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Is Consciousness the Unified Field? A Field Theorist's Perspective

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Abstract

Progress in theoretical physics during the past decade has led to a progressively more unified understanding of the laws of nature, culminating in the recent discovery of completely unified field theories. The parallel discovery of a unified field of consciousness raises fundamental questions concerning the relationship between the two. Following a general introduction to unified quantum field theories, we consider the proposal due to Maharishi Mahesh Yogi that the unified field of modern theoretical physics and the field of "pure consciousness" are identical. We show that the proposed identity between consciousness and the unified field is consistent with all known physical principles, but requires an expanded physical framework for the understanding of consciousness. Such a framework may indeed be required to account for experimentally observed field effects of consciousness and phenomenological aspects of higher states of consciousness.

CONTENTS

FOREWORD

This article is divided into two parts. Part I is a general introduction to unified quantum field theories, which provides a conceptual foundation for the analysis in Part II. Although written for the nonspecialist, it is our hope that this presentation of fundamental principles will be of sufficient depth and clarity to be of interest to the specialist as well. The specialist may however, if he chooses, proceed directly to Part II, as both Part I and Part II are intended to be self-contained.

PART I: AN INTRODUCTION TO UNIFIED QUANTUM FIELD THEORIES

It was Einstein's deep conviction that the laws of nature had a simple, geometric, unified foundation and that this unification could be understood by the human intellect. In an attempt to construct such a unified theory, he devoted the later part of his life to extending his geometric theory of gravity, known as general relativity, to include the electromagnetic force. Unfortunately, the theoretical tools and understanding needed to achieve such a unification were not yet available, and his quest for a unified field theory remained largely unfulfilled.

Within the past decade, there have been a number of significant breakthroughs that have led to a revitalization of progress and hope in this fundamental research area. One of these is the principle of spontaneously broken symmetry, which locates deeply hidden symmetries of nature at fundamental space-time scales and explains the emergence of diverse forces from an initially unified field. A second breakthrough has been the discovery of a profound symmetry principle called supersymmetry, which is capable of unifying force fields and matter fields in the context of a single field. A third is the discovery of superstring theories.

Here we present an introduction to the conceptual foundations of unified field theories. This analysis includes a discussion of quantum field theory, spontaneous symmetry breaking and the Higgs mechanism, electro-weak unification and grand unification, supersymmetry, supergravity and superstring theories. In our presentation, we have strived to maintain some of the quantum-mechanical and field theoretic aspects of these subjects that are usually omitted in an introductory treatment. We also provide an up-to-date appraisal of the experimental and theoretical status of these theories.

1.1 Quantum Field Theory

The quantized theory of fields, in both its particle and string formulations, is the most sophisticated and successful framework to emerge within the field of physics. It provides a natural extension of quantum mechanics from the nonrelativistic domain of atomic and molecular systems to the relativistic domain of nuclear and elementary particle physics.

Quantum field theory is fundamentally a theory of fields, which formally stands in relation to classical field theory as nonrelativistic quantum mechanics stands in relation to the classical mechanics of a point particle. The application of quantum mechanics to fields has immediate and profound consequences. One such consequence is that the energy levels of the field become discrete or "quantized." Unlike a classical field, whose propagating waves can have any amplitude and can thereby possess arbitrary energy, the stable propagating states of a quantum field are constrained to have discrete energies.

This discreteness in the energy levels of a quantum field provides a natural framework for the understanding of elementary particles: under certain conditions, this discreteness can give rise to a granular or particulate appearance to nature, which we then interpret as composed of elementary particles. For example, particles of light or "photons" are simply propagating waves of the quantized electromagnetic field, the discreteness of whose energy levels gives the appearance of a discrete number of particles. In a similar way, all the elementary particles in nature represent discrete states of excitation of their respective underlying quantum fields.

The energy levels of a quantum field are illustrated in Figure 1. The least excited state of a field or *ground state* corresponds to the state of no particles, and is therefore also called the *vacuum state*. The first excited state of a field corresponds to the presence of a single particle with energy $E \cong Mc^2$. The second excited state corresponds to the presence of two particles, with total energy $E \cong 2Mc^2$, etc.[1]

In addition to these stable particle states, a quantum field can sustain other forms of activity (Figure 1, dashes). These other configurations are unstable; they do not propagate and do not possess well-defined energy, and therefore do not have a natural interpretation in terms of particles.[2] These transient modes of activity of a quantum field play the role of forces between particles.

This dual characteristic of a quantum field as "particle" and "force" is illustrated in Figures 2a and 2b, which display the *Feynman diagrams* responsible for the scattering of electrons and photons, respectively. A Feynman diagram is a graphical representation of the time evolution of all the quantum fields involved in any basic scattering process. For a given process there may be many contributing diagrams. Figure 2a represents the simplest and most important contribution to electron scattering. It shows two incoming electron lines exchanging energy and momentum through the exchange of a photon, followed by two outgoing lines. These incoming and outgoing lines are called *external lines*, and represent physical particle states of the electron field. The internal photon line does not correspond to a stable particle state of the electromagnetic field, even though it is often called a *virtual photon*. It represents a nonpropagating, transient state of the electromagnetic field which transfers energy and momentum from one electron line to the other. It has no natural interpretation in terms of particles, but plays the role of a force between particles. Thus we observe in Figure 2a that the electromagnetic field plays the role of a force while the electron field assumes a particle role.

Now let us consider an analogous process where the respective roles of the electromagnetic and electron fields are reversed. The dominant contribution to the scattering of photons is shown in Figure 2b, in which two photons scatter through the intermediate agency of the electron field. In this example, the electromagnetic field plays the role of incoming and outgoing particles while the electron field transfers energy and momentum be-

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[1]Actually, a system of N particles does not have a precisely discrete spectrum of energies, since the particles can possess kinetic energy of motion in addition to mass-energy. The energy levels are truly discrete for states corresponding to nonrelativistic particles or to particles all traveling with the same momentum. A proper relativistic statement of the principle is that the stable "particle" states of a field obey a *mass-shell condition* which says that the energy and momentum for each particle with mass M are related by the relativistic formula $E = \text{sqr}(p^2 + M^2)$.

[2]These virtual configurations formally correspond to a superposition or quantum-mechanical coexistence of particle states.

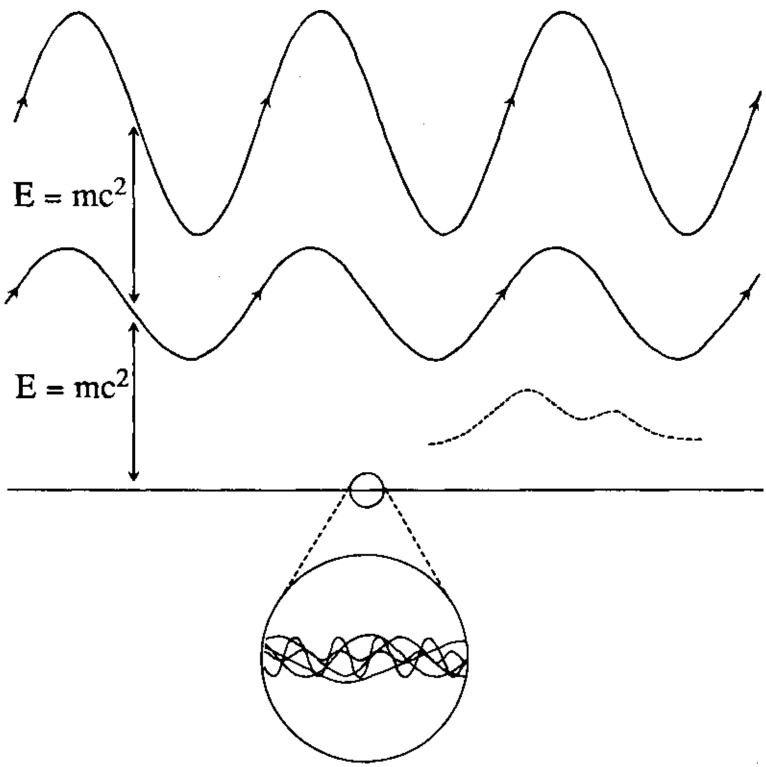

Figure 1. The modes of activity of a quantum field include 1) the stable, propagating states of the field with well-defined, discrete energies, which have a natural interpretation as elementary particles; 2) transient field configurations which do not propagate and play the role of forces between particles (dashed); and 3) vacuum fluctuations—the continuous, quantum-mechanical activity of the field present in the vacuum state and in all the excited states.

tween photons and thereby acts as a force. One can therefore conclude that any quantum field can assume either the role of particle or force, depending on whether that quantum field is in a physical particle state or in a "virtual" state. The historical distinction between the fundamental ***force fields*** such as the photon field and ***matter fields*** such as the electron field is nevertheless useful, and we will return to it shortly.

The scattering of light by light (Figure 2b) is an interesting process because there is no analogous effect in classical electromagnetic theory. Because the classical equations governing the electromagnetic field (i.e., Maxwell's equations) are linear in the field strength, light does not interact with itself and the scattering of two electromagnetic waves does not occur ***in vacuo.*** The scattering of light by light is therefore a uniquely quantum-mechanical effect and is consequently miniscule at ordinary energies and distances.

The fact that electron scattering corresponds to a familiar classical process whereas the scattering of light does not is explained by the fact that the Feynman diagrams in Figures 2a and 2b belong to different classes. Figure 2a is called a "tree" diagram. Tree diagrams are diagrams without closed loops and correspond to processes associated with classical field behavior. Figure 2b is representative of a "loop" diagram. Each loop in a Feynman diagram is accompanied by one power of Planck's constant (ft), hence Figure 2b represents

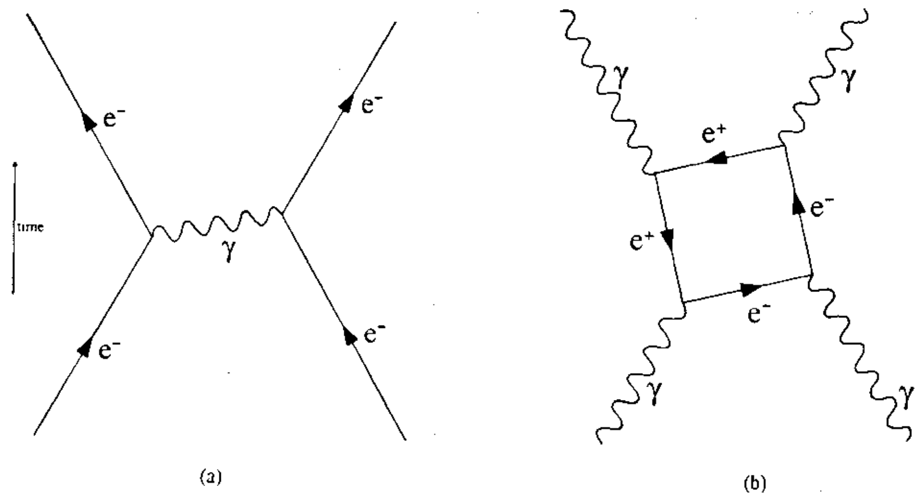

Figure 2. The dominant Feynman contributions to electron scattering and photon scattering. Figure 2a shows the scattering of two electrons through the exchange of a virtual photon. Figure 2b shows the scattering of two photons through a virtual electron-positron loop.

a process that is proportional to $\hbar$. Loop diagrams thus pertain to processes that are inherently quantum-mechanical. They often result in nonlinear effects that are not present at the classical level, such as the scattering of light by light.

Besides the discreteness of the energy levels of a quantum field, there is a second consequence of the application of quantum mechanics to fields, which follows from the uncertainty principle. The uncertainty principle states that one cannot simultaneously specify the value of two or more properties of a system if the quantum-mechanical operators corresponding to those properties do not commute with each other—i.e., if they are quantum-mechanically "incompatible." For example, nonrelativistic quantum theory treats the state of a particle as a wave function which evolves according to the Schroedinger wave equation. Because the particle is represented by a wave, it is impossible to precisely define the position of the particle (unless the wave function were infinitely peaked about some value of x) or the momentum of the particle (unless the wave function were a pure, oscillatory complex exponential). Certainly the conditions on the wave function that would allow a precise specification of position (i.e., infinitely peaked) and a precise specification of momentum (i.e., infinitely spread out) are incompatible. This leads to a reciprocal relation between the uncertainty (Δx) in the particle's position and the uncertainty (Δp) in its momentum known as the uncertainty principle: $(\Delta x)(\Delta p) \geq \hbar/2$.This does not necessarily imply that quantum-mechanical knowledge is incomplete. It simply means that the set of observables (e.g., position and momentum) that are familiar and useful at the macroscopic level of classical mechanics provides an inappropriate basis for the description of reality at microscopic scales.

The application of this same uncertainty principle to fields in the context of quantum field theory has an analogous effect. Classically, the amplitude or strength of a field at any point in space and the rate of change of the amplitude can both be simultaneously specified. In quantum field theory, these two quantities are incompatible—i.e., they do not commute, just as the position and momentum of a particle are incompatible in nonrelativistic quantum mechanics. The result is very similar to what occurs in the nonrelativistic theory. In nonrelativistic quantum mechanics, the point particle assumes a description in terms of a wave function, which expresses the indefiniteness of the particle's position and momentum. In quantum field theory, at every point in space the amplitude of the field is described by a "wave function" that expresses the indefiniteness of the field and rate of change of the field at that particular point. This result can be expressed in a more global but equivalent way: whereas the amplitude of a classical field has a definite shape described by a definite function of space and time, a quantum field can be seen as coexisting in all possible shapes at once—i.e., in a ***superposition*** of field shapes.

It is instructive to consider the vacuum state of a quantum field from this perspective. Classical expectations would lead us to expect that the least excited state of a field would be a state in which the field amplitude is zero everywhere. However, such a state would be highly unnatural from the standpoint of the uncertainty principle, according to which a definite field shape (flat, or otherwise) necessarily implies that the rate of change of the field is completely unspecifiable, corresponding to a state of infinite energy density. This situation is directly analogous to the nonrelativistic quantum theory of a point particle, in which the localization of the particle to a definite position in space requires a sharply peaked wave function which, according to the uncertainty principle, implies an infinite spread in momentum and therefore an infinite spread in energy. Hence, a quantum field that is everywhere flat would constitute a poor candidate for the lowest energy state of the field. The vacuum state of a quantum field must therefore correspond to a coexistence of field shapes (see Figure 1).

Another constraint that must be satisfied in constructing the vacuum state of a quantum field is ***Poincare invariance.*** Since the vacuum state corresponds to the absence of all physical particles and forces, it actually corresponds to the dynamics of empty space. It must therefore possess all the symmetries of space, which include invariance with respect to translations, rotations, and "boosts" (changes in the velocity of an observer's frame of reference). An arbitrary superposition of field shapes would not be invariant with respect to translations, rotations and boosts, but would in general have a "lumpy" structure. The vacuum state must therefore correspond to a very definite balance of field shapes which is stable in time, uniform in space, etc.—i.e., Poincare invariant. This state is not the state of complete inertia associated with the classical vacuum. The true, quantum vacuum possesses an intrinsic dynamism which is increasingly evident at more fundamental scales. A high resolution "picture" or measurement of a quantum field ***in vacuo*** would reveal highly energetic field shapes, as shown in Figure 1.[3]

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[3]One can expand the vacuum state of a quantum field in a basis of classical shape states in the following way. Consider a free, hermitian scalar field $\phi(\vec{x},t)$. One can define eigenstates of the field operator with the property that

$$\phi(\vec{x},t_0)\,|\,f,t_0\rangle = f(\vec{x})\,|\,f,t_0\rangle$$

where the eigenstates $|f,t_0\rangle$ correspond to definite shapes $f(\vec{x})$ of the Heisenberg field $\phi(\vec{x},t)$ at some fixed time $t=t_0$. Since these *classical shape states* form a complete (continuum normalized) basis, one can expand the vacuum state $|0\rangle$ as a superposition of these states:

$$|0\rangle = \int [df]\,\Omega\,[f]\,|\,f,t_0\rangle .$$

By requiring that all particle lowering operators $a(\vec{k})$ annihilate the vacuum, it is easy to show that

These energetic field shapes, which are present in the vacuum state as well as in all the excited states of the field, are known as ***vacuum fluctuations.*** They formally give rise to a large vacuum energy, which for convenience is usually subtracted out of the theory. However, it should not be felt that these quantum-mechanical fluctuations are consequently less real, for they have important physical ramifications, which include the spontaneous de-excitation of atoms and the ***Lamb shift.*** In addition, the energy associated with these vacuum fluctuations is expected to have additional consequences in any theory which includes gravity. In particular, it can lead to a potentially large gravitational self-attraction of space that is experimentally not seen. In fact, the astrophysical bounds on this gravitational self-attraction are approximately one hundred orders-of-magnitude smaller than the vacuum energy one would expect from a naive calculation. This enormous discrepancy remains a persistent puzzle that has not been satisfactorily resolved, although several clues have recently appeared in the context of supergravity and superstring theories.

We have thus identified three distinct modes of activity of a quantum field:

1) the stable "particle" states of a field, which possess well-defined, discrete energies and lend themselves naturally to an interpretation in terms of particles;
2) transient field configurations that do not propagate and do not have well-defined energy, which appear as internal lines in Feynman diagrams and play the role of forces between particles; and
3) vacuum fluctuations—the continuous, purely quantum-mechanical activity of a quantum field present in the vacuum state as well as in all the excited states.

Quantum field theory thereby presents a rather simple and profound view of nature in which the previously unrelated concepts of particle and force are naturally unified within a single theoretical construct: "particle" and "force" simply correspond to different modes of activity of an underlying quantum field.

Over the past fifty years, quantum field theory has enjoyed profound success as a theory of the electromagnetic interactions. Within the last decade, it has seen renewed success as a fundamental theory of the strong interactions and weak interactions as well. There is at present no experimental evidence to indicate that quantum field theory is in any sense incomplete. There are, however, recent theoretical arguments that this quantum field theoretic framework of elementary particles may need to be expanded into a quantum field theory of elementary strings. This will be the topic of a later section.

1.2 Electro-Weak Unification and Broken Symmetry

In recent years, the primary challenge in theoretical physics has been to further simplify our understanding of nature by reducing the number of fundamental fields needed to ac-

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the vacuum wave functional $\Omega\,[f]$ is given by

$$\Omega\,[f] = e^{-\frac{1}{4\pi}\int d\vec{x}\,d\vec{y}\,d\vec{k}\; f(\vec{x})f(\vec{y})e^{i\vec{k}\cdot(\vec{x}-\vec{y})}\sqrt{k^2+m^2}}$$

Because this vacuum wave functional $\Omega[f]$ is nonvanishing for all $f(\vec{x})$, one observes that the quantum vacuum actually corresponds to a superposition of all classical field shapes.

In a similar way, the physical particle states of a field, like the vacuum state, do not correspond to definite field shapes but to quantum-mechanical superpositions of shapes. However, for these excited states the associated wave functionals are no longer Poincaré invariant.

count for the very rich and diverse particle phenomenology observed in accelerators during the past few decades. This search for simplicity led to the introduction of the ***quark model*** by physicists Murray Gell-Mann and George Zweig, which replaced a large number of strongly interacting particles or "hadrons" by a few fundamental subconstituents called quarks. The quark model in turn led to the modern theory of the strong interactions, known as ***quantum chromodynamics,*** in which the strongly interacting hadrons are described as bound states of quarks held together by ***gluons.*** These quarks and gluons are believed to be inextricably confined within the interior of hadrons by a dynamical mechanism known as "quark confinement." As a consequence, quarks and gluons can never exist as free particles, implying that their associated quantum fields are dynamically prevented from assuming free particle states, further illustrating the inadequacy of the particle concept for physics at fundamental scales.

Much of the recent progress towards a unification of the fundamental particles and forces has been based on the principle of ***spontaneously broken symmetry,*** which locates deeply hidden symmetries of nature at fundamental space-time scales. The application of this profound, unifying principle has resulted in the successful unification of the weak and electromagnetic forces by physicists Glashow, Salam and Weinberg. In addition to the unification of the weak and electromagnetic forces, this unified electro-weak theory unites various matter fields into "doublets," which include the electron and the neutrino, the up-quark and the down-quark, etc. (see Table 1).

The electron and the neutrino belong to a class called ***leptons***—matter fields that do not participate in the strong interactions. Apart from this common feature, the electron and the neutrino appear to have little in common. The neutrino is a massless particle and is therefore constrained to move at the speed of light. In addition, the neutrino has no electric charge and as a consequence does not interact electromagnetically. The neutrino interacts with other matter only through the weak force, which is extremely feeble in comparison with the electromagnetic force. As a consequence, a neutrino can pass directly through the sun or the earth with very little chance of scattering.

In contrast to the neutrino, the electron has a mass and is therefore forbidden to move with the speed of light. Due to the electron's charge, it interacts very readily with matter via the electromagnetic force. This interaction is responsible for upholding atomic and molecular structure, for chemical interactions, and thus for the majority of macroscopic, observable behavior.

It may seem peculiar, given these distinctions, that the electron and the neutrino are believed to be fundamentally indistinguishable—unified components of a single field known as a left-handed lepton doublet.[4] The apparent difference between these two fields is in a sense superficial—the result of ***spontaneous symmetry breaking.***

One way in which to understand the fundamental indistinguishability of these apparently diverse fields is to compare the scattering of electrons (Figure 2a) to the scattering of neutrinos (Figure 3). Because the neutrino has no electric charge, neutrino scattering cannot occur through the agency of the electromagnetic field. It occurs by virtue of the neutral Z° boson, one of the force fields responsible for the weak interaction (see Table 1). In comparison with electron scattering via the electromagnetic field (Figure 2a), the scattering of

[4]It is actually the left-handed component of the electron field which is unified with the neutrino. Any massive fermion, such as the electron, really consists of two separate components or chiralities, corresponding to a left-handed and a right-handed polarization state.

neutrinos through the weak interaction (Figure 3) is observed to be very much weaker. It is easy to see why this is so.

The Z^0 boson has a mass order of 90 GeV/c^2, where 1 GeV/c^2 is comparable to the mass of the proton. This means it requires 90 GeV worth of energy to "create" a Z^0 boson—i.e., to excite the Z^0 field from its ground state to its first excited state (see Figure 1). At ordinary scales and temperatures, there is not nearly enough energy available to excite the Z^0 field, with the result that Z^0 bosons are not a familiar part of our universe.

Despite the absence of Z^0 particles, neutrino scattering can occur via Figure 3, albeit at a very suppressed rate. This is possible since the Z^0 boson in Figure 3 does not correspond to a physical particle state of the field, which would require at least 90 GeV of energy to create. It corresponds to a non-propagating virtual state of the field which transfers energy and momentum from one incoming neutrino line to the other. Because this virtual state of the Z^0 field is non-propagating, the range of influence of the weak force is extremely short, which helps to explain why the weak interaction is so weak at ordinary scales and energies.

Matter Fields

color symmetry (↔ across u_r, u_g, u_b); electro-weak symmetry (↕ between rows); grand unified symmetry (↔ across the whole row)

ν_e	u_r	u_g	u_b
e	d_r	d_g	d_b

ν_μ	c_r	c_g	c_b
μ	s_r	s_g	s_b

ν_τ	t_r	t_g	t_b
τ	b_r	b_g	b_b

Force Fields

Photon: (γ)

Weak Bosons: ($W^\pm$, Z^0)

8 Gluons: (g)

Graviton: (G)

Table 1. The fundamental matter fields and force fields of the standard low-energy theory. The matter fields, which have spin-½, include the electron e and its associated neutrino ν_e, the muon μ and its associated neutrino ν_μ, the tau τ, and its associated neutrino ν_τ, and six quark flavors: up u, down d, charm c, strange s, top t and bottom b. Each quark flavor comes in three identical replications or "colors": red r, green g and blue b. The spin-1 force fields include the photon γ responsible for the electromagnetic force, three weak bosons $W^\pm$, Z^0 responsible for the weak force, and 8 gluons g responsible for the strong force. The spin-2 graviton G is responsible for the force of gravity.

However, the strength of neutrino scattering (Figure 3) and electron scattering (Figure 2a) become comparable at high energies, where the energy barrier associated with the Z^0 mass is increasingly negligible.[5] When the energy of the incoming particles is very large compared to the Z^0 mass, the two scattering strengths become identical. This example demonstrates how the electron and the neutrino take on identical physical characteristics at extremely high energies, which is an indication of their fundamental indistinguishability. It also suggests that if the Z^0 were massless and therefore actively participated in physics at ordinary scales, the electron and the neutrino would possess identical physical properties and behavior: the fundamental equivalence of the electron and the neutrino would be restored. It is therefore the mass of the Z^0 boson which makes the weak interactions weak, and thereby leads to the apparent asymmetry between the electron and the neutrino. If the Z^0 were massless like the photon, the electron and the neutrino would behave as indistinguishable components of a *unified field* called the left-handed lepton doublet.

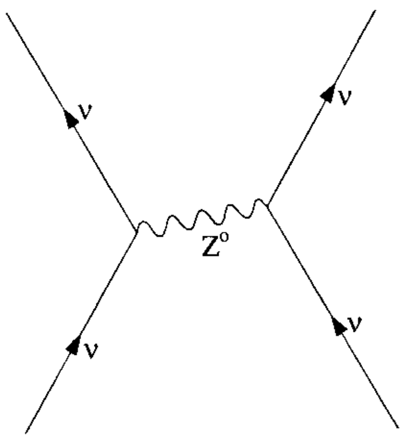

Figure 3. The dominant Feynman contribution to neutrino scattering involves the exchange of a massive virtual Z^0 boson.

The concept of a unified field is a profound one and deserves further reflection. Consider the example of a one-dimensional field theory, e.g., a vibrating guitar string. There are two independent but physically equivalent ways in which a guitar string can be excited. If the guitar is held vertically, it can vibrate in the left-right direction or the forward-backward direction. Both directions elicit the same tone and hence no musician invests a great deal of effort exciting one mode as opposed to the other. And though the string possesses two independent degrees of freedom, it would seem unnecessarily cumbersome to speak of two **different** strings. In precisely the same way, the electron and the neutrino, if the electroweak symmetry were an *unbroken symmetry*, would constitute two independent but physically equivalent degrees of freedom of a single unified field.

[5]Here again, the physical equivalence of electron scattering and neutrino scattering pertains to experiments with left-handed polarized electrons only. This technical distinction is not important to the physical arguments being made.

In this way, the unified electro-weak theory of Glashow, Salam and Weinberg provides a unification of the electron with the neutrino, and in a precisely analogous way, a unification of the muon and the taon with their associated neutrinos (see Table 1). It also leads to a unification of the up-quark with the down-quark, the charm-quark with the strange-quark, and the top-quark with the bottom-quark.

However, this unification may seem rather insubstantial, as it occurs only at asymptotically high energies or in a hypothetical world where the weak bosons $W^{\pm}$,Z^0 are massless. In point of fact, this hypothetical world of massless weak bosons is not purely imaginary. According to the standard Big Bang cosmological model and its new inflationary innovations, the universe began in a primordial state of astronomically high temperature and density.

In the extremely high temperature environment characteristic of the first one-billionth of a second in the evolution of the universe, the weak interaction bosons are believed to have been massless, and the fundamental symmetry between the weak and electromagnetic forces, and between the electron and the neutrino, etc. was exactly restored. The mechanism responsible for breaking the electro-weak symmetry as the universe cooled and for giving the $W^{\pm}$ and Z^0 their mass is called the *Higgs mechanism*.

The Higgs mechanism of symmetry breaking requires the introduction of new spinless quantum fields called Higgs fields. We will illustrate the Higgs mechanism using the simplest example of a single massless force field (e.g., the electromagnetic field) interacting with two Higgs fields S_1 and S_2. Classically, the strength or amplitude of the Higgs fields in their ground state is determined by the minimum of a potential energy function $V(S_1,S_2)$ which describes the energy of the fields S_1 and S_2 as a function of their amplitudes (Figure 4a,b). We will assume that the theory has a *symmetry* whereby the theory is unchanged when the fields S_1 and S_2 are swapped or rotated continuously into each other, which implies that the fields S_1 and S_2 enter the potential energy function V in a symmetric way; e.g.,

$$V(S_1,S_2) = m^2(S_1^2 + S_2^2) + g(S_1^2 + S_2^2)^2.$$

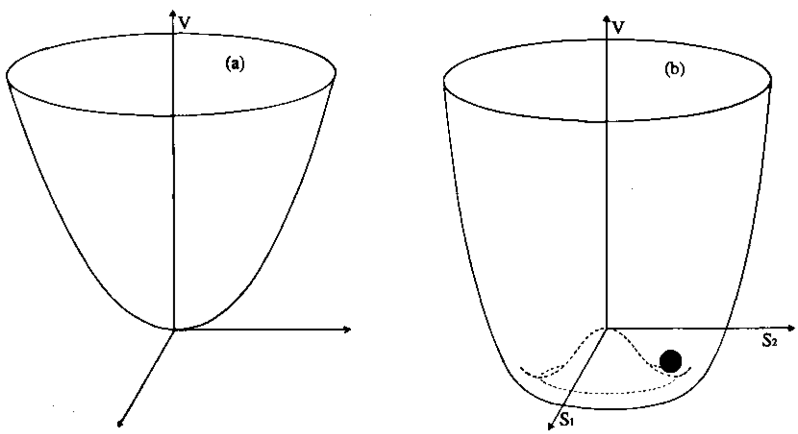

Figure 4. The potential energy function $V(S_1,S_2)$ corresponding to (a) the case of unbroken symmetry, and (b) the case of broken symmetry.

Such a theory is said to possess a one-parameter continuous symmetry, since the theory is invariant under the replacement of the fields (S_1,S_2) by any rotated combination $(\cos\Theta\ S_1 - \sin\Theta\ S_2, \sin\Theta\ S_1 + \cos\Theta\ S_2)$ for an arbitrary angle Θ.

The theory behaves differently under the influence of the potential $V(S_1,S_2)$ depending on the sign of m^2. (The positivity of g is required for the stability of the theory.) For small values of S_1 and S_2, the shape of the potential V is dominated by this quadratic term proportional to m^2. If $m^2 > 0$ as in Figure 4a, the equilibrium value of the fields S_1 and S_2 is located at the origin. This case corresponds to a symmetric theory containing two identical particles with mass m. If $m^2 < 0$, the potential assumes the shape of a "Mexican hat" and the origin becomes unstable (Figure 4b). The fields S_1 and S_2 settle into a new equilibrium point somewhere along the trough of the hat, where $S_1^2 + S_2^2 = |m^2|/2$. This minimum corresponds to a state of *broken symmetry*, for once the fields S_1 and S_2 have assumed a definite nonzero value, the manifest S_1-S_2 rotational symmetry of the theory is lost—the theory has settled into an asymmetric minimum. This can occur despite the fact that the underlying mathematical structure of the theory, expressed by the potential $V(S_1,S_2)$, is symmetric.

Whereas the unbroken theory (Figure 4a) describes two identical particles with mass m, the broken theory contains one massive and one massless particle. The massive particle corresponds to radial vibrations of the fields S_1,S_2. The massless particle corresponds to vibrations along the perimeter of the rim itself, where the potential V is flat. The presence of a massless particle is a completely general feature of spontaneous symmetry breaking, and is an illustration of Goldstone's theorem. The massless particle which results from spontaneous symmetry breaking is called a *Goldstone boson*.

In the presence of a force field, the result of spontaneous symmetry breaking is quite different. If a force field is introduced in such a way that the underlying mathematical structure of the theory remains symmetric, then in the broken symmetry case (Figure 4b) the force field's interaction with the massless Goldstone boson has very special consequences. The massless Goldstone boson responds to the force field in such a way as to produce a screening or cancelling effect on the force. This situation is analogous to the cancellation of an electromagnetic field inside a conductor. The free electrons within the conductor automatically respond to any applied electromagnetic field in such a way that the electric field is cancelled by the electrons' own electromagnetic influence. In a similar way, the massless Goldstone boson responds to the force field in such a way that the influence of the force is cancelled. As a consequence, the propagation of the force field is severely attenuated and the influence of the force becomes extremely short ranged.

Thus the combined influence of a massless, long-range force and the massless Goldstone boson is to produce a short-range force. Since in quantum field theory, for reasons we have previously discussed, a short-range force is generally associated with a massive field, the result of spontaneous symmetry breaking in the presence of a massless force field is effectively to produce a *massive* force field. This process is known as the Higgs mechanism. It is often said that the massless force field "eats" the massless Goldstone boson that results from symmetry breaking and thereby becomes massive (i.e., short ranged).

One can observe from the form of the potential V and from Figures 4a,b that whether or not the symmetry is broken and the force fields acquire a mass depends on the sign of m^2. However, m^2 is a temperature-dependent parameter. A finite, nonzero temperature has the effect of adding a positive constant to m^2, with the result that m^2 is effectively an increasing function of temperature. Hence, even if m^2 is negative at low temperatures, corresponding to a state of broken symmetry, it is possible for m^2 to become positive at high temperatures. This would result in a restoration of symmetry.

Such is believed to have been the case for the electro-weak symmetry in the very early stages of cosmic evolution. For the first one-billionth of a second in the evolution of the universe, when the cosmic temperatures were above 10^{15} K degrees, the universe was in a unified phase, in which the weak bosons $W^{\pm}, Z^0$ were massless and the electron and the neutrino were indistinguishable particles. Then as the universe expanded and cooled, the m^2 term in the potential gradually became negative, and the universe entered a broken phase in which the $W^{\pm}$ and Z^0 bosons acquired a mass and the electron and neutrino, etc. assumed very different physical characteristics.

In an approximate sense, physics at high temperatures, physics at high scattering energies, and physics at fundamental space-time scales are all equivalent. Formally, a high temperature field theory is equivalent to a field theory with a periodic boundary condition in the time coordinate, or to a theory on a tiny time slice. For this reason, one often speaks of physics at fundamental scales and physics at high temperatures as equivalent. These are somewhat distinct from scattering experiments performed at high energies, where we have seen that nature appears only approximately symmetric as one goes to asymptotically high energies. This can be contrasted with the effect of high temperatures, which results in a sudden transition to a completely symmetric phase of the theory.

I.3 Grand Unification

Electro-weak unification derives its name from the fact that the weak fields $W^{\pm}, Z^0$ and the electromagnetic field become members of the same mathematical symmetry group called $SU(2)\times U(1)$. The fact that this symmetry is actually the product of two separate factors shows that the unification of the weak and electromagnetic forces occurring at this level is not very complete. A more profound unification of the fundamental forces and particles occurs in the context of *grand unification.*

Grand unified theories are theories which unify the strong, weak, and electromagnetic forces. They also automatically result in a unification of quarks with leptons (see Table 1). The simplest and in many respects the most compelling model of this type was proposed in 1974 by H. Georgi and S. Glashow. This model is based on a simple mathematical symmetry group called SU(5). In addition to the strong, weak and electromagnetic forces, these theories predict the existence of new supermassive forces, which are needed to complete the grand unified family (Figure 5). These superheavy fields are expected to have masses of order $10^{14}-10^{15}$ GeV!

At extremely high temperatures characteristic of the very early universe, or at scattering energies large compared to this superheavy mass scale, these supermassive fields structure a unification between quarks and leptons, just as the weak interaction bosons $W^{\pm}, Z^0$ uphold the unification of the electron and neutrino at high energies. However, with grand unification it is more evident how the principle of spontaneously broken symmetry constitutes a framework for a profound unification of the fundamental forces. In the Georgi-Glashow SU(5) theory, the strong, weak and electromagnetic forces, together with the new superheavy "X" and "Y" bosons (Figure 5), become indistinguishable components of a single grand unified force field with 24 degrees of freedom.

Unlike the weak interaction $W^{\pm}$ and Z^0 bosons, the superheavy bosons associated with grand unification cannot be produced in any existing or conceivable particle accelerator on account of their superheavy mass. However, as virtual particles in Feynman graphs, these superheavy fields can give rise to exotic processes with highly distinctive experimental

$$\begin{bmatrix} G-\frac{2B}{\sqrt{30}} & G & G & \bar{X} & \bar{Y} \\ G & G-\frac{2B}{\sqrt{30}} & G & \bar{X} & \bar{Y} \\ G & G & G-\frac{2B}{\sqrt{30}} & \bar{X} & \bar{Y} \\ X & X & X & \frac{W^3}{\sqrt{2}}+\frac{3B}{\sqrt{30}} & W^+ \\ Y & Y & Y & W^- & \frac{-W^3}{\sqrt{2}}+\frac{3B}{\sqrt{30}} \end{bmatrix}$$

Figure 5. In the Georgi-Glashow SU(5) grand unified theory, the strong, weak, and electromagnetic forces (G, W and B) are unified along with new superheavy X and Y fields, giving rise to a single 24-component grand unified force field.

signatures. In particular, because these grand unified forces change quarks into leptons, in most grand unified theories the proton is unstable, with lifetimes ranging from 10^{26} - 10^{32} years. For example, the Georgi-Glashow SU(5) model predicts proton decay into various final states, especially into $e^+\pi^0$, at a rate which depends sensitively on the mass of the superheavy X and Y bosons. Most estimates place this mass between (1 to 6) $\times$ 10^{14} GeV, with a consequent range for the proton lifetime between 2×10^{26} and 10^{31} years.

In the past several years, there have been a number of major collaborative experimental programs looking for proton decay in deep underground detectors using pools of water or massive iron detectors as proton sources. These experiments have not found definitive evidence for proton decay, resulting in a lower bound on the proton lifetime of $\tau_p > 2 \times 10^{32}$ years.

The fact that this bound already conflicts with our previous estimate in the simplest SU(5) grand unified theory is rather embarrassing from the standpoint of this model and has prompted many interpretations. The most optimistic appraisal is that the theoretical uncertainties in the proton lifetime are too large to say whether or not the simplest grand unified model is ruled out. The proton lifetime depends very sensitively on the grand unified mass scale, which is only approximately known, and there are additional uncertainties associated with the low-energy strong interaction dynamics of the decay process. Others have interpreted the proton's longevity as evidence in favor of their own, more complicated unified models, in which the proton lifetime is often more difficult to pin down. Unfortunately, the existing bounds on the proton lifetime make it somewhat unlikely that a detailed analysis and comparison of various proton decay modes required to discriminate among competing theories will ever be experimentally feasible. It may be that the competition among the various extant grand unified models will have to be settled on the basis of more theoretical considerations.

Of the competing theories, there is one class of models which is of special importance. These are the *supersymmetric* extensions of grand unification. Supersymmetry not only provides a new and profound degree of unification in physics, but it offers a natural framework for resolving one of the most difficult technical problems with previous grand unified and electro-weak theories— namely the "naturalness" or "gauge hierarchy" problem.

I.4 Supersymmetry

Until this point, our discussion has focused on a symmetry principle capable of uniting fields belonging to the same spin class, e.g., spin-½ electrons with spin-½ neutrinos, the spin-1 photon with the spin-1 $W^{\pm}$ and Z^0 weak interaction bosons, etc. A more profound degree of unification has recently become possible through the discovery of a new mathematical symmetry principle capable of unifying particles of different spin. This new unifying principle, termed *supersymmetry*, thereby provides a possible framework for the unification of all the fundamental particles and forces.

According to quantum field theory, all quantum fields belong to one of several fundamental categories distinguished by their quantum-mechanical spins. The most pedagogical approach to understanding spin is to consider the physical particle states of a quantum field. If one adopts a very classical and particulate view of such states, then one can imagine these "particles" as physically spinning and therefore possessing intrinsic angular momentum. According to quantum field theory, the magnitude of this angular momentum is quantized, i.e., constrained to take discrete values equal to half-integer multiples of Planck's constant: 0, ½, 1, 3/2, 2, etc. in units of ($\hbar$). Fields with spin-½, such as the electron and neutrino, are generically called *matter fields*. The *force fields*, which include the photon, the gluons and the weak interaction bosons, have spin-1. The graviton has spin-2. Among the spin-0 fields are the Higgs fields responsible for spontaneous symmetry breaking.

Spin is of fundamental importance in quantum field theory, since the spin determines to a large degree the properties of a field. For example, the fact that the graviton has spin-2 is enough to derive all the essential characteristics of gravity.

The fundamental spin types can be further grouped into two hyper-categories called *bosons* and *fermions*. Bosons include all fields with integer-valued spins—spin 0, 1, 2, etc. Fermions are fields with half-integer values—spin ½, 3/2, etc. These two categories—bosons and fermions—possess highly contrasting statistical properties.

Bose particles display an enhanced statistical tendency to occupy the same quantum-mechanical state (i.e., to have the same position, the same momentum, etc.). This tendency leads to phenomena of collective coherence among bosons. For instance, laser light derives its remarkable intensity and focus from the fact that photons of light (i.e., bosons) emitted by atoms in the process of de-excitation tend to be produced in perfect directional and phase coherence.

In contrast, fermions are actually forbidden from occupying the same quantum state by a principle known as the *Pauli exclusion principle*. This principle is responsible for the fact that only a single electron can occupy any given atomic state. (An atomic state is defined as an electron orbital possessing definite energy, orbital angular momentum and spin.) This essential limitation means that the electrons in a complex atom are forced to occupy larger and more complicated orbitals, whereas if the electrons were bosons, they would all tend to occupy the least excited state or ground state. This fermionic property of electrons is ultimately responsible for the great diversity of chemical behavior among the various elements.

Bosons and fermions, with their highly contrasting properties, have been extremely difficult to reconcile. For example, electro-weak and grand unified theories have only resulted in the unification of spin-½ matter fields among themselves (including the electron, the neutrino and the quarks) and the unification of spin-1 force fields among themselves (including the photon, the weak interaction bosons and the gluons). Since the universe includes a variety of spin types, it is obvious that this type of theory is fundamentally incapable of producing a completely unified field theory.

Prior to the discovery of supersymmetry, it was not at all clear how to generalize these theories to include the unification of bosons with fermions. In fact, it was several years after the introduction of supersymmetry before the scientific community became aware of its potential significance (Ramond, 1971; Neveu and Schwartz, 1971; Wess and Zumino, 1974).

Supersymmetry, in its simplest form, unifies particles of adjacent spin types—spin-0 fields with spin-½ fields, spin-½ fields with spin-1 fields, etc. It thereby links bosons and fermions into a special type of unified field called a *superfield*. In this way, simple supersymmetry or "N=1 supersymmetry" provides a new degree of unification which is in principle capable of unifying force fields (spin-1 bosons) with matter fields (spin-½ fermions).

The most straightforward application of this principle fails in that none of the observed matter fields of nature constitute suitable "supersymmetric partners" of any of the known forces. The unification of force fields with matter fields through supersymmetry can apply only to force fields and matter fields with identical physical characteristics such as mass, electric charge, color charge, etc. Unfortunately, there are no such pairs of force fields and matter fields with identical physical characteristics among the known elementary particles and forces.

This would seem to rule out supersymmetry as a possible symmetry of nature, were it not for the fact that the requirement of equal masses for the force fields and matter fields can be relaxed if supersymmetry is spontaneously broken. The breaking of supersymmetry results in a mass splitting between the elementary particles and their supersymmetric partners, which can account for the fact that no supersymmetric partners of any known particles or forces have yet been observed. In fact, it is relatively easy to construct spontaneously broken supersymmetric models in which all the supersymmetric partners are heavy enough to have escaped detection at present accelerator energies. However, such models generally do predict the exciting prospect of discovering supersymmetric particles in the near future.

One might feel compelled to ask what justification there could be to introduce a fundamentally new symmetry principle like supersymmetry for which there are no known examples and for which no experimental evidence exists. The most obvious incentive, which is to unify the observed force and matter fields, is obstructed by the fact that none of the observed force fields and matter fields are suitable supersymmetric partners of each other, possessing different charges, etc. As a consequence, the introduction of supersymmetry requires the addition of new supersymmetric partners for all of the known force fields and matter fields, and is therefore extremely uneconomical. One must therefore find some other strong theoretical justification for supersymmetry.

One important justification for supersymmetry has to do with the breaking of the electroweak symmetry, i.e., with the Higgs mechanism by which the $W^{\pm}$ and Z^0 bosons acquire their mass. A necessary feature of the Higgs mechanism is that the Higgs boson's mass is of the same order of magnitude as the scale of electro-weak breaking, i.e., the $W^{\pm}$ and Z^0 mass scale, which is O(100) GeV. However, it is difficult to understand how the Higgs boson could be so light compared to the grand unified scale, which is $O(10^{15})$ GeV. The difficulty stems from the fact that there are quantum-mechanical contributions to the Higgs boson masses that are themselves of the order of the grand unified scale.

These quantum-mechanical contributions result from Feynman loop diagrams involving virtual spin-1 forces (Figure 6a). One can always arrange for a cancellation of these large quantum-mechanical contributions to the Higgs boson masses by a judicious and careful adjustment of parameters in the underlying theory, but this requires an unattractive and artificial fine-tuning of parameters to an accuracy of one part in 10^{26}! This unmotivated juggling of parameters which is apparently needed to explain the lightness of the Higgs bosons (and therefore the scale of weak interaction symmetry breaking) in the presence of large quantum-mechanical contributions is called the "naturalness" or "gauge hierarchy" problem. The term hierarchy refers to the widely disparate mass scales associated with electroweak symmetry breaking and grand unified symmetry breaking: M_W, $M_Z << M_{GUT}$.

Supersymmetry provides an elegant solution to this problem in which the large quantum-mechanical contribution to the Higgs mass disappears. A natural cancellation occurs due to the presence of new, supersymmetric partners of the spin-1 forces appearing in Figure 6a. The new spin-½ partners, known as *gauginos*, give rise to extra contributions to the Higgs mass (Figure 6b) which precisely cancel the quantum-mechanical contributions from Figure 6a. The cancellation results from the fact that the usual spin-1 forces and the spin-½ gauginos have precisely the same couplings and interaction strengths, as required by supersymmetry. This cancellation also extends to more complicated Feynman diagrams containing an arbitrary number of loops. Such a cancellation is, in fact, required among diagrams containing as many as thirteen loops if the desired technical solution to the gauge hierarchy problem is indeed to be achieved. The fact that supersymmetry accomplishes this miracle provides a natural solution to a long-standing technical problem with all previous unified field theories.[6]

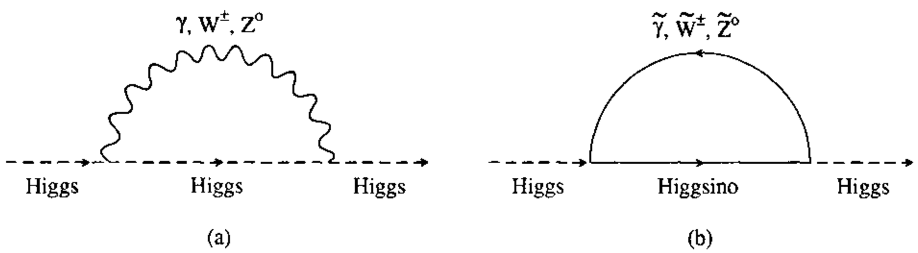

Figure 6. Large quantum-mechanical contributions to the Higgs mass due to Feynman diagrams involving (a) ordinary spin-1 force fields, and (b) their spin-½ supersymmetric "gaugino" partners. These contributions cancel in the limit of exact supersymmetry.

[6]This supersymmetric mechanism does not explain why the Higgs bosons would be so light to begin with, even in the absence of large quantum-mechanical contributions. This issue is treated differently in various extant supersymmetric models, and a great deal of success has been achieved here, too.

The desired cancellation of quantum-mechanical contributions only occurs if the new supersymmetric particles have masses that are comparable to the familiar particles and forces: the cancellation is precise if and only if supersymmetry is unbroken, in which case all the supersymmetric particles have precisely the same mass as their familiar partners. One can use this argument to conclude that all the new supersymmetric particles should have masses that are not much heavier than the known particles and forces, otherwise a sufficiently precise cancellation would not occur. This raises exciting prospects for the discovery of supersymmetric particles at existing particle accelerators and at those presently under construction.

There are many experimental searches for supersymmetric particles currently underway. For example, there have been experimental searches for strongly interacting supersymmetric particles in hadron colliders, such as the proton-antiproton collider at CERN in Geneva. So far, these experimental searches have been able to put lower bounds on the masses of strongly interacting supersymmetric particles, which include "gluinos" (the spin - ½ supersymmetric partners of the spin-1 gluons) and "squarks" (the spin-0 supersymmetric partners of the spin -½ quarks).

It would appear sensible to focus experimental attention on looking for what should theoretically be the lightest supersymmetric particles, since they would be expected to show up first in today's particle accelerators. According to theoretical and experimental constraints (Ellis et al., 1984), the lightest supersymmetric particle or "LSP" is probably some type of neutral gaugino or Higgsino, which are respectively the spin-½ supersymmetric partners of spin-1 force fields and spin-0 Higgs fields. Of these the photino, which is the supersymmetric partner of the photon, is perhaps the most plausible from the standpoint of astrophysical and cosmological constraints.

Although the photino formally interacts with electromagnetic strength, being the supersymmetric partner of the photon, its interaction with ordinary matter is very much suppressed because such interactions necessarily involve the exchange of charged supersymmetric virtual particles, which are known to be quite heavy. Hence the photino, much like a neutrino, would escape detection in ordinary particle detectors, which makes the photino difficult to see experimentally. It is nevertheless possible to search for "missing energy" in particle interactions, which can be a signal for a photino escaping the interaction region. Missing energy and momentum can be a distinctive signature for photino production and is currently being used to search for photinos in e^+e^- annihilation experiments and in hadron colliders as well.

In most supersymmetric theories the LSP is absolutely stable against decay (Fayet, 1980). This fact has profound cosmological and astrophysical implications. It means, for example, that photinos might populate the universe today in large numbers and contribute significantly to the overall mass density of the universe. This follows from the fact that the photino, along with all other particles, would have been present in thermal equilibrium in the very early universe, when according to the Big Bang cosmology, temperatures were extremely high. Later, as the universe expands and cools, the heavier particles naturally decay into lighter ones, leaving a universe that is populated by only the lightest particles. However, the LSP is stable against decay, and can disappear from the universe only by pair annihilation. Since pair annihilation is rather inefficient, many of the primordial LSPs should survive today as supersymmetric relics of the Big Bang.

The presence of photinos in the universe today would be rather inconspicuous since they interact so weakly with ordinary matter. However, if their numbers are as large as calculations imply, they can contribute significantly to the overall mass density of the universe. They can consequently change the geometrical structure of the universe from an ***open*** universe to a ***closed*** universe.

An open universe is a universe that continues to expand forever, and for which the curvature of space-time is negative (similar to the geometry of a saddle). A closed universe is a universe which stops expanding after a finite time and begins to recollapse, and where the curvature of space-time is positive (similar to the surface of a sphere).

According to the equations of general relativity, whether the universe is open or closed depends on the average mass density of the universe. The observed mass density of the universe associated with luminous objects like stars suggests that our universe is open, since this mass density is a factor of five or more below the critical density required for a closed universe. However, this observation is incompatible with the new, inflationary cosmology, which predicts that the universe must appear to be on the brink of closure whether the universe is fundamentally open or closed (for reviews, see Guth, 1984; Linde, 1984). Inflationary cosmologies therefore require considerably more mass density than can be ascribed to luminous matter. This additional mass density must be in the form of "dark matter" whose presence would have thus far been undetected.

The LSP is a natural candidate for this dark matter. In fact, the mass density of photinos predicted within the framework of the most promising supersymmetric theories, i.e., supergravity and superstring theories, agrees very well with the cosmological mass density needed to close the universe (Ellis, Hagelin and Nanopoulos, 1985; Campbell et al., 1986). This contrasts with other, non-supersymmetric dark matter candidates, which do not naturally predict the correct amount of dark matter needed to close the universe, but which are made to fit in an ***ad hoc*** way.

Supersymmetric dark matter has an added advantage of belonging to a category known as "cold" dark matter. Cold dark matter consists of relatively massive particles, which would have been nonrelativistic at the time when galaxy formation occurred. Cold dark matter has a tendency to coalesce gravitationally into clumps of all sizes and mass scales. This leads to the prediction that cold dark matter would be concentrated in galaxies, galactic clusters, stellar clusters, etc. and would actually have participated in the formation of these objects (for a review, see J. Primack, 1984).

The fact that supersymmetric dark matter would cluster in galaxies, etc. leads to a possible solution to a second dark matter puzzle related to the dynamics of these gravitationally bound systems. For example, the rotational velocities of stars within galaxies suggests that the true mass of a galaxy is much larger than that which can be ascribed to its visible components. Indeed, the rotational dynamics of galaxies suggests that as much as 90% of their mass is dark matter, which surrounds the galaxy in the form of an invisible "halo." Cold dark matter, such as supersymmetric dark matter, can thereby provide a simultaneous solution to both the universal and galactic dark matter puzzles.

It may be that supersymmetric dark matter in the galaxy is observable (Silk et al., 1985). Galactic photinos passing through the sun would scatter and become trapped at a predictable rate. As photinos accumulate within the sun, the probability that two photinos will collide and annihilate increases. An equilibrium concentration results when the rate at which photinos annihilate is equal to the rate of trapping. The annihilation of photinos can give rise to neutrinos in the final state, which can easily escape the sun due to their weak interaction with matter. These neutrinos would strike the earth at a calculable rate and could then be observed in underground detectors designed to look for proton decay. For photino masses greater than 6 GeV and less than **0(40)** GeV, the estimated neutrino fluxes can easily exceed the isotropic cosmic ray neutrino flux backgrounds, and are therefore potentially observable (Hagelin et al., in press).

Rather than attempt an exhaustive survey of the numerous experimental proposals for discovering supersymmetry at various experimental facilities, we would like to discuss a long-standing problem of fundamental importance to which supersymmetry has recently brought great hope.

1.5 Quantum Gravity and Supergravity

Since the publication of his ***Principia*** in 1686, Newton's inverse square law of gravity has continued to provide an adequate computational framework for nearly all terrestrial and celestial applications. However, it became clear near the beginning of this century that Newton's gravitational theory would require substantial modification in order to be compatible with Einstein's special relativity. This, in part, led Einstein to develop his general theory of relativity, an elegant geometrical framework in which gravity is viewed as the curvature of space-time geometry.

Einstein's theory led to more precise computations of conventional gravitational phenomena as well as to entirely new predictions, such as the bending of light in a gravitational field and the formation of black holes. However, it was soon after the introduction of general relativity that quantum mechanics replaced classical mechanics as the foundational theory of nature, and that the classical theory of general relativity was recognized to be fundamentally incomplete.

During the past few decades, there have been many attempts to reformulate Einstein's general relativity as a quantum theory. These efforts have been largely unsuccessful. One positive outcome has been the realization that the force of gravity must be described by a massless spin-2 "graviton" field. This spin is sufficient to guarantee that the gravitational force will attract all objects proportionally to their mass-energy. It is this universally attractive nature of the gravitational field which lends itself to a geometrical interpretation. In this respect, gravity is different from the other fundamental forces, which have spin-1 and therefore possess both attractive and repulsive aspects.

A quantum theory of gravity raises fundamental questions concerning the structure of space-time and the causal framework on which our understanding of nature rests. It is relatively easy to understand why this is so based on our previous consideration of quantum field theory. We can apply our description of a quantum field to the field of space-time geometry itself, since the field of gravity can be viewed as the curvature of space-time geometry. The uncertainty principle then implies that space-time itself cannot have a definite shape, but instead exists as a quantum-mechanical superposition of shapes (see Figure 1).

This fact has profound implications regarding the nature of time and distance. The measured distance between any two points A and B depends upon the curvature of the geometry in which one imbeds one's measuring stick. Since many geometries coexist simultaneously, the distance between any two points is not well-defined. The concept of distance has, at best, a statistical meaning, pertaining to measurements that are repeated numerous times.

In practice, when we measure distances at laboratory scales, we are effectively averaging over such quantum fluctuations, since the time and distance scales over which measurements are typically sustained are very large compared to the scale of such quantum fluctuations. The scale at which quantum gravitational effects are expected to become important is the Planck scale: $D_{Pl} \cong 10^{-33}$ cm, $T_{Pl} \cong 10^{-44}$ sec, or $E_{Pl} \cong 10^{19}$ GeV, depending on whether we characterize the Planck scale in terms of distance, time or energy. The Planck scale defines an intrinsic uncertainty in our ability to assign a definite length or time interval.

The inability to specify time and distance precisely results in a corresponding indefiniteness in the notion of causality. In the usual space-time framework of special relativity, the causal relationship between two events is strictly defined by whether or not a light signal originating from an initial event A could reach a subsequent event B in time to influence it. If so, event B is said to be in the future light cone of event A. Because the speed of light represents the ultimate velocity for the propagation of information in special relativity, event A can causally influence B if and only if B lies in the future light cone of A. Moreover, if B lies outside the future light cone of A, it becomes impossible to specify whether event A or event B occurs first, for this will now depend upon the state of motion of the observer. In such a case, where neither event lies within the other's future light cone, the events are said to be "space-like separated" and no causal relationship or influence between the two events is possible. Thus, two events have a well-defined temporal sequence only if one event lies within the future light cone of the other.

Due to the intrinsic uncertainty in the definition of time and distance in quantum gravity, it is generally not possible to specify with certainty whether one event lies within the future light cone of another, hence the sequence of events is not well defined. Under these circumstances, it becomes difficult to assign cause and effect relationships, and there is little reason to believe that the familiar concepts of space, time, and causation have meaning at the Planck scale.

Moreover, the dynamics of the gravitational field possess an intrinsic nonlinearity which makes these quantum fluctuations even more interesting. Because gravity is attracted to mass-energy, and because these gravitational fluctuations can themselves possess significant mass-energy, gravitational fluctuations can be strongly self-attracting. The Planck scale is the scale at which the energy inherent in these quantum fluctuations is so great that these gravitational fluctuations become profoundly modified by their own self-interaction. This nonlinear dynamics is expected to produce a phase transition in the structure of space-time geometry at the Planck scale, in which the microscopic structure of space-time can assume a multiply-connected or "foamy" structure (Harrison et al., 1965).

Certain implications of these *topological* fluctuations for physics at ordinary scales have been explored (Zel'dovich, 1976; Hawking et al., 1979, 1980). One possible consequence is that spin-0 particles propagating through a background of space-time foam would receive a large gravitational contribution to their mass of order $M_{Pl} \cong 10^{19}$ GeV/c^2. This would appear to compound the gauge hierarchy problem regarding the lightness of the Higgs field needed for the breaking of the electro-weak symmetry, were it not for the fact that supersymmetry can again protect the Higgs from acquiring large masses through this mechanism.

A second class of behavior that can arise as a result of topological fluctuations is nonlocal effects. It seems plausible that multiply-connected geometries could result in nonlocal influences. Hawking has identified one such class of effects that appears to require a nonlocal interpretation. He has demonstrated that initially pure quantum-mechanical states can evolve into mixed states as they propagate through a background of gravitational "knots" or instantons (Hawking, 1982, 1984).[7]

The key point here is that the evolution of pure states into mixed states cannot (Hawking, 1984) be accommodated within a local framework, or even a framework that is local on scales much larger than the Planck length, for such would necessarily involve unacceptably large violations of energy and momentum conservation (Banks et al., 1984). Such an effect therefore requires a nonlocal framework relating pure states in the infinite past to mixed states in the infinite future.

Further progress in quantum gravity during the past quarter of a century has been blocked by serious technical difficulties. The quantization of Einstein's general relativity leads to problems when quantum-mechanical contributions to gravitational processes are computed. These quantum-mechanical contributions, which result from Feynman loop diagrams, appear to be infinite, whereas such quantum corrections are known to be very small. Many years of research in quantum gravity have found no simple solution to this difficult problem, which has led to a consensus among theorists that general relativity as a quantum theory is fundamentally inconsistent.

One clue to the solution to this problem is that the formal behavior of the theory is improved if all the force and matter fields apart from gravity are removed from the theory: pure, self-interacting gravity has been shown to be free of infinities resulting from Feynman diagrams containing up to one loop. This technical improvement suggests an avenue for progress, wherein gravity is ***unified*** with other fields through supersymmetry. Rather than introducing other fields into the theory in an arbitrary way, if the gravitational field itself were expanded through supersymmetry to incorporate other spin types, perhaps the formal behavior of the theory would be as good as for pure self-interacting gravity. Such an approach turns out to be very successful. The extension of the gravitational field by supersymmetry to include additional spin types preserves all the technical advantages of pure, self-interacting gravity, and in many cases improves them (for a review, see van Nieuwenhuizen, 1981).

The application of supersymmetry to quantum gravity is called ***supergravity.*** The simplest example of a supergravity theory is N=1 supergravity, in which gravity is unified with its nearest spin neighbor—the spin-3/2 ***gravitino*** field. For such a theory to be realistic, it is also necessary to add the other known force and matter fields into the theory, which can also be done in a supersymmetric way, as in the N=1 supersymmetric models discussed earlier. Although a great deal of attention has been given to these N=1 supergravity models, which provide a highly successful description of physics at energies well below the Planck scale, as a fundamental theory they are inadequate. In these theories, only the gravitino is actually unified with gravity: force fields and matter fields are still added to the theory as separate fields, and infinities reappear once these fields interact with gravity.

It would therefore seem desirable to extend the principle of supersymmetry so that more fields can be unified with gravity in a fundamental way. It turns out that such "extended" supergravity theories are not difficult to formulate. The number of spin types that can be unified with the spin-2 graviton can be sequentially expanded to include spin 3/2***, 1, 1/2*** and 0. N=1 supergravity is the simplest theory, in which only one other spin type, spin-3/2, is unified with gravity via supersymmetry. In N=2 supergravity, two other spin types, spin-3/2 and spin-1, become unified with gravity, and so forth. The maximum number of supersym-

[7]**This effect can be viewed as a violation of unitary time evolution as a result of quantum-mechanical phase information falling irreversibly across gravitational event horizons associated with micro black holes (Hawking, 1984).**

merries is N=8, since any larger number would necessarily introduce fields with spins greater than 2. It is widely held to be impossible to construct quantum field theories involving spins greater than 2, since such theories contain infinities that appear to be fundamentally incurable. N=8 supergravity is therefore the largest and richest supergravity theory one can construct.

The formal properties of N=8 supergravity are remarkably good for a quantum field theory of gravity involving many other spin types. N=8 supergravity is known to be free of infinities for Feynman diagrams with as many as three loops, and it is conceivable that N=8 supergravity may be free of infinities altogether, although at present this seems unlikely. The absence of infinities in the N=8 theory for diagrams with up to three loops does not occur by magic, nor is it simply the attitude or conviction that all fields are unified with gravity which renders the theory finite. It results from a precise cancellation of infinities among the many loop diagrams that contribute to a given scattering process. Such cancellations occur as a result of the precise number and nature of the different spin components united by supersymmetry. Taken together, these spin components constitute a unified family of fields known as the N=8 supermultiplet (see Table 2).

N=8 Supermultiplet

Spin:	2	3/2	1	1/2	0
Multiplicity:	1	8	28	56	70

Table 2. The particle content of the N=8 supergravity theory.

It follows that the number and type of fields present in a unified supersymmetric theory is strictly determined, which gives the theory considerable predictive power. For example, one can examine the particle content specified by N=8 supergravity theory to check whether or not it resembles the observed elementary particles in nature. Comparing Table 2 with the observed structure of elementary particles in Table 1, one finds an apparent discrepancy between the number of fields associated with each spin type. For example, there are 28 spin-1 fields belonging to the N=8 supermultiplet, which is in apparent conflict with the 8 strong interaction gluons, 3 weak bosons, and 1 photon, which is a total of 12 spin-1 force fields seen in nature.

Furthermore, the 12 known force fields do not fit mathematically within the 28-member structure of the N=8 supermultiplet. The formal structure of the relationship of the 12 force fields among themselves shown in Figure 5 is such that they cannot be made to fit within the structure of the supermultiplet. (The situation is analogous to fitting a tall cigar into a wide-mouthed jar—the volume may be sufficient but the shape is inappropriate.) One is forced to conclude that the N=8 supermultiplet is simply not big enough to accommodate the observed force fields of nature, let alone the extra spin-1 forces required for grand unification. The same conclusion applies to the spin-1/2 matter fields—the 56 spin-1/2 members of the N=8 supermultiplet are insufficient to account for three "generations" of quarks and leptons (Table 1).

One possible way out of this problem is the creation of additional force fields through the binding of spin-0 fields within the supermultiplet into spin-1 bound states (Ellis, 1983). This mechanism is suggested by the presence of a hidden symmetry in the structure of the N=8 theory, in which pairs of spin-0 fields formally behave like spin-1 force fields (Cremmer and Julia, 1979). If a physical binding of these spin-0 fields were to occur, there would be 63 resulting spin-1 fields that could uphold a rich, SU(8) grand unified structure. These 63 force fields would include the 24 force fields required by an SU(5) grand unified theory (Figure 5), which in turn would include the 12 familiar fields responsible for the strong, weak and electromagnetic forces.

Furthermore, if such a binding of spin-0 components within the N=8 supermultiplet were to occur, it is reasonable to assume that a similar binding would occur among all the other components of the N=8 supermultiplet in a symmetric way. This provides a possible mechanism for the production of additional spin-½ matter fields, which appear to have the structure needed to account for the known matter fields.

This binding process also leads to the formation of states with spin >2, which typically result in an inconsistent theory. These do not represent a fundamental problem here since they are not fundamental components of the theory—they are simply bound states of more fundamental constituents with spin ≤ 2. They may however represent a phenomenological problem, since these higher spin particles are not seen at ordinary energies. These higher spin states would have to be exorcised from any realistic theory, possibly by giving them a large mass, although it is presently not obvious how to do so. It is also not clear that the binding of components within the supermultiplet needed to accommodate the observed particles and forces actually occurs in the N=8 supergravity theory, and the problem of gravitational infinities beyond three loops remains a fundamental problem which has to be addressed before this theory can be considered realistic.

It is worth noting that N=8 supergravity has a more elegant, compact and powerful formulation in $10 + 1 = 11$ space-time dimensions (Duff et al., 1986; de Wit and Nicolai, 1984). One can formulate the N=8 supergravity theory as a much simpler N=1 supergravity theory in 11 dimensions, which when viewed from the usual $3 + 1$ dimensional perspective appears as the more complicated N=8 theory. The extra $11 - 4 = 7$ spatial dimensions occurring in this formulation might be real physical dimensions of space-time, or they may simply represent a formal construction invented to simplify the theory. There is a growing theoretical preference to regard these extra dimensions as real, in which case one has to explain why these extra dimensions of space-time are not ordinarily observed.

The answer lies in *space-time compactification*, a process in which the extra dimensions of space-time, for dynamical reasons, get spindled into tubes of such small radius that they are unobservable. Starting from the 11-dimensional theory, there are several geometrically distinct ways in which the extra dimensions can be compactified. These result in different $3 + 1$ dimensional theories at low energies, only one of which corresponds to the N=8 supergravity theory described above. As a second example, it may be possible starting from 11-dimensional supergravity to obtain an N=1 supersymmetric theory in $3 + 1$ dimensions. These alternative possibilities give the 11-dimensional approach greater flexibility in addition to its simplified mathematical structure.

I.6 The Heterotic String

Within the past several months, supergravity has been displaced in the affections of theorists by the $E_8 \times E_8$ heterotic string theory (Schwartz, 1982; Green, 1983; Gross et al., 1985; Candelas et al., 1985; Witten, 1985; Dine et al., 1985). Superstring theory is a natural extention of the framework of quantum field theory which may provide both an elegant framework for the unification of all the fundamental particles and forces and a quantum theory of gravity that is completely free of infinities.

A superstring theory is fundamentally a quantum field theory of elastic strings. As a quantum theory, it stands in relation to a classical string as quantum field theory stands in relation to a classical particle (see Figure 7). A classical particle is a point-like object described by a definite position x. A string is a one-dimensional extended object described by a position function $x(\sigma)$ that depends on a "string parameter" σ, which specifies where one is on the string (Figure 7). Whereas a classical particle has no internal structure and possesses only the ability to move through space, a string has the added ability to sustain internal modes of vibration. A vibrating string therefore has a much richer spectrum of energies than a simple particle in motion. This richness is reflected in the energy levels of a quantized string field, which have a more complex structure than those of a quantum field theory of elementary particles.

The spectrum of string excitations includes a number of "massless" modes and an ascending tower of "massive" modes corresponding to more and more excited vibrational states of the string. Because the distance scale associated with the length of the string is of the order of the Planck length, the uncertainty principle states that the energies associated with these higher vibrational string modes are of the order of the Planck energy. In the low-energy limit of the theory relevant to physics below the Planck scale, only the massless modes of the string play an important role. In this low-energy limit, the string theory resembles an ordinary quantum field theory of elementary particles. There is nothing in the world of observable scales and measurements that could reveal that these elementary "strings" possess a one-dimensional structure or are otherwise any different from elementary "particles."

However, one important difference does arise when we consider the formal properties of gravity in the context of the string theory. The spin-2 graviton comprises one of the massless modes of the string, which has all the usual properties and problems of the graviton in any other field theory. However, in the case of the string theory, the massless modes of the string are supplemented by massive string modes. These massive string modes will modify any field theoretic calculation at high energies, and they lead to a precise cancellation of the infinities that result from the graviton alone. In this way, the string theory provides what seems to be a completely consistent, finite theory of gravity—something which is apparently not possible within the framework of an ordinary quantum field theory.

The $E_8 \times E_8$ heterotic string is a theory of interacting "closed" strings. A closed string is a string in which the two ends are tied together to form a continuous unbroken loop. For mathematical consistency, the heterotic string is necessarily formulated in $9 + 1 = 10$ space-time dimensions. The ordinary $3 + 1$ dimensional structure of space-time is recovered upon compactification of the extra $9 - 3 = 6$ spatial dimensions.

This string theory has no free parameters: the structure of the theory is completely determined by geometric principles. This gives the theory remarkable predictive power, provided one's computational tools are sufficient to unfold its dynamics. The massless modes, which comprise the low-energy or "field theory" limit of the theory are in principle determined by the underlying structure of the theory. This low-energy limit looks like a supersymmetric field theory containing two E_8 families of force fields in addition to the graviton and

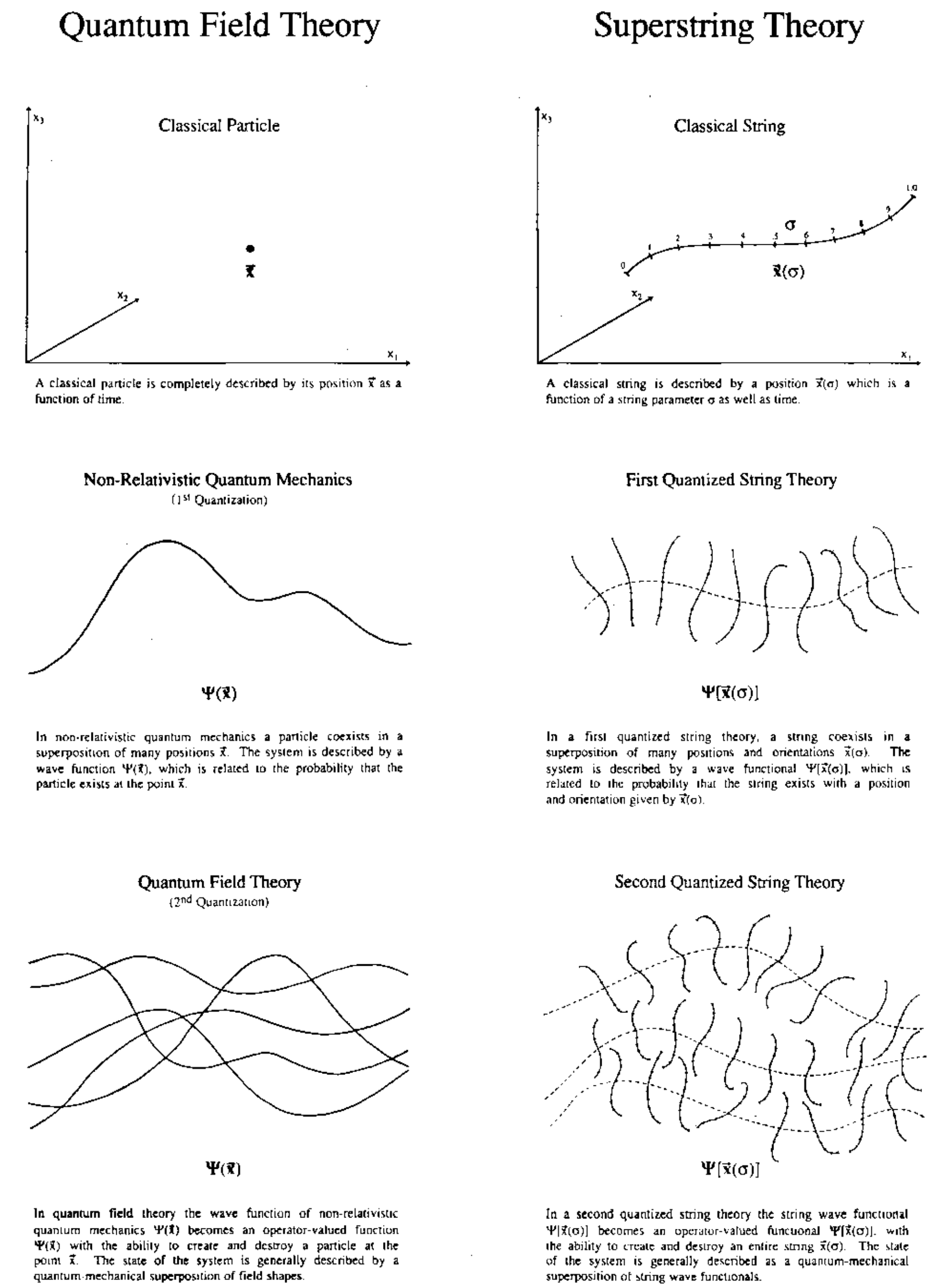

Figure 7.

gravitino. One of the E_8 families contains the familiar spin-1 force fields along with their spin-$^1/_2$ supersymmetric partners. The fields associated with the other E_8 family decouple from the observable universe—they do not interact with ordinary matter except through the force of gravity. It has been a source of speculation that this "invisible" E_8 family might be a natural candidate for the dark matter needed to close the universe and to explain the gravitational dynamics of galaxies and galactic clusters. Such hopes are probably misplaced, since there is not expected to be much of this "shadow matter" left in the universe today.[8] However, there is a natural dark matter candidate in the visible E_8 sector of the superstring theory. In realistic low-energy models derived from the superstring (Ellis, Enqvist et al., 1985, 1986), the lightest supersymmetric particle (LSP) is similar to that of previous supersymmetric theories, namely a gaugino-Higgsino mixture which is predominantly a photino (Campbell et al., 1986). However, in the superstring case, the mass and composition of the LSP are more tightly constrained, leading to a more definite prediction for the density of dark matter in the universe today. Fortunately, this prediction agrees remarkably well with the estimated quantity of dark matter required to close the universe. The superstring theory therefore appears highly successful from a cosmological standpoint.

There are many other phenomenological predictions from the superstring, limited only by our calculational ability to unfold its detailed dynamics. As a consequence of the compactification from 10 dimensions to 4, the E_8 symmetry associated with the visible sector is broken at the Planck scale to a smaller grand unified symmetry known as E_6, or possibly to a subgroup of E_6. E_6 is one of the few generalizations of SU(5) that is known to provide a realistic grand unified theory. At the same time, the extra 6 dimensions of space which undergo compactification form a compact geometric manifold that has its own states of vibration. The massless vibrational modes associated with this manifold give rise to the appearance at low energies of several generations of matter fields, which provide natural candidates for the quarks and leptons along with their supersymmetric partners. According to the underlying E_6 symmetry, each generation contains twenty-seven matter fields as opposed to the fifteen quarks and leptons associated with each generation in the standard low-energy theory (Table 1).[9] The extra twelve fields represent new particles predicted by the superstring, which include an extra charge - 1/3 quark and a pair of Higgs doublets that can be used to break the weak interaction symmetry.

A key feature of these theories is that they are supersymmetric. The supersymmetric structure of the underlying 10-dimensional string theory survives the compactification process, leading to precisely the type of low-energy supersymmetric model that has successfully been used to address the gauge hierarchy problem.

Thus superstring theory, in addition to providing the first consistent quantum theory of gravity, automatically leads to a realistic low-energy structure in which the gauge hierarchy is naturally protected by supersymmetry. These are significant achievements which were not possible in the context of previous unified field theories based on supergravity. These achievements have resulted in a consensus among many theorists that the $E_8 \times E_8$ heterotic string theory may ultimately provide the fulfillment of Einstein's quest for a completely unified understanding of the fundamental particles and forces of nature.

[8]The hidden sector gauge interactions are expected to become strong at some high mass scale and have a spectrum of bound states which are gauge and flavor singlets. There is therefore no quantum number to prevent them from decaying gravitationally into pairs of observable sector particles, and thus one does not expect the hidden sector to contain a stable dark matter candidate.

[9]Each of the matter fields in Table 1, with the exception of the neutrinos, has both a left-handed and a right-handed polarization state, leading to a total of 15 states for each generation of quarks and leptons.

Part II:
Consciousness and the Unified Field

Progress towards a foundational theory of consciousness has recently become possible through the investigation of the simplest and most fundamental structures of awareness using experiential technologies provided by Vedic science. These fundamental states of consciousness have been observed to possess a close structural correspondence to the physical structure of natural law at fundamental scales. Indeed, the discovery of a unified field of consciousness at the foundation of conscious experience has prompted the proposal that this unified field of consciousness and the unified field of modern theoretical physics are identical, providing a possible framework for a completely unified understanding of both subjective and objective existence.

Following a brief historical perspective, we will review the research pertaining to this unified state of consciousness. In light of this research, we will consider the proposal made by Maharishi Mahesh Yogi that the unified field of modern theoretical physics and the field of pure consciousness are identical. We will then discuss recent experimental evidence in support of field effects of consciousness predicted on the basis of this proposal. We will show that the proposed identity between pure consciousness and the unified field is consistent with all known physical principles, but requires an expanded physical framework for the understanding of consciousness which leads to a more integrated picture of the physical world and the full range of human experience. Indeed, such a framework appears to be required to account for experimentally observed field effects of consciousness and other phenomenological aspects of higher states of consciousness, which are otherwise anomalous within the paradigms that are currently in vogue.

II.l Historical Perspectives

In our previous discussion of unified quantum field theories, there has been no reference to consciousness or to any subjective aspect of experience. Indeed, the empirical approach of modern science has been designed to remove the element of subjectivity as much as possible from the field of scientific investigation. The term "consciousness" has been excluded from science largely because it has been too vague and indefinite in its meaning to lend itself to scientific discussion. Moreover, because consciousness by its very nature can never be the object of sensory experience, it would seem to lie outside the realm of objective investigation.

This same empirical approach has come to dominate the field of psychology, which has adopted a behavioral approach to the study of human interaction. Indeed, of the more than forty divisions of the American Psychological Association, none are directly concerned with the phenomenon of consciousness ***per se.*** Each of these divisions is concerned only with a specific and isolated aspect of conscious experience (Knibbeler, 1985). Within this empirical framework, no single, foundational theory of consciousness comparable to a unified quantum field theory in physics has emerged. Thus there remains a critical need in modern psychology to develop a single, comprehensive theory of mind and consciousness that can account for the structure and full range of mental processes (Vroon, 1975).

Now, for the first time in history, Maharishi Mahesh Yogi has provided a highly coherent theoretical account of what consciousness is and how it relates to the objective field of investigation. Even more importantly, he has provided a reliable, systematic method by which consciousness can be isolated and directly experienced in its most fundamental state.

Maharishi's work, which will be further outlined in subsequent sections, is based on his revival of an ancient science of consciousness known as Vedic science. Vedic science gives consciousness a unique ontological status. According to the Vedic tradition, consciousness is not an emergent property of matter that comes into existence through the functioning of the human nervous system, but is considered fundamental in nature. It is the essential core of life—a vast, unbounded, unified field which gives rise to and pervades all manifest phenomena (Maharishi Mahesh Yogi, 1966; ***Bhagavad Gita,*** 1975; Sankaracharya, 1977; ***Principal Upanishads,*** 1974). The nature of consciousness which is said to characterize this unified field is ***pure consciousness—an*** abstract, unbounded field of consciousness which is not qualified by any object or individual experience. From this viewpoint, the crucial role of the human nervous system is to provide a material structure of sufficient integrated complexity to reflect, qualify and individualize consciousness, providing the potential for individual experience (Maharishi Mahesh Yogi, 1977; Dillbeck et al., 1986).

The Vedic tradition also holds that it is possible for the individual to experience pure consciousness—the essential nature of consciousness itself. For this to occur, individual consciousness must be allowed to experience its "pure, self-interacting state," in which consciousness is awake only to itself, rather than identified with objects of perception, thought, or feeling. In this state, the knower, the process of knowing, and the known are said to be unified, since consciousness itself constitutes both the knower and the content of experience (Maharishi Mahesh Yogi, 1985, pp. 64-66). A systematic refinement of the functioning of mind and body is said to be necessary for this experience to take place, and a set of procedures for such a refinement is described in the Vedic texts (Maharishi Mahesh Yogi, 1966, 1969; Patanjali, 1978).

Although historically this perspective has inspired a number of thinkers within psychology and philosophy, its empirical consequences have lain dormant for lack of availability of the experiential procedures critical to validating the theoretical principles. Over the past thirty years, however, Maharishi has revived the experiential and empirical basis of this knowledge through a simple mental technology taught to over three million people around the world and has stimulated scientific research on its effects (Chalmers et al., in press; Orme-Johnson and Farrow, 1977). At the same time, by reformulating the theoretical basis of Vedic knowledge in a scientific framework that is accessible and empirically testable, he has placed the Vedic knowledge in a position to enter the intellectual mainstream of the West and revived it in the East as well. This modern scientific formulation of the Vedic knowledge is known as Maharishi Vedic Science (Maharishi Mahesh Yogi, 1985).

The Vedic perspective, in which consciousness occupies an ontologically fundamental position, contrasts with the largely mechanistic view of nature characteristic of our particular time and culture. This mechanistic world view is the product of more than three centuries of scientific investigation dedicated almost entirely to the analysis of macroscopic, inert matter. The extremely inert and mechanical view of nature that has emerged from the physics of prior centuries defines a certain ***paradigm*** or world view which is deeply inscribed in our thinking and in our educational institutions (Kuhn, 1970). This paradigm would seem to preclude the possibility that nature could possess in any fundamental sense the lively and dynamical characteristics that we normally associate with consciousness.

According to this inherited perspective, consciousness is entirely the product of complex biochemical processes occurring within the brains of man and other higher animals. Thus to impute conscious characteristics to nature (or specifically to the unified field) is, according to this perspective, to ***anthropomorphize.*** It must be emphasized, however, that this point of view is merely one among many. It has no direct foundation in knowledge and should not therefore be formally associated with science. At present, it represents only a particular ***metaphysics,*** and one which is not well supported by facts. Within this limited framework, for example, there has been essentially no progress in the development of a consistent interpretation of the quantum theory in the last half century (Herbert, 1985). We will also see that this view of consciousness is incompatible with a growing body of data in the domain of individual and collective consciousness.

There are many indications that consciousness may require a more fundamental position in our conception of nature. Within particle physics, for example, many authors have noted the emergence at fundamental scales of characteristically subjective qualities, such as dynamism, intelligence, and attributes of self-awareness (Davies, 1984, pp. 104-112; Llewellyn Smith, 1981; Pagels, 1982). Dynamism, for instance, results from the fact that quantum-mechanical operators associated with position and momentum do not commute,[10] leading to a reciprocal relationship between distance and momentum known as the ***uncertainty principle,*** which results in the fact that nature becomes increasingly energetic at more fundamental space-time scales. The vastly greater energy associated with nuclear transitions compared with chemical transformations provides a practical demonstration of the increasing dynamism intrinsic to more fundamental scales. An extension of the same principle to the scale of super-unification leads to an estimated energy density of 10^{112} ergs per cubic centimeter [i.e., one Planck energy (1.2×10^{19} GeV/c^2) per Planck volume $(10^{-33}\ \mathrm{cm})^3$]. This can be compared to the observable mass-energy of the known universe, which is an estimated 10^{80} ergs.[11] Hence the historically inert view of the universe resulting from the investigation of macroscopic matter is a poor characterization of nature at microscopic scales.

It may also be said that "intelligence" is more concentrated at fundamental scales. This can be seen, for instance, in the context of grand unified theories, in which the strong, electromagnetic and weak interactions become unified components of a single field whose behavior is governed by a single compact expression. Since the laws of nature formally express the order and intelligence governing the behavior of natural phenomena, as the laws of nature become more compact and concentrated, intelligence can be said to become more concentrated. If, as particle theorists are inclined to believe, all the laws of nature have their ultimate origin in the dynamics of the unified field, then the unified field must itself embody the total intelligence of nature's functioning.

From a field theorist's perspective, an attribute of "self-awareness" can be seen in the ***non-Abelian*** property of self-interaction present in unified, non-Abelian gauge fields. An example of an ***Abelian*** field is electromagnetism, which governs most phenomena at macroscopic scales. Because the equations governing the electromagnetic field are linear in the field strength, the electromagnetic field does not possess the self-interacting property of a non-Abelian field. As a consequence, two rays of light pass through each other with no interaction and hence no "awareness" of the other's presence. A non-Abelian field, such as the gluon field of quantum chromodynamics, a grand unified field or a super-unified field, possesses the nonlinear property of self-interaction which is not found in an Abelian

[10] Please refer to Part I of this article for details regarding these and other technical subjects where necessary.

[11] Assuming $\Omega = 1$ and a closed Friedman universe.

field. **As a consequence, a** non-Abelian field responds dynamically to its own presence.

As these characteristically subjective qualities begin to emerge, much of the objective character of macroscopic matter begins to disappear at microscopic scales. The concrete notion of a particle is supplanted in nonrelativistic quantum mechanics by a more abstract and unlocalized wave function, which represents only the probability for a particle to exist. In a second quantized field theory, this wave function (which is technically a field) is replaced by a still more abstract and unlocalized quantum field, in which the state of the field is described by a wave functional, representing only the probability that a given field shape exists (see Figure 7). Furthermore, in the context of quantum gravity, even the essential framework of space-time itself becomes indefinite, being replaced by a quantum-mechanical superposition of space-time metrics. Thus one could argue that as certain subjective characteristics become more dominant, the concrete and objective nature of existence starts to become more tenuous at fundamental scales.

One interpretation of these observations is that the distinction between "subjectivity" and "objectivity" becomes less meaningful at microscopic scales. This point has already become clear in the context of quantum measurement. Because the uncertainty principle implies that the act of measurement inevitably disturbs the system under observation, the classical notion of an objective and independent observer is inconsistent with the structure of quantum-mechanical reality. Indeed, one of the few significant developments in the understanding of the measurement process is based on a framework in which the quantum-mechanical system and the measurement apparatus are formally treated as a single quantum system evolving under the influence of a Schroedinger-like equation (Hepp, 1972; Bell, 1975; Zurek, 1982, 1983). From this viewpoint, the separation between the observer and the observed is seen as a rather artificial construction from a mathematical standpoint. Thus the clear separation between the observer and the observed, which is the cornerstone of modern empiricist thinking, is ultimately a conception whose utility may be limited to the classical domain.

According to Vedic science, the separation between the observer and the observed **is** a matter of viewpoint only. It represents a particular perspective which is viable only on a gross sensory level, but which must ultimately be abandoned for a fully consistent understanding of self and the environment (Maharishi Mahesh Yogi, 1985; Sankaracharya, 1977; Patanjali, 1978). The unified field, experienced as the most fundamental state of human awareness, is considered to be **a** level of reality at which such a separation cannot be inferred. The experience of the unified field of consciousness, in which the observer, the process of observation and the observed are unified, is considered to be a means of realizing the ultimate inseparability of the observer and the observed, leading to a completely unified view of self and the environment traditionally known as "enlightenment" or "unity consciousness" (Maharishi Mahesh Yogi, 1966, 1985).

The structure of the unified field from the standpoint of modern theoretical physics is consistent with this view in which the unified field is both a subjective and an objective reality. Since it is generally assumed that the unified field is the only dynamical degree of freedom present at the super-unified scale, to the extent that a subject-object relationship can be defined there at all, the "observer" and the "observed" must both be found within the dynamical self-interaction of the unified field itself. From this perspective, the unified field is formally **as** much a field of subjectivity as a field of objectivity. Hence the proposed identity between the "objective" unified field of modern theoretical physics and a "subjective" unified field of consciousness is consistent from a logical standpoint.

Most particle theorists would agree that the unified field is the source of both subjective and objective existence. This is because most physicists would like to avoid the necessity of introducing anything external to the laws of physics, such as a metaphysical explanation for consciousness, feeling that the unified field should be the dynamical origin of all phenomena. This point of view has been frequently attacked by individuals outside the sciences as being too "reductionistic," i.e., reducing one's inner experience to the "billiard ball" behavior of elementary particles. This objection may result from a misunderstanding of the nature of physics at fundamental scales, which is not mechanical in the Newtonian sense, but is increasingly dynamic and subtle. Recall that the classical notion of a particle is supplanted in the nonrelativistic quantum theory by a more abstract and unlocalized wave function, which in turn gets replaced by a still more abstract and unlocalized quantum field in a second quantized theory. Thus "reducing" subtle mental phenomena to the Poincare invariant dynamics of a unified quantum field might more accurately be described as "expansionism" as opposed to reductionism.

II.2 A Unified Field of Consciousness

A detailed consideration of the relationship between the unified field and consciousness would benefit from a precise and comprehensive theory of consciousness comparable to the understanding of the unified field available through modern theoretical physics. Unfortunately, no single, comprehensive theory of consciousness has historically been available. In fact, psychologists have avoided theorizing about consciousness because they have felt conceptually ill-equipped to do so. According to Neisser (1976), "To tackle the issue of consciousness [within the framework of existing ideas] would lead only to philosophically naive and fumbling speculation." Thus there still remains a critical need in modern psychology for a single, comprehensive theory of consciousness that can account for the structure and full range of mental processes (Vroon, 1975).

Progress in the direction of a foundational theory of consciousness has recently been made possible through the investigation of the simplest and most fundamental structures of awareness using experiential technologies provided by Maharishi Vedic Science.

In this section, we will attempt to summarize and interpret some of the most important and relevant experimental and theoretical developments in this field. Throughout this investigation, it will be useful to consider consciousness from the most universal perspective, resisting the egocentric tendency to confine one's view of consciousness to the very limited range of ordinary waking experience. Indeed, much of the recent progress in this field has come from accessing a broader data base of conscious experience than has traditionally been available through the waking, dreaming and deep sleep states of consciousness.

Waking consciousness is a complex form of awareness which results from an excited state of the brain physiology. As a consequence, it has been difficult to construct a simple and coherent theory of consciousness based on the analysis of waking experience. This obstacle has prevented any single, universally accepted theory of consciousness from arising in the field of psychology. This situation would be analogous in physics to developing the quantum theory through an analysis of complex macro-molecules in a high temperature environment (Domash, 1977). The solution in physics is to replace the complex macro-molecule with the hydrogen atom. Similarly, in psychology the solution primarily comes from studying simpler, more fundamental structures of awareness.

Whereas waking consciousness represents a complex form of awareness corresponding to a complex state of neurophysiological functioning, the brain is also capable of sustaining simpler and more integrated states of functioning, corresponding to more silent and more unified states of awareness (Maharishi Mahesh Yogi, 1966, 1977; Wallace, 1986). These unified states are fundamental to the understanding of psychology from the classical Vedic perspective, and the Vedic texts prescribe specific procedures for the experience and investigation of these states (Maharishi Mahesh Yogi, 1966, 1969; Patanjali, 1978).

According to Vedic science, the mind is hierarchically structured in layers from gross to subtle, from excited to de-excited, from localized to unlocalized or field-like, and from diversified to unified. Underlying the subtlest level of mind is said to be the Self—a purely abstract, least excited, completely unified field of consciousness, identified as the dynamic and self-sufficient source of all mental processes (Maharishi Mahesh Yogi, 1966).

While we are typically aware of only the more active, surface levels of the mind which are engaged in thought, perception and action, according to Vedic science, every thought or perception undergoes a "vertical" microgenesis from a least excited, holistic or seed form to a more precipitated and concretely articulated manifestation until it is finally available to conscious awareness and participates in the process of experience and action (Maharishi Mahesh Yogi, 1966).

Hence Vedic science posits a vast realm of subtle levels of mind and cognitive processing that typically lies outside of conscious awareness. The traditional view in the psychodynamic literature is that the unconscious domain of mind serves as a repository for primitive or repressed thoughts and desires. In contrast, Vedic science describes deeper levels of the mind as causally prior, intrinsically more dynamic, abstract, comprehensive and unified—parallel to the structure of more fundamental levels in physics (Alexander, Davies et al., 1987).

Subjectively, these unified states of awareness arise when the mind systematically experiences, through a subjective technology, more abstract and fundamental stages in the development of a thought. As the mind thereby becomes less and less localized by the specific boundaries of a thought, awareness becomes correspondingly more expanded. When the faintest impulse of thought or feeling is "transcended" in this manner, consciousness is left alone to experience itself. In this state of ***pure consciousness,*** said to be the least excited state of consciousness, consciousness is experienced as an abstract, unbounded field (Maharishi Mahesh Yogi, 1966).

From a structural standpoint, ordinary waking consciousness is characterized by the threefold structure of "observer" (i.e., the lively field of subjectivity itself or ***rishi*** in the language of Vedic science), the "process of observation" (the mechanics of thought and perception or ***devata),*** and the "observed" (the content of experience or ***chandas)*** (Maharishi Mahesh Yogi, 1985). Thus, in the waking state of consciousness there is always an object of perception, whether this is a gross object of sensory experience, or a thought, or merely an abstract feeling. Although the object of perception provides the essential content of waking experience, both the observer and the process of observation are necessarily also present. At deeper levels of awareness, the object of perception is experienced as more intimate to the subject, i.e., the separation between the "observer" and the "observed," which is the defining characteristic of waking consciousness, becomes less distinct. In the state of least excitation or "ground state" of consciousness, the three essential components of waking experience—the observer, the process of observation, and the observed—are unified in one structure of "pure, self-interacting consciousness" known as ***samhita*** in Maharishi Vedic Science (Maharishi Mahesh Yogi, 1985).

This unified ground state of consciousness is marked by the onset of a unique complex of physiological and neurophysiological changes indicating profound integration and coherence of brain functioning. Physiological research on this unified state of awareness began in 1970 with the work of R.K. Wallace (1970).

This research, together with much of our discussion, focuses on the Transcendental Meditation (TM) and TM-Sidhi programs developed by Maharishi. The Transcendental Meditation technique has been described as a systematic means for taking the conscious mind from active levels of awareness to more abstract and fundamental levels of mental activity, resulting in the experience of pure consciousness. The TM-Sidhi program trains the individual to engage thought from the level of pure consciousness as a means to more quickly stabilize the experience of pure consciousness. There are several reasons for confining our discussion to this unique set of mental procedures:

1) The TM technique is widely practiced throughout North America and most of the world, resulting in the widespread availability of subjects with experience ranging from several months to over 25 years.
2) The TM technique is taught throughout the world in a highly standardized manner, which ensures that different subjects are practicing the identical mental procedure.
3) There now exists a large body of published scientific research on the physiological, psychological, and even sociological effects of the TM and TM-Sidhi programs. There is no comparable body of literature connected with other specific mental techniques, and an analysis of what literature is available finds little evidence that other meditative practices affect basic physiological or psychological parameters to the same degree (Eppley et al., in press; Ferguson, 1981).

It was Maharishi who originally proposed that each state of consciousness should be accompanied by a unique style of physiological functioning, and who thereby predicted that the experience of pure consciousness would have physiological correlates distinct from waking, dreaming, and deep sleep states of consciousness (Maharishi Mahesh Yogi, 1966, p. 132-134). This prediction motivated Wallace's original research on the TM technique, which found evidence from studies of the electroencephalogram (EEG), skin resistance, and metabolic indicators that a fourth state of consciousness might indeed be occurring during the TM practice (Wallace, 1970; Orme-Johnson, 1973).

Subsequent research has produced a variety of physiological and biochemical data indicating that the state occurring during TM differs markedly from eyes-closed relaxation and that the repeated experience of this state is accompanied by lasting changes in the style of physiological functioning (see reviews by Alexander et al., 1986; Wallace and Jevning, in press). Many of the observations appear to fall into one of the following three categories: (1) indicators of deep rest, which include alternative breathing patterns, reduced blood lactate, and decreased glycolytic metabolism (Jevning et al., 1983; Wolkove et al., 1984; Jevning et al., 1985; Kesterson, 1986); (2) signs of increased alertness, such as faster reaction times and faster recovery of motor reflexes (Appelle and Oswald, 1974; Haynes et al., 1977; Wallace et al., 1983); and (3) indications of reduced levels of stress and improved resiliency to stressful experiences, for example, lowered plasma **Cortisol** and faster recovery of normal galvanic skin resistance following a loud noise (Jevning, Wilson and Davidson, 1978; Orme-Johnson, 1973).

A recent in-depth study of breathing patterns during TM (Kesterson, 1986) concluded that a highly distinctive feature of the physiology of meditation is the maintenance of alertness along with reduced sensitivity to CO_2, hypoventilation, apneustic breathing, and decreased respiratory quotients.

The improved resistance to stress, which appears to be a direct result of the regular practice of TM, may be explained in part by an increase in neuromodulators such as serotonin (Bujatti and Riederer, 1976; Walton et al., in press). Serotonin appears to exercise a global influence on brain systems related to conscious experience and alertness (Jacobs, 1985) and is also capable of mediating the increased prolactin levels seen in TM (Jevning, Wilson and VanderLaan, 1978) as well as the decreased **Cortisol** levels and altered respiratory patterns noted above. In addition, increased plasma levels of the neuromodulator vasopressin (O'Halloran et al., 1985) may be responsible (de Weid and Gispen, 1980) for the improvements in memory and learning that result from regular practice of the TM technique (Miskiman, 1977; Nataraj and Radhamani, in press). Hormonal changes, which include striking longitudinal decreases in plasma levels of TSH and growth hormone that occur with the practice of the TM and TM-Sidhi programs (Werner et al., 1986), are suggestive of a more efficient neuroendocrine system.

EEG changes consistently associated with the practice in contrast to eyes-closed relaxation include significant increases in EEG coherence above a .95 threshold, particularly in frontal regions (Dillbeck and Bronson, 1981; Levine, 1976); an increase in high amplitude alpha activity in frontal and central derivations, particularly in the slow alpha frequencies; and the occurrence of synchronous theta trains and high-amplitude theta activity (Banquet, 1973; Hebert and Lehmann, 1977; Wallace et al., 1971).

These studies provide evidence that the state occurring in TM is uniquely different from waking, dreaming, and deep sleep. Indeed, the integrated complex of physiological changes occurring spontaneously during the TM technique is consistent with the suggestion of a fourth major state of consciousness. Because this state appears to have characteristics of both heightened wakefulness and deep rest together, it has been characterized as a state of "restful alertness." The prefix "major" is used to indicate that this state of consciousness appears to be universally attainable and hence as natural as waking, dreaming, and deep sleep states of consciousness.

One obvious difference between pure consciousness and the three primary states of consciousness is that some initial guidance (i.e., personal instruction in the TM technique) is necessary to systematically experience pure consciousness. A second difference is that whereas the three primary states of consciousness are considered necessary for the survival of the organism, pure consciousness apparently is not. On the other hand, the cumulative research on the Transcendental Meditation technique has shown that almost every parameter of physiological and psychological health is positively affected by the regular experience of pure consciousness. As a consequence, for example, it has been shown that the normal deterioration of physiological and psychological functioning which results from biological aging can be retarded and even arrested and reversed through the regular practice of TM (Wallace et al., 1982; Alexander et al., 1986). Thus, although pure consciousness is apparently not necessary for survival, it can be argued that it is important for the longevity and optimal functioning of the system.

It is important to note that during the technique, the subjective and physiological process is such that the quality of experience varies at different times of the practice. While the majority of the research on the TM technique has focused primarily on physiological changes averaged over the duration of the practice, some studies have been able to identify profound changes occurring during specific periods of the practice identified by the subjects as experiences of pure consciousness. During such periods the physiological changes were found to be an intensification of those found during the practice as a whole, particularly respiratory changes and EEG coherence (Badawi et al., 1984; Farrow and Hebert, 1982). Among these more distinct effects were periods of spontaneous breath suspension for periods up to 60 seconds. A sudden increase in EEG coherence also occurred at these times, in contrast to controls holding their breath for comparable periods (Badawi et al., 1984).

These and related studies indicate that the experience of pure consciousness involves a mode of functioning of the mind and nervous system that is distinctly different from other known states of consciousness. Even the term "experience" in connection with pure consciousness has an entirely different meaning from that of ordinary waking consciousness, since the three essential components of waking experience have become united in one unified structure of experience, in which consciousness is itself the observer, the process of observation, and the object of experience simultaneously (Maharishi Mahesh Yogi, 1985).

The existence of this unified ground state of consciousness and the availability of systematic experiential procedures to investigate this state together with its unique physiological correlates has been described by many researchers as a new empirical foundation for a unified psychological theory and the basis of a comprehensive science of consciousness (Alexander, Davies et al., 1987; Dillbeck, 1983a, 1983b; Orme-Johnson, Dillbeck et al., in press; Wallace and Jevning, in press).

It is this unified state of consciousness—the state of pure, self-interacting consciousness—which according to Maharishi Vedic Science corresponds to the direct experience of the unified field of all the laws of nature (Maharishi Mahesh Yogi, 1985).

II.3 Field Effects of Consciousness

The primary exponent of the proposed identity between pure consciousness and the unified field is Maharishi Mahesh Yogi, who formulated this understanding in conjunction with a number of distinguished scientists based upon his experience teaching the Transcendental Meditation and TM-Sidhi programs throughout the world and upon the Vedic tradition of knowledge which he represents. Here we present some of the main arguments and evidence in support of this proposal and address some of the scientific and philosophical issues that such a proposal raises.

Our approach will be essentially empirical, emphasizing established research findings on the physiological, psychological, and sociological effects of pure consciousness, in addition to the direct experience of subjects trained in the relevant experiential methods. The subjective technologies considered in this study (the Transcendental Meditation and TM-Sidhi programs) utilize highly specific procedures that produce reliable, verifiable, and repeatable results, with a high degree of intersubjective consistency. Since a scientific fact is generally held to be an observation that is repeatable and that can be independently confirmed by anyone possessing the requisite apparatus and training, these subjective technologies should be considered scientific in the strictest sense.

At present, the most concrete experimental evidence in support of a field theoretic description of consciousness, aside from the subjective accounts of a large number of subjects trained in the relevant experiential techniques, is the ***Super Radiance effect*** or ***Maharishi effect*** produced by the collective practice of the TM-Sidhi program. These are consistent demonstrations of extended field effects of consciousness that have withstood many consecutive replications on a variety of scales. These studies employ standard sociological measures to study the coherent influence of groups of experts collectively practicing the TM-Sidhi program on a surrounding population.

In 1960, Maharishi predicted that one percent of a population practicing the TM technique would produce measurable improvements in the quality of life for the whole population. The first study designed to test this prediction (Borland and Landrith, 1977) analyzed crime rate trends in 22 U.S. cities (population > 25,000) in 1973. Crime rates decreased in the 11 cities with one percent of the population practicing the TM technique, while crime rates in the matched control cities continued to rise. A more extensive study (Dillbeck et al., 1981) analyzed crime rate trends in 48 U.S. cities (population > 10,000) over the eleven-year period from 1967-1977. Crime rates decreased significantly in the 24 "one percent" cities compared with their own previous trends and compared with 24 matched control cities over the same period.

Subsequent replications have analyzed crime rate trends in 160 cities and 80 metropolitan areas in the United States using increasingly powerful design and analysis techniques (Dillbeck, 1981), and have further demonstrated Maharishi's prediction that participation in the TM program would lead to a reduction in crime rate trends.[12]

With the introduction of the more advanced TM-Sidhi program in 1976, Maharishi anticipated a more powerful influence of coherence in the collective consciousness of society and predicted that the group practice of the TM-Sidhi program by as few as the square root of one percent of a population would have a demonstrable effect on standard sociological measures.[13] The relatively small numbers participating in the TM-Sidhi program predicted to generate this effect of societal coherence has made it possible for many direct experimental studies to be performed, in which the necessary number of participants come together on courses in various locations for periods of time ranging from one week to several months. Most of these studies, including studies at the state, national, and international scales, have used time-series intervention analysis to reliably estimate experimental effects independent of cyclical trends in time-dependent data (e.g., Alexander, Abou Nader et al., in press; Dillbeck, Foss and Zimmermann, in press; Dillbeck, Larimore and Wallace, in press; Orme-Johnson, Alexander et al., in press; Orme-Johnson, Cavanaugh et al., in press). The data clearly indicate significant and positive changes across a wide range of standard sociological indicators including decreased crime rate, automobile fatalities, suicides, and infectious diseases, and increased economic productivity. In fact, in several studies these parameters have been compiled to form a single quality of life index that has been observed to vary quadratically with the size of the coherence-creating group (Orme-Johnson, Alexander et al., in press; Orme-Johnson and Gelderloos, in press).

One especially critical experimental test of the hypothesis that the group practice of the TM-Sidhi program by the square root of one percent of a population would positively

[12] In an attempt to rule out unmeasured "third-cause" variables as alternative hypotheses, studies of cities and metropolitan areas have used cross-lagged panel analysis, a variant of causal modeling procedures (Dillbeck, Landrith et al., in press). Studies at the city level have also used partial correlation or analysis of covariance methods to control for specific alternative hypotheses in terms of demographic variables related to the particular parameters studied (see, e.g., Dillbeck, Landrith et al., in press; Dillbeck, Landrith and Orme-Johnson, 1981).

[13] This prediction is based on a field theoretic model utilizing a coherent superposition of amplitudes, in which the intensity of the effect generated is proportional to the square of the number of participants.

affect sociological measures was conducted in Israel in August and September of 1983 (Orme-Johnson, Alexander et al., in press). Based on the results of previous experiments, the research hypotheses and the specific measures to be used in the study were lodged in advance of the experiment with an independent review board of scientists in the United States and Israel.

Figure 8 shows the remarkable covariation between the size of the group of TM-Sidhi participants (dotted line) and a composite index of quality of life that was the arithmetic average of standardized scores for crime rate, traffic accidents, fires, stock market, national mood, and the number of war deaths as a measure of war intensity in Lebanon.

Time series analysis demonstrated the statistical significance of the impact of the group on the quality of life measures and showed that the effect could not be attributed to seasonality (such as weekend effects or holidays) or to changes in temperature. The hypothesis that the influence occurs on a fundamental and holistic level of nature is supported by the fact that the arithmetic average of the different measures produced the clearest results and by the observation that the different sociological measures tended to change independently of each other when the group size was small, but all changed coherently in a positive direction as the group size was increased.

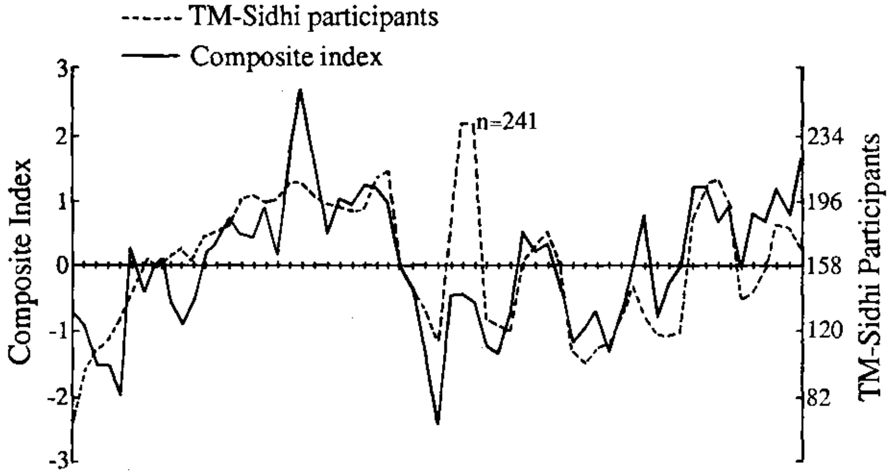

Figure 8. This figure illustrates the covariation between the number of TM-Sidhi participants (dashes) and a composite index of quality of life in a study conducted in Israel during August and September of 1983. The composite index was the arithmetic average of standardized scores for crime rate, traffic accidents, fires, stock market, national mood, and the number of war deaths as a measure of war intensity in Lebanon. The sociological parameters employed in this study were lodged in advance of the experiment with an independent review board of scientists in the United States and Israel. (Figure courtesy of D. Orme-Johnson.)

A subsequent study (Figure 9) assessed the impact on the Lebanon crisis of three successive assemblies in which large groups practiced the TM-Sidhi program during the six-month period from November 13, 1983, to May 18, 1984 (Alexander, Abou Nader et al., in press). Greater progress towards peaceful resolution of the Lebanon conflict was observed during these three assemblies than would have been expected based on the prior six-month history of the war ($p < .00005$). The measure of war intensity used was based on a con-

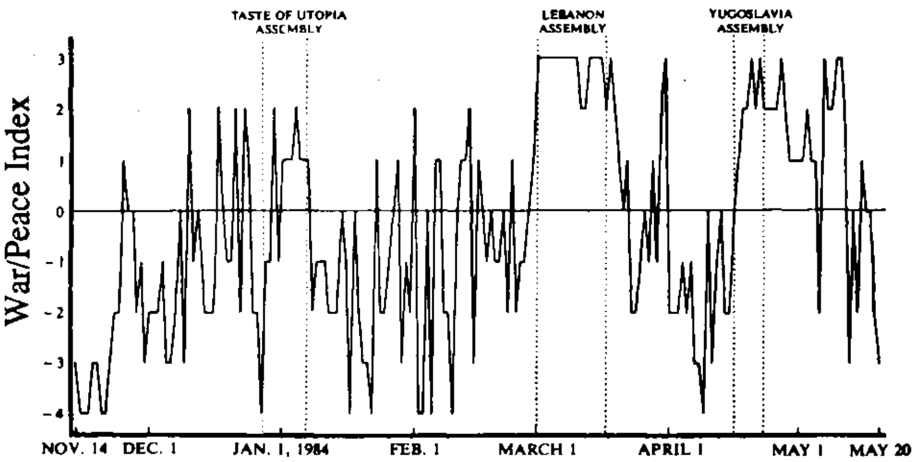

Figure 9. During the six-month period from November 13, 1983, to May 18, 1984, a measure of war intensity in Lebanon was most positive during three assemblies in which the number of TM-Sidhi participants exceeded the predicted thresholds required for an influence on the war. Time series analysis indicates significantly greater progress toward peaceful resolution of the conflict during these assemblies than would have been predicted from the prior history of the Lebanon war ($p<.00005$). The particularly large effect coincident with the Lebanon assembly held in the immediate vicinity of the conflict suggests the importance of proximity in the generation of societal coherence. (Figure courtesy of C.N. Alexander.)

flict rating scale developed by E.E. Azar (1980). The scoring was performed by representatives of the different factions involved in the conflict, and inter-rater reliability was high. War deaths were observed to decrease by over fifty percent during the three experimental periods as compared to the nonexperimental periods. The particularly large effect coincident with the Lebanon assembly held in the immediate vicinity of the conflict suggests the importance of proximity in the generation of societal coherence.

Although it would be more accurate to say that the Super Radiance data constitutes evidence for an "action at a distance" with respect to consciousness rather than "field effects" ***per se,*** physics has historically come to associate action at a distance with field phenomena. The observed attenuation of the effect with distance would support such a field theoretic interpretation. The quadratic dependence of the intensity of the effect upon the size of the coherence-creating group is also characteristic of a field phenomenon in which the radiators are operating coherently. Specifically, the coherent superposition of amplitudes required to produce such an intense constructive interference suggests the behavior of a bose field (e.g., electromagnetism, gravitation, or a supersymmetric unified quantum field).

However, there are certain features of the Maharishi effect that are not easily understood on the basis of a conventional field. The main difficulty with a simple field theoretic model is in understanding the Super Radiance data on the basis of any of the ***known*** fields. The only known candidates for such long-range interactions are electromagnetism and gravity. Any conventional gravitational interaction between individuals is presumably orders of magnitude too weak.[14] Moreover, it is generally agreed that the electromagnetic interac-

[14]This also holds true for possible spin-1 forces that interact with gravitational strength, such as a proposed "fifth force" (Fischbach, 1986) or the gauge bosons associated with the hidden sector of a supergravity or superstring theory. (The latter would probably operate only at short distances anyway

tion between individuals would also be too weak to give rise to any significant effects. This conclusion is probably reasonable despite new evidence that the physiology may be sensitive to environmental AC electric fields six to seven orders of magnitude weaker than had been previously considered possible (Adey, 1981). In fact, the brain appears to be particularly sensitive to EEG-modulated microwave radiation in the 0.5-10 gigahertz range, offering a potential mechanism for EEG communication and entrainment. It has been shown by Tourenne (1985) that certain cellular structures within the cortex that support the propagation of electromagnetic solitons could provide highly efficient radiators of microwave radiation, which would presumably be modulated in the EEG band.

While we therefore feel it is essential to pursue possible electromagnetic mechanisms for the Super Radiance phenomenon, these mechanisms will probably be unable to account for the observed phenomenon. For example, there was no evidence of attenuation in an instance where the coherence-creating group was electromagnetically shielded by a metallic enclosure (Orme-Johnson, Cavanaugh et al., in press).

If conventional mechanisms are unable to account for the Super Radiance data, then an unconventional mechanism involving new physics will be needed. As there are no alternative long-range forces of electromagnetic or comparable strength, one is compelled to consider alternative theoretical frameworks that might serve to overcome the substantial distance factors involved. One such framework is suggested by the structure of space-time geometry at the scale of super-unification—the proposed domain of pure consciousness.

Although we do not currently possess the calculational tools needed to unfold the full dynamics of quantum gravity, there are several indications that the local structure of space-time geometry observed below the Planck scale may provide a totally inappropriate framework for physics at the scale of super-unification. For example, Hawking has shown that topological effects in quantum gravity can lead to inherently nonlocal phenomena. Specifically, he has shown that space-time metrics with nontrivial topologies can cause initially pure quantum states to evolve into mixed states (Hawking et al., 1979, 1980; Hawking, 1982, 1984). Such effects cannot be accommodated within a local framework, or even a framework that is local on scales much larger than the Planck length, for such would necessarily lead to large and phenomenologically unacceptable violations of energy and momentum conservation (Banks et al., 1984).

Moreover, these nonlocal effects have been derived in a perturbative context in which the nonlocal effects of gravity are expected to be relatively benign. The full, non-perturbative theory of quantum gravity can be expected to contain even more profoundly nonlocal effects. Indeed, there are strong indications that the Planck scale is associated with a fundamental phase transition in the dynamics of quantum gravity and/or the structure of space-time geometry (e.g., a transition from four dimensions to ten dimensions). Such a phase transition would be expected to produce long-range correlations that could enhance the nonlocal structure of the theory. Hence the local structure of a relativistic field theory may provide a totally inappropriate framework for physics at the super-unified scale. Therefore, one might expect that if the domain of consciousness is fundamentally the super-unified scale, then phenomena of consciousness would include influences that are inherently nonlocal. The Super Radiance data could thereby be viewed as evidence that individual con-

due to confinement effects.) The same is presumably true of other weakly interacting bosons that have escaped detection in particle physics experiments.

sciousness can access the scale of super-unification, consistent with the proposed identity between pure consciousness and the unified field.

A key issue from a physiological standpoint is how the nervous system could conceivably interface with the super-unified scale in any significant way. Perhaps the first question to consider in this context is to what extent the nervous system actively participates in the experience and phenomena of pure consciousness. The dominant physiological characteristic of the state of pure consciousness is the silencing of activity in the central nervous system and throughout the body, including a suspension of ordinary thought and perception, a reduction of noise in the nervous system, and respiratory suspension during periods of pure consciousness (Farrow and Hebert, 1982; Badawi et al., 1984).

It has consequently been suggested that by closing the usual channels of activity and perception, the nervous system simply provides pure consciousness with an opportunity to experience itself. From this "passive" perspective, the nervous system participates less actively in the experience of pure consciousness than in other experiences possessing specific and localized content which involve the usual channels of thought and perception.

Even from this passive perspective, there would have to be some interface between the nervous system and the unified field, since many of the associated phenomena of pure consciousness (e.g., Super Radiance and the sidhis) are at least initiated by individual nervous systems. Moreover, if pure consciousness—the subject—is identified with the unified field, then such an interface is needed even in waking consciousness in order to connect the usual cognitive and perceptual content of experience to the experiencer.

The physiological basis for such an interface is presently unclear, and would probably require some as yet undiscovered quantum-mechanical neurological mechanism. Maharishi has proposed that the DNA molecule itself is a central participant in the physiology of pure consciousness, and has suggested looking for cooperative phenomena among DNA molecules located throughout the system. A similar quantum field theoretic analysis of molecular excitations has recently been proposed to account for the collective dynamics of biological systems (Del Guidice et al., 1985). A cooperative mechanism in the context of pure consciousness could help to explain the periodic episodes of synchronous neural firing throughout the entire brain complex.

Further research is needed to establish the underlying physiological mechanisms that uphold the experience of pure consciousness, and to consider what type of interface with the dynamics of fundamental scales could be supported by these mechanisms. It must also be determined to what extent a dynamical interface is actually needed to support a subjective experience of the unified field and to account for the Super Radiance data.

There exists an entirely different class of nonlocal effects in physics that does not explicitly involve the dynamics of the super-unified scale and which might be proposed as an alternative mechanism for the Maharishi effect. This is the ***reduction of the wave function*** in quantum mechanics.

The time evolution of a quantum-mechanical system ordinarily proceeds deterministically according to a Schroedinger equation (or a quantum Liouville equation in the more general case of a density matrix describing a mixed state). However, when a classical measurement is performed on the system, the wave function, which may represent a superposition or mixture of more than one value of the measured observable, undergoes a sudden "collapse" or reduction to a wave function possessing a definite value of the measured observable. In this way, a unique value of the measured observable is registered when a measurement is performed.

This reduction of the wave function or density matrix is thought to occur simultaneously throughout the system, with the result that a measurement in one region of an extended quantum-mechanical system has a demonstrable effect upon the state of the system in a far-distant region, which might even be space-like separated (Aspect, Grangier and Roger, 1981, 1982; Aspect, Dalibard and Roger, 1982).

In this context, a "system" can comprise any number of objects or subsystems that may have interacted sometime in the past and thereby possess quantum-mechanical correlations. (Strictly speaking, this characterization would not appear to exclude any objects within the causal horizon of our universe. In fact, in an inflationary cosmological model, one might naturally expect significant quantum-mechanical correlations among the extant macroscopic objects which comprise the observable universe.[15]) It follows that the reduction of the wave function or density matrix associated with some apparently isolated subsystem might lead to significant changes in the quantum-mechanical states of objects located throughout the universe.

Circumstances that can lead to the reduction of a wave function are generally thought to be those associated with nonequilibrium thermodynamic processes, and may exist commonly throughout the macroscopic environment (Zurek, 1982, 1983). These circumstances are at present known to include interactions between quantum-mechanical systems and macroscopic measuring devices with quantum sensitivities, including the sense organs (Bialek, 1985; Bialek and Schweitzer, 1985; Bayler et al., 1979; Bayler et al., 1980). Hence, even the perception of objects in the environment has an inescapable influence upon the microscopic state of the object, even if the macroscopic, observable properties of the ob-

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[15]Consider the production of two spin-1/2 particles in an S-wave from the decay of a scalar particle, as in the original EPR-type setup. In order to conserve angular momentum, the two particles must be in a J=0 spin state, which is antisymmetric and can therefore be written:

$$\Psi(1,2) = (\uparrow_1\downarrow_2 - \downarrow_1\uparrow_2)/\sqrt{2}$$

where the arrows indicate $J_z = \pm 1$ and the subscripts label the particles. It follows from (1) that neither particle possesses a definite spin value along the z-direction, nor in fact along any other direction, for such would not constitute a J=0 state. Hence each particle is individually described by a density matrix representing a mixture of spins and thus possessing nonzero quantum-mechanical entropy:

$$\varrho_{1(2)} = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \begin{matrix} \uparrow \\ \downarrow \end{matrix} \quad \text{where } S_{1(2)} = -\mathrm{Tr}\ \varrho \log(\varrho) = \log(2).$$

The entropy associated with the two particles is therefore 2log(2), whereas the total entropy of the combined two-particle system must be zero since it is in a pure S-wave state. One is therefore led to define a "correlational entropy," defined as the total entropy of the system (i.e., zero) minus the sum of the entropies of its component parts:

$$S_{corr} = 0 - 2\log(2).$$

The fact that S_{corr} is negative indicates that there is *information* stored in the quantum-mechanical correlations between the two particles.

Since the vacuum state of a quantum field has zero entropy, in any cosmological model in which the universe emerges from the vacuum through a quantum-mechanical time evolution, the universe would be expected to have total entropy zero. This would imply that the observed entropy in the universe should be balanced by negative correlational entropy among the numerous objects or subsystems that comprise it. Such a universe would be characterized by strong quantum-mechanical correlations among its various component parts (A. Hankey, private communication).

ject are unaffected by these microscopic changes. Once again, any resulting reduction of the wave function could be expected to have nonlocal effects.

It has previously been suggested that the possibility of such long-range correlations might provide a mechanism for mental communication among individuals who are strongly correlated. Here one should worry that the term "communication" overstates the nature of the actual effect. It is easy to show that if the reduction of the wave function is fundamentally a random process as is generally believed (and is not therefore subject to conscious control), then the reduction of the wave function cannot be used to transmit information, in agreement with relativistic causality. The effect of the reduction might be present at far separated distances, but the "message" that is transmitted will be purely random.

This essential limitation would appear to rule out the nonlocal reduction of the wave function as a possible mechanism for the communication of information and as a possible mechanism for the Maharishi effect. Although the Maharishi effect may not appear to involve the communication of any specific information, the fact that Super Radiance leads to certain predictable and observable consequences (e.g., a reduction in crime rates) means that the presence or absence of a coherence-creating group could in principle be used to transmit a signal.

On the other hand, it may be premature to rule out the seemingly more radical hypothesis of a conscious or even intentional component to the reduction of the wave function, with its nonlocal and hence potentially acausal implications. To be fair, it is difficult to know what is "radical" in the absence of a "conservative" model for the reduction of the wave function. One such hypothesis, due to Wigner (1962), is that consciousness is somehow responsible for the reduction of the wave function during perception, possibly by the introduction of some mathematically nonlinear effects. Wigner has also pointed out that this assumption leads to serious problems (e.g., the paradox of Wigner's friend).

Recently, however, it has been pointed out by Stapp (1982) that if the reduction of the wave function is treated as an independent "event" in its own right, a number of major philosophical problems might be overcome. For example, it may be possible to unify quantum theory with special relativity on a new and profound basis. In addition, Stapp has shown that the assumption that consciousness ***selects the outcome*** of the reduction of the wave function on a metaphysical level, not in perception, but in thought and action, provides a solution to the mind-body problem which, because it can be used to model freedom of choice, is rather attractive.

Such **a** framework is not unmotivated from a psychobiological standpoint. The emergence of specific avenues of classical behavior from certain underlying brain processes that are manifestly quantum-mechanical would seem to require the reduction of a wave function which represents a superposition of several classical alternatives. The associated subjective impression that the emergent behavior is not purely stochastic but involves an exercise of will would support an intentional component to this reduction (Stapp, 1982).

At the same time, it must be clearly stated that if the reduction of the wave function is subject to conscious control or any other form of manipulation, then the nonlocal character of the reduction of the wave function could lead to long-range influences in apparent violation of relativistic causality. However, the severe logical problems usually associated with such acausal influences may not apply if the agent responsible for the collapse (i.e., consciousness) is itself nonlocal and unique. It follows that any physical model for the Maharishi effect based on the conscious reduction of the wave function may logically require the existence of a unified field of consciousness. Indeed, it may be highly significant that the nonlocal or "cosmic" component of consciousness required (Stapp, 1982) in such a framework has become an empirical component of human experience with the widespread experience of pure consciousness.[16]

In this section, we have considered two possible frameworks for the Super Radiance phenomenon which utilize nonlocal effects associated respectively with the structure of space-time geometry at the scale of super-unification and the reduction of the wave function in quantum mechanics.[17] Whether or not the conscious reduction of the wave function with its implied nonlocal communication provides a viable mechanism for the Maharishi effect, in the following section we will show that a full understanding of consciousness requires a more fundamental framework than the nonrelativistic quantum theory employed in this approach to Super Radiance.[18] For instance, we will show that the widespread experience of a translationally invariant ground state of consciousness already suggests a more fundamental, quantum field theoretic framework, and that the more advanced experiences pertaining to the TM-Sidhi program, in which the universe is perceived as the vibrational modes of consciousness, would favor a still more fundamental, unified field theoretic framework. We will also show that the concrete demonstration of certain ***sidhis*** phenomena would directly support the proposed identity between pure consciousness and the unified

[16] **A *stochastic formulation* of quantum mechanics may provide a natural framework for incorporating a conscious component into quantum mechanics. In this type of approach, the reduction of the wave function only represents a discontinuous change in the observer's** knowledge **about the system that results when a measurement is made. The system itself undergoes a continuous, deterministic time evolution controlled by the random fluctuations of an underlying background field—a process which has been compared to Brownian motion. Recent work has shown that such a stochastic approach can be consistently formulated to give the same experimental predictions as quantum mechanics (Nelson, 1985; Zambrini, 1986). However, in order to correctly reproduce the results of quantum mechanics (including EPR-type correlations and Bell's theorem), this fluctuating background field must itself be nonlocal in space (Nelson, 1985; Zambrini, 1986) and possibly in time as well (Zambrini, 1986). Apart from this, stochastic models say little about the nature of this underlying background field.**

As a theoretical framework for modeling the effects of coherence in individual and collective consciousness, one can identify this fluctuating background field with the field of consciousness. Ordinary (incoherent) consciousness might be essentially stochastic, resulting in the usual statistical predictions of quantum mechanics. Coherence in individual or collective consciousness could be represented by correlations within the background field which can be used to model the Maharishi effect and/or the sidhis (see Section II.5).

[17] **These two frameworks are not necessarily incompatible. The nonlocal reduction of the wave function may ultimately result from the nonlocal structure of space and time associated with the scale of super-unification. We have already noted that topological fluctuations in quantum gravity can lead to non-unitary time evolution in quantum-mechanical systems, and at present there is no evidence for any alternative source of nonlocality in physics.**

[18] **included in the category of quantum-mechanical mechanisms is the possibility that the nervous system may be far more sensitive to environmental influences than is generally assumed. It is known, for example, that certain sense organs respond to stimuli at the extreme quantum limits of sensitivity (see Section II.4). This sensitivity of the nervous system to quantum-mechanical events might help to explain various subtle phenomena, including phenomena of collective consciousness, without recourse to nonlocal effects associated with the reduction of the wave function. This possibility will be explored in a subsequent article.**

field, as they would demonstrate the capacity for conscious activity on or near the scale of super-unification. At present, however, the Super Radiance effect represents the central core of experimental evidence in support of the proposed identity between pure consciousness and the unified field. It is therefore essential to design future experiments with an improved capability to discriminate among plausible mechanisms. While the evidence for the Super Radiance effect is in itself compelling, further research is needed to identify the underlying physical principles and/or to rule out all local mechanisms.

II.4 Pure Consciousness and the Unified Field

Since the foundation of psychology as an independent discipline over a century ago, its theories of consciousness and human behavior have been modeled entirely on classical concepts derived from physics of the nineteenth century. Meanwhile, developments in the fields of molecular biology and neuroscience have demonstrated that relatively few processes involving the central nervous system can actually be understood on the basis of classical models. Yet the emergence of more fundamental theoretical frameworks within the discipline of physics has had almost no impact on the field of psychology. This may be due to the fact that few psychologists (and few lay physicists in general) have been educated beyond the Newtonian era.

The quantized theory of fields is the most profound and successful framework to emerge within the field of science. In addition to the fact that the entire universe is believed to **be** fundamentally built out of quantum fields, the same basic field theoretic framework has been successfully applied to complex physical systems outside the domain of elementary particle physics, as in statistical mechanics and condensed matter physics. In light of the apparent failure of current ideas within the field of psychology to account for consciousness in a satisfactory and compelling way (Hilgard, 1980; Niesser, 1976; Natsoulas, 1978, 1983), it makes sense to seek a more fundamental, field theoretic framework for consciousness, particularly in light of evidence for field effects of consciousness and the widespread experience of states of consciousness that do not fit the current psychological paradigm.

The idea of a single, unified reality underlying both mental and physical processes is not new. It was proposed, for example, by Benedict Spinoza in the 17th century as a basis for bringing unity to the mind-body duality introduced by Descartes in the 16th century. There is a certain elegance and simplicity to this view, which if denied leads straightway into a dualistic view of nature, according to which body and mind are fundamentally different in kind and ultimately disconnected aspects of reality.

Here, however, it is on the basis of the widespread experience of a unified field of consciousness and experimental evidence for field effects of consciousness that we are led to consider a field theoretic framework for consciousness. The subjective accounts of a unified field of consciousness experienced through the Transcendental Meditation and TM-Sidhi programs are highly consistent across subjects and provide a principal ground for the proposed identity between pure consciousness and the unified field. The following accounts are typical of experiences with the TM and TM-Sidhi programs, respectively (Maharishi Mahesh Yogi, 1977; Orme-Johnson and Haynes, 1981):

> **As I spontaneously become aware of more fundamental and abstract levels of the object of attention during meditation, the rigid boundaries of the object begin to fade. As the object becomes more and more unlocalized and the focus of attention continues to spread, comprehension becomes more and more unbounded. When the faintest impulse of the [object] dissolves and there is no localized content to experience, my awareness**

> **is completely unbounded. I am left with the experience of a pure, abstract, universal field of consciousness, unlocalized by specific content or activity of the mind—just the Self wide awake within its own unbounded nature.**
>
> **During the TM-Sidhi performance, established in the state of pure, unbounded consciousness, the most delicate and fundamental impulses of activity within the field of consciousness are projected one by one. These delicate modes of vibration of consciousness are themselves universal and unbounded. It is as though the Self is simply reverberating within certain set patterns or frequencies, with the result that consciousness, which was previously abstract and self-contained, assumes various "flavors." These basic impulses of consciousness are seen as the building blocks of the whole subjective and objective existence. Matter itself appears to be a highly precipitated form of these vibrations.**

What might a field theoretic framework for consciousness mean in light of experiences similar to those reported above? Taken at face value, these experiences suggest that consciousness behaves like a field with translational invariance (i.e., "unboundedness") and a spectrum of vibrational modes. This translational invariance at first seems highly unusual: the vast majority of conscious experience, including the mechanics of perception and memory, are ostensibly localized within the confines of the nervous system. In a field theoretic framework, the solution to this apparent paradox is potentially no different from the emergence of localized excitations (e.g., particles and bulk matter) from the Poincare-invariant dynamics of a quantum field. It is simple to construct a localized wave packet as a superposition of unbounded eigenstates. Indeed, such an interpretation is supported by the closely related experience that impulses of thought constitute localized waves of activity on an unbounded field of consciousness (Maharishi Mahesh Yogi, 1977).

If consciousness indeed behaves like a field, there are biological reasons to expect that it may behave like a quantum field. Of the five sense organs, at least three (smell, sight, and hearing) are known to respond to stimuli at the quantum level of sensitivity (e.g., single molecules of an olfactory stimulant and single photons in the case of sight) (Bialek and Schweitzer, 1985; Bialek, 1985; Bayler et al., 1979; Bayler et al., 1980; Bouman, 1961; DeVries and Stuiven, 1961). It therefore seems plausible that with the extremely low noise and elevated state of alertness associated with the state of pure consciousness, the brain should be able to discern individual quanta of conscious activity (Domash, 1977). A quantum field theoretic model would also help to explain the sudden transition to the state of pure consciousness from more active states of the brain physiology. The observed transition is not unlike the spontaneous relaxation of an atom to its ground state.

The experiences pertaining to the advanced TM-Sidhi practice that the "modes of consciousness...are the building blocks of the whole subjective and objective existence" is more surprising from a biological standpoint and closer to the central issue: a literal interpretation of these experiences would identify pure consciousness as the unified foundation of both subjective and objective existence. There are a number of close structural parallels between the subjective accounts of the unified field of consciousness experienced through the TM and TM-Sidhi programs and the unified field that is emerging within the context of modern theoretical physics. Because this close structural correspondence lends support to the proposed identity between pure consciousness and the unified field, we will develop a few of these parallels here.

Of the numerous "modes" of consciousness which arise in the context of the TM-Sidhi program, five correspond to "objective" modes said to be responsible for material existence. These are the so-called "subtle elements" or ***tanmatras*** (Maharishi Mahesh Yogi, 1969; Patanjali, 1978). These five are known as (starting with the most fundamental) the ***akasha*** or "space" tanmatra (lit. "elementary space"), the ***vayu*** or "air" tanmatra, the ***agni*** or "fire" tanmatra, the ***jala*** or "water" tanmatra, and the ***prithivi*** or "earth" tanmatra. (These tanmatras must be distinguished from the five "gross elements" or ***mahabhutas,*** also called akasha, vayu, agni, etc., which have previously been identified with classical space-time and the four states of bulk matter, i.e., gaseous, plasma, liquid, and solid, respectively [Hagelin, 1983.])

A very similar structure is observed within the framework of quantum field theory, where there are also five fundamental categories of quantum field or "spin types" consistent with relativistic causality and renormalizability, which are responsible for the entire material universe. These are the spin-2 graviton (responsible for space-time curvature and the force of gravity), the spin - 3/2 gravitino (appearing only in the context of a supersymmetric field theory), spin-1 force fields, spin -1/2 matter fields, and the spin-0 Higgs fields responsible for symmetry breaking.

There appears to be a striking correspondence between the five tanmatras and these quantum-mechanical spin types: between the space tanmatra and the gravitational field; between the air tanmatra, which stands as a link between space and the other elements, and the gravitino field; between the fire tanmatra, responsible for chemical transformations and the sense of sight, and the spin-1 forces; and between the water and earth tanmatras and the spin-% and spin-0 matter fields, respectively. (These correspondences are discussed in more detail in Hagelin, 1983.)

This correspondence is even more striking in the context of a supersymmetric theory, where there is a natural pairing of the five quantum-mechanical spins into three types of N=1 superfields (see Figure 10). The spin-2 graviton and the spin-3/2 gravitino become unified in the context of the ***gravity superfield,*** the spin-1 force fields and spin -1/2 "gauginos" combine to form ***gauge superfields,*** and the spin - 1/2 matter fields and their spin-0 supersymmetric partners give rise to ***matter superfields.*** The same pairings are also fundamental in the context of Vedic science ***(Caraka Samhita,*** 1981), where akasha and vayu appear unified in the structure of ***vata prakriti,*** agni and jala become united in the structure of ***pitta prakriti,*** and jala and prithivi are united in the structure of ***kapha prakriti.*** Like the N=1 superfields, the prakritis pertain to the structure of natural law at fundamental scales—at or near the scale of super-unification. They form the principal content of the ***Upavedas,*** which are concerned with the structure of manifest existence in relation to the unified field (Maharishi Mahesh Yogi, 1985). They appear to constitute a profound point of contact between modern science and Vedic science.[19]

If pure consciousness is identified with the unified field, and if the five "subtle elements" or tanmatras indeed correspond to the five spin types, it is interesting to consider what the additional, "subjective" modes of consciousness occurring in the TM-Sidhi program and described by Vedic science might correspond to (Patanjali, 1978). These subjective modes

19Maintaining a proper balance among the three prakritis at the most fundamental level of the physiology is described as the basis for a profound and comprehensive science of health known as *Ayurveda,* one of the principal Upavedas.

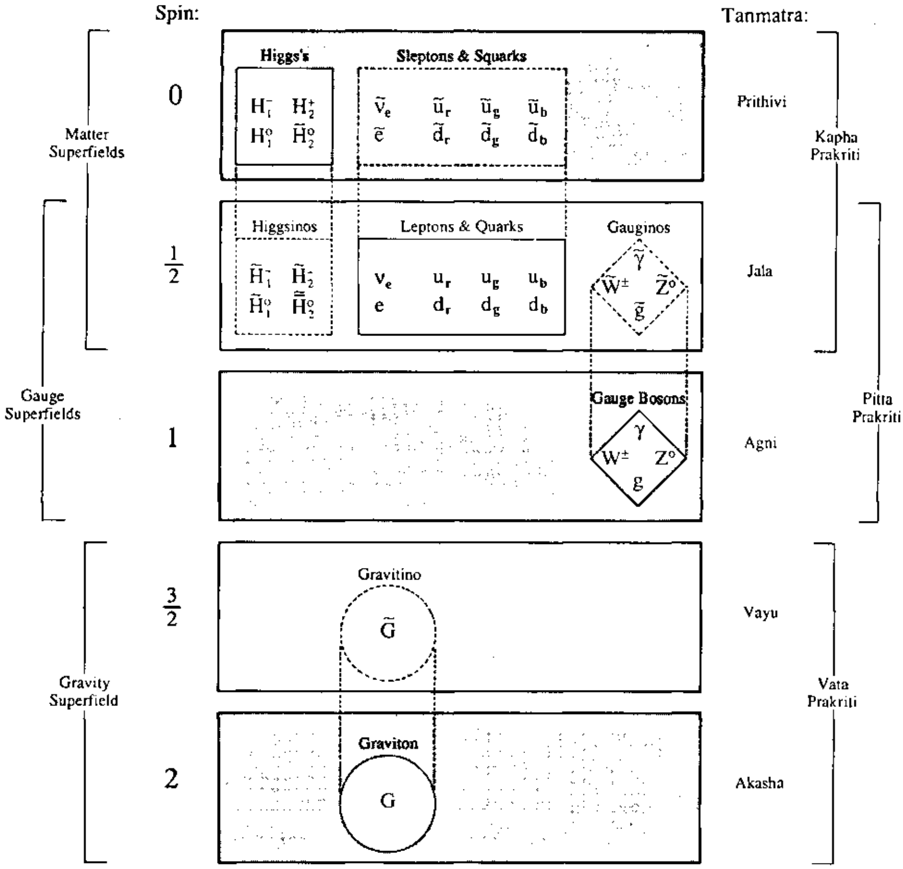

Figure 10. This figure illustrates the proposed correspondence between the five "subtle elements" or tanmatras and the five quantum-mechanical spin types, and the correspondence between the prakritis and the N=1 superfields in a supersymmetric field theory.

of experience have no obvious counterpart in a unified field theory based on extended supergravity, where any additional spin states would lead to a nonrenormalizable theory. In this regard, the more recent superstring theories provide a closer parallel to subjective experiences during the TM and TM-Sidhi programs and a closer correspondence to the structure of the unified field according to Vedic science. In a superstring theory, the five quantum-mechanical spin types comprise only the massless modes of vibration of the string, which survive at distances well below the Planck scale as the macroscopic, low-energy limit of the theory. There are many additional massive string modes which are operational only at the Planck scale and which could naturally correspond to the additional "subjective" modes of experience if the domain of pure consciousness is taken to be the scale of super-unification.

There is another sense in which the superstring theory provides a closer correspondence to subjective experiences through the TM and TM-Sidhi programs and thereby provides a more natural framework for a unified understanding of both subjective and objective reality. In a string theory, all the elementary particles and forces arise as the vibrational states of an underlying string field. For example, in the $E_8 X E_8$ heterotic string theory, the graviton and gravitino correspond to "clockwise" modes of the string, the 496 force fields associated with an $E_8 X E_8$ internal gauge symmetry correspond to "counterclockwise" modes, and the matter fields correspond to massless vibrational modes of the compact ***Calabi-Yau*** manifold on which the theory compactifies. This corresponds closely to subjective experiences during the TM-Sidhi program, in which the "building blocks of the whole subjective and objective existence" are experienced as the various "modes of consciousness." There is no corresponding sense in which the fundamental particles and forces arise as vibrational modes of a single field in an extended supergravity theory.

One of the most obvious and basic structural similarities between pure consciousness and a supersymmetric unified field (i.e., a superfield or superstring field) is the "three-in-one" structure of pure consciousness, in which the observer, the observed, and the process of observation are unified (Maharishi Mahesh Yogi, 1985). A parallel structure is found within a supersymmetric theory, in which bose fields (e.g., force fields) and fermi fields (e.g., matter fields) are united through the agency of supersymmetry. Here, the bose fields may be compared to the intelligence or "observer" aspect of the unified field, the fermi fields can be compared to the material or "observed" aspect, and the "process of observation" can be found in the dynamical principle of gauge supersymmetry, which connects and unifies the two. From this perspective, the unified field or superfield itself corresponds to the samhita of Maharishi Vedic Science.

In this context it is interesting to note that a supersymmetric unified field or superfield, which represents the unification of boson, fermion and gauge supersymmetry, exhibits the statistical properties of a bose field. This may be reflected in the fact that pure consciousness, which represents the unification of the observer (i.e., consciousness), the observed and the process of observation, retains consciousness as its dominant characteristic.

Such comparisons are, of course, complicated by the wide disparity in the associated languages. The subjective language naturally associated with a subjective technology contrasts with the highly analytical language which has evolved in the context of particle physics and field theory. Indeed, the whole empirical approach of modern science is carefully designed to remove the element of subjectivity as much as possible from the field of investigation. This objective approach has enjoyed considerable success within its domain of applicability, which includes systems that can be meaningfully isolated from the observer and the process of measurement—classical systems. However, it should be noted that quantum mechanics, which was born of the objective approach, establishes the intrinsic limitations of this approach by showing that a quantum-mechanical system cannot be meaningfully isolated from the observer. This limitation may especially apply to the unified field, which cannot be isolated or observed and which cannot therefore be considered to be an objective system. Indeed, we have previously argued that the unified field is formally as much a field of subjectivity as a field of objectivity. The use of a purely objective language in relation to the unified field might therefore appear somewhat artificial, and to some extent can be viewed as an historical artifact.

Indeed, one could argue that the objective approach of modern science, which is founded upon the separation of the observer from the system under observation, is essentially unsuited to investigate the fundamentally indivisible structure of natural law at its unified foundation. What seems to be required is a subjective approach to the investigation of the unified field which would allow the individual awareness to identify with the unified field and thereby provide a systematic means of investigating the structure and dynamics of the unified field on its own, self-interacting **level.** One must not, therefore, preclude the possibility of a subjective approach to the investigation of the unified field, nor should one allow a difference in methodology or language to become an insurmountable barrier. Maharishi has demonstrated in his formulation of Vedic science that it is possible to construct a subjective methodology and language that is as precise and as rigorous as the objective approach of modern science.[20]

If this subjective approach provides knowledge and experience of the most fundamental dynamics of natural law, one would expect this knowledge to result in competencies or other advantages that are in some sense comparable to knowledge acquired through more conventional means. For example, bringing the awareness repeatedly to the most abstract and fundamental levels of natural law might significantly affect and improve physical intuition, abstract and synthetic reasoning, creativity, and/or other forms of behavior that draw upon deeper levels of the mind and personality.

In fact, Maharishi goes further to predict that a growing intimacy with natural law at its most fundamental levels should result in greater success in virtually all spheres of activity (Maharishi Mahesh Yogi, 1966). Instead of acting in relative ignorance of the natural laws governing the dynamics of behavior and the environment, which leads to mistakes, problems, ill health, and other forms of suffering, the individual would take natural advantage of these laws. Such activity should spontaneously be more successful, and because it reflects a more comprehensive level of natural law, should be more supportive to the whole environment.

There are many indications that this is indeed the case. For example, the Transcendental Meditation program does lead to increased creativity, as indicated by enhanced fluency, flexibility, and originality in creative thought (Orme-Johnson and Haynes, 1981; Travis, 1979). Longitudinal studies involving prisoners instructed in the TM program showed significant gains on Loevinger's scale of self-development and decreased anxiety, aggression and recidivism (Abrams and Siegel, 1978; Alexander, 1982; Bleick and Abrams, in press). A four-year longitudinal study on college students regularly practicing the TM-Sidhi program found a statistically significant increase in fluid intelligence at an age where intelligence is not supposed to change (Aron et al., 1981).

These studies would seem to indicate an increased fluency and competency at more abstract and fundamental levels of mental activity, in accordance with Maharishi's prediction. By engaging deeper levels of the mind, it has been suggested (Alexander, Davies et al., 1987) that these developmental technologies may be activating latent biological structures and thereby providing a maturation foundation for further, morphogenetic-type growth to higher stages of human development.

II.5 Higher States of Consciousness and the Sidhis

Any consideration of concrete evidence for the proposed identity between pure consciousness and the unified field will necessarily include at least a brief discussion of the

[20]There are many detailed and compelling connections between modern science and Vedic science which follow from a more comprehensive analysis of the Vedic literature. This literature provides an extraordinarily detailed elaboration (in over 2000 volumes) of the spontaneous and dynamical process of symmetry breaking through which the unified field sequentially gives rise to the diverse laws of nature governing the dynamics of the entire universe. These comparisons would require a more detailed analysis of the Vedic literature, which lies beyond the scope of this work.

sidhis or "supernormal" abilities traditionally associated with higher states of human development. Although some of these abilities constitute natural extensions of qualities and abilities already developed in waking consciousness, others appear to involve physics in a fundamental way.

From a purely developmental standpoint, it seems reasonable to expect that new behavioral competencies would accompany higher developmental stages. In the normal sequence of development from childhood to adolescence, the individual passes through several distinct stages of physiological and psychological development, each associated with its own characteristic world-view and accompanied by a distinct set of behavioral competencies (Piaget and Inhelder, 1969). This sequence of development typically ends at adolescence in a stage known as "formal operations."

Recently, developmental psychologists have considered the possibility of continued growth to higher developmental stages beyond formal operations (Commons et al., 1984; Alexander, Langer and Oetzel, 1987). Indeed, there are four distinct states of consciousness beyond waking, dreaming, and deep sleep that are described in Maharishi Vedic Science (Maharishi Mahesh Yogi, 1977; Alexander, Davies et al., 1987; Dillbeck, 1983a, 1983b). These can be briefly summarized as:

1) ***Pure consciousness—the*** unified ground state of consciousness in which consciousness is identified with the unified field.
2) ***Cosmic consciousness—***in which the experience of pure consciousness is permanently established along with waking, dreaming, and deep sleep states of consciousness. In this state, consciousness maintains its identification with the unified field while the mind and emotions are fully engaged in activity.
3) ***Refined cosmic consciousness—***similar to cosmic consciousness except that the functioning of the mind and senses has become further refined. Sense objects are perceived in their most refined values and the emotions are said to achieve their full development.
4) ***Unity consciousness—***in which the object, as well as the subject, is experienced as the unified field.

The higher developmental stages (2-4) are said to develop spontaneously on the basis of the regular alternation of pure consciousness with activity, and result from an increasingly profound understanding and experience of pure consciousness and its self-interacting dynamics (Maharishi Mahesh Yogi, 1985).

This same understanding and experience is said to provide the basis for the classical sidhis, which involve the ability to utilize the mind, body, and environment in increasingly fundamental ways. Some of these sidhis, if demonstrated under suitable conditions, would constitute striking evidence for the proposed identity between pure consciousness and the unified field.

Certain sidhis, for instance levitation, appear to violate the classical laws of Newtonian gravity and general relativity, which at first sight would seem highly implausible. However, neither Newtonian gravity nor general relativity represent consistent theories of gravity from a quantum-mechanical standpoint, and it might become necessary to reassess the circumstances under which these classical theories can be expected to apply (generally macroscopic circumstances). Physicists have been profoundly surprised on a number of prior occasions by the appearance of striking quantum-mechanical behavior at macroscopic, observable scales. Such phenomena of macroscopic quantum coherence, which have been observed thus far under conditions of low temperature, present a striking contrast to classical intuition and experience, as in the examples of superconductivity and superfluidity.

Most of the laws governing macroscopic behavior arise as the classical limit of deeper, quantum-mechanical laws. The transition from quantum-mechanical to classical behavior generally requires a statistical averaging over quantum-mechanical fluctuations. It is therefore conceivable, in the case of the sidhis, that a sustained influence of coherence at the quantum-mechanical level might upset the balance of statistical averaging that ordinarily gives rise to the familiar classical laws. If the sidhis do constitute a departure from established classical patterns of behavior, then a deeper, quantum-mechanical understanding will indeed be necessary.

In general, more fundamental space-time scales offer natural mechanisms for transforming the environment in increasingly profound ways. For example, transformations among electrons and neutrinos, lepto-quark transformations, and bose-fermi transformations along with modifications in the curvature of space-time geometry are natural phenomena at the electro-weak, grand unified, and super-unified scales, respectively. More profound sidhis might therefore involve a progressive extension of the capacity for conscious activity to more fundamental space-time scales.[21]

Indeed, the phenomenon of levitation, with its implied control over the local curvature of space-time geometry, would appear to require the ability to function coherently at the scale of quantum gravity, which is the assumed scale of super-unification and the proposed domain of pure consciousness. In this way some of the sidhis, if demonstrated under laboratory conditions, would provide striking evidence for the proposed identity between pure consciousness and the unified field.

II.6 Conclusion

We can summarize our phenomenological discussion as follows. It is the experience of over three million individuals trained in the relevant experiential techniques that there is a unified ground state of consciousness in which the observer, the process of observation, and the observed are unified in a structure of "pure, self-interacting" consciousness. That this is a real experience and not something imagined is confirmed by approximately 360 studies indicating unique physiological and psychological changes that accompany this subjective experience. It is the further experience that this subjectively unbounded field is the unified origin of what we ordinarily call subjective and objective existence. We have observed a striking correspondence between structural aspects of this experience and the physical structure of natural law at fundamental scales. The most straightforward interpretation of these experiences, of the Super Radiance data, and of the sidhis phenomena is that the unified field that has become the primary focus of modern theoretical physics and the unified field of consciousness are identical.

Conversely, if one were to reject all such experiences and conclude that there were no fundamental connection between the unified field of consciousness and the unified field responsible for physical existence, one would then be forced to provide an alternative

[21]The subjective accounts associated with the sidhis would support such an interpretation. The individual in fully developed unity consciousness is said to experience all objects of perception as precipitated modes of consciousness. From this fundamentally unified perspective, it is claimed that the transformations required to change one object into another are generally obvious (i.e., molecular, nuclear, electro-weak, etc.). Intention is said to accomplish the desired changes (Maharishi Mahesh Yogi, private communication).

explanation for the Super Radiance phenomenon. This would probably require the introduction of nonlocal mechanisms outside the domain of physics and hence more radical than those considered here.

We favor the simpler view in which there is only one unified field, for we have emphasized previously that the reasons for favoring some other more complicated interpretation are primarily historical and somewhat unique to our time and culture.

We would also regard Maharishi's strong support for this proposal as significant. Maharishi's clear scientific penetration into a tradition that was previously dominated by obscure and conflicting metaphysical understandings has enabled him to evolve extremely powerful and systematic procedures to experience pure consciousness, and to make numerous specific predictions regarding the physiological, psychological, and even sociological effects and correlates of the pure consciousness state, which have since been verified by scientific means. It is on the basis of his own, unified field theoretic understanding and explication of the TM and TM-Sidhi programs that these experiential technologies, along with their group applications in a sociological context, have been described as the "Maharishi Technology of the Unified Field."

At present, most physical scientists are relatively unacquainted with the scientific literature on the Super Radiance effect, and tend to regard such phenomena with skepticism. This attitude is easily understood, for at first glance such phenomena may appear to require substantial modifications in the conceptual foundations of physics, and such changes have never met with enthusiasm. Here, we have tried to show that the Super Radiance effect and other phenomenological aspects of higher states of consciousness do not require the modification of existing physical principles and are compatible with the framework of physical science as it currently stands.

What appears to be required is an expanded physical framework for the understanding of consciousness, in which consciousness occupies a fundamental position in nature. Indeed, the Super Radiance data may require that consciousness is more fundamental than the classical space-time framework generally associated with distances larger than the Planck scale. In this context, the most parsimonious, precise, and hence attractive framework for understanding the Super Radiance data and the subjective accounts of a unified field of consciousness is the proposed identity between pure consciousness and the unified field. Such a framework also presents a completely unified basis for understanding both subjective and objective experience, according to which the most modern description of natural law available through the objective approach of modern science and the most ancient understanding of natural law available through the predominantly subjective approach of Vedic science are seen as complementary approaches to gaining knowledge of the most fundamental aspects of natural law.

As a foundational theory of consciousness, this integrated framework developed by Maharishi would supplant the very limited view of consciousness based upon the analysis of waking experience, which is poorly motivated from a theoretical standpoint and which is presently at odds with an expanding range of phenomenology. This new framework includes, as an empirical component, systematic procedures for the direct experience of the ground state of consciousness together with the most elementary states of excitation of consciousness and their associated physiological correlates. Such a framework, which combines the most modern field theoretic principles with the understanding of ancient Vedic science, could fulfill the significant promise that a fundamental science of consciousness should offer and that has not been fulfilled by contemporary psychology with its limited empirical methods and models based on outmoded physical constructs. Indeed, the Maharishi effect already provides a striking demonstration of the applied technologies that can emerge from such a framework by demonstrating the capacity to reduce crime rates, accidents, infectious diseases, etc., including violence and war deaths in regions where military and negotiated settlements have historically demonstrated their inability to do so.

The potential contribution of such a science to the development of physics is not inconsequential. There is growing concern in the scientific community regarding the long-term empirical basis for fundamental particle physics resulting from severe financial and technological constraints on future particle accelerators. Already theorists have had to rely increasingly upon their analytic and intuitive abilities as the principal focus of theoretical physics has shifted to the experimentally inaccessible domains of grand unification and super-unification.

If there were a subjective means of gaining knowledge that was reliable (i.e., verifiable and consistent among scientists), this could help compensate for a lack of useful accelerator data pertaining to the physics of fundamental scales. For example, if the Maharishi Technology of the Unified Field indeed provides the direct conscious experience of more abstract and fundamental levels of intelligence pertaining to deeper levels of natural law, then it could represent a means for developing physical intuition and even for gaining direct insights into the most fundamental aspects of nature's dynamics—e.g., the structure and dynamics of the unified field and the mechanics of symmetry breaking. The Maharishi Technology of the Unified Field thereby offers the possibility of a new research methodology based on a subjective technology that could fulfill the ultimate goal of objective science to fully unfold its unified foundation and to apply this knowledge for the holistic development of the individual and society.

It is also possible that the Super Radiance effect and/or sidhis might in themselves provide a useful laboratory for the investigation of fundamental physical principles in the domains of quantum theory, quantum field theory and/or unified quantum field theories. If, for instance, conventional electromagnetic mechanisms do not provide an adequate framework for understanding the Super Radiance effect, a fundamental new mechanism for long-range interactions will be needed. We have seen that in the context of present theories, this mechanism may involve non-local effects associated with the structure of space-time at the scale of super-unification or long-range quantum-mechanical correlations. Future experiments should help to resolve these fundamental issues, and a more complete understanding of the physical basis of consciousness is likely to emerge.

Our motivation throughout this work has been primarily empirical. We have attempted to understand certain fundamental phenomena for which there exists strong empirical evidence and which seem to require a deeper and expanded physical framework for the understanding of consciousness.

The evolution of scientific knowledge often requires extending the domain of scientific inquiry to include areas that were previously outside the range of scientific investigation. Many eminent physicists feel that the final and most important scientific frontier is consciousness. Now with the experiential technologies provided by Maharishi Vedic Science, consciousness has entered the realm of systematic, scientific investigation. The resulting science of consciousness already suggests a profound and previously unsuspected unification of objective and subjective realms of experience. Indeed, if the applied technologies of Vedic science provide the direct experience of the structure and dynamics of the unified field, this could lead to a revolution in the field of scientific knowledge and methodology, and would constitute one of the key discoveries of our age.

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