from the overall spacetime.

Recall that in the inflaton spacetime model, spacetime is made up of fermionic points and bosonic points. The expansion is driven by the endless creation of more fermionic points, which are prevented from occupying the same position by an exclusion principle that manifests itself as a *degeneracy pressure*. The fermionic points are swept towards each other by gravity, which results from coupling between the fermionic points and the bosonic points as the latter attempt to occupy the same quantum state, including the same position. The fundamental length of spacetime, the Planck length, is the mean distance between fermionic points and is determined by the balance between the two forces: gravity and degeneracy pressure. The degeneracy pressure is not infinite and the universe is getting larger and larger, so eventually we can expect the gravity of the expanding spacetime to overwhelm its degeneracy pressure so that spacetime and everything in it collapses to a black hole. This is a true black hole—a singularity—the only singularity in the inflaton spacetime model. In other words, spacetime looks very flat at the current epoch, but ultimately, it will be closed. This behavior is like a dying star, which will collapse to a black hole only if it is big enough. Just looking at the matter subset of spacetime does not reveal that this will happen. It is a prediction of the inflaton spacetime model. The collapse will probably start slowly and accelerate with time. Once it has collapsed, the universe probably does not "bounce" and expand again, as expected in some theories, because the final state, a black hole, is different from the initial state, which is more like a white hole, generating rather than swallowing.

About Time

Earlier, we saw that the particles of which we are made are not hard little balls, but processes. As the universe steps through its logical expansion, at each step a new image of every point is created. Quantum fluctuations occur, so that each point has a different position at each step and therefore seems to vibrate. The amount of this energy is quantized. There is a ground state, or state of lowest energy, and there can be higher energy states. These higher energy states are particles. Thus, a particle is a process that depends on time. Without time there are no particles. Without time, we could not exist, since we are made of particles.

Time that flows, that is, time that behaves as we perceive it to behave, is a problem for some physicists. Julian Barbour [11] notes that the Wheeler-DeWitt equation, an attempt to write down the wave function of the universe, *is independent of time*. This shouldn't surprise us, because we know that there is a reference frame in which the universe is atemporal. However, Barbour goes so far as to conclude that time that flows is merely an illusion. Brian Greene[12] points out that Einstein's theory of special relativity *requires* that *all of spacetime*, that is, all of space and all of time, be *present at once*. Since special relativity is well-verified by experiment, Greene, too, concludes that the time we perceive, the time that flows, is merely an illusion. He actually states flatly that there is no justification in the laws of physics for a time that flows. This is a little like the meteorologist stating flatly that it cannot possibly rain, when a look out the window would show that it is already raining quite cheerfully. If the laws of physics cannot accommodate a time that flows, there must be something wrong with them, because the flow of time is also well-verified by experiment, most notably our experience. Both Barbour and Greene imagine time sliced up into "nows" or instants. They imagine that each instant is like a photograph that shows everything that exists at that instant, including the position of every particle and the feelings and memories of every person. Then they imagine mixing up all of these instants randomly, and they point out that at each instant, our memories would still tell us that we had experienced the entire series of instants in correct time order. Moreover, you could put the mixed-up instants back in order just by looking at them. This is supposed to show that the order of time instants and therefore the flow of time are irrelevant. The flaw in this argument is that if you slice spacetime into instants, you will not see particles and persons, but only a spacetime that, except for random fluctuations, looks the same from instant to instant. Since particles are processes, they must be observed over a period of time to be recognized as particles. Thus, slices of spacetime that contain particles and memories cannot be infinitesimally thin, but must be more like slices of bread, spanning some finite period of time. In other words, particles, brains, and memories do not exist without the flow of time. *We are made of time, and that is why we can only experience time as something that flows.*

What is the resolution of this seeming conflict between the "laws of physics" and our experience? We have seen that the universe has a logical structure that seems to say that it has many cardinalities at once. Looked at in another way, the universe seems to expand, with the logical progression from lesser to greater cardinalities playing the role of time. However, there is actually no time between these logical levels. *Time, like spatial position, is an intrinsic quantum number of a spacetime point.* Two points can have different time quantum numbers without there being any point with an intermediate time quantum number. In other words, there is actually no time, just as there is no space. What we perceive is the position and time *quantum numbers* of spacetime points, and since our existence depends on their differences, we see time flowing.

Thus, time either flows or doesn't flow, depending on how you look at it. The "laws of physics" see it one way, and we see it another way. It is all right to have it both ways. We simply have here an example of *Bohr's principle of complementarity*, the same physics principle that makes wave-particle duality acceptable. From one frame of reference the universe is timeless, and Barbour and Greene are right. Time is an illusion, just as space is an illusion. From another reference frame, the universe expands in time. Our universe is made of time, so the flow of time is real to us.

Comments

The inflaton spacetime model presented in this paper supports the standard model of particle physics and the standard cold dark matter cosmology. It does this by illuminating the spacetime and particle structure that underlies the mathematical theory. The physics of the inflaton spacetime model is a mixture of classical and quantum effects. The inflaton spacetime model and the standard model complement each other, the inflaton spacetime model describing the structure of spacetime and the standard model making that description quantitative by applying symmetry principles. There does not seem to be a need for ten, eleven, or 26-dimensional spaces to account for the observed phenomenology. The inflaton spacetime model does not support a string or membrane model for particles.

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