

# Introducing surface tension to spacetime

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**Abstract.** Concepts from physical chemistry of surfaces and surface tension are applied to spacetime. More specifically, spacetime is modeled as a spatial fluid continuum bound together by a multi-dimensional membrane of time. A metric tensor that relates empty flat spacetime to energetic curved spacetime is found. Equations of motion for an infinitesimal unit of spacetime are derived. The equation of motion in a time-like direction is a Klein-Gordon type equation. The equations of motion in space-like directions take the form of Schrodinger's equation where Plank's constant is related to membrane elastic modulus. Although much work remains, it is suggested that the spacetime surface tension may serve as a mechanical model for many phenomena in quantum mechanics and atomic particle physics.

## 1. Introduction

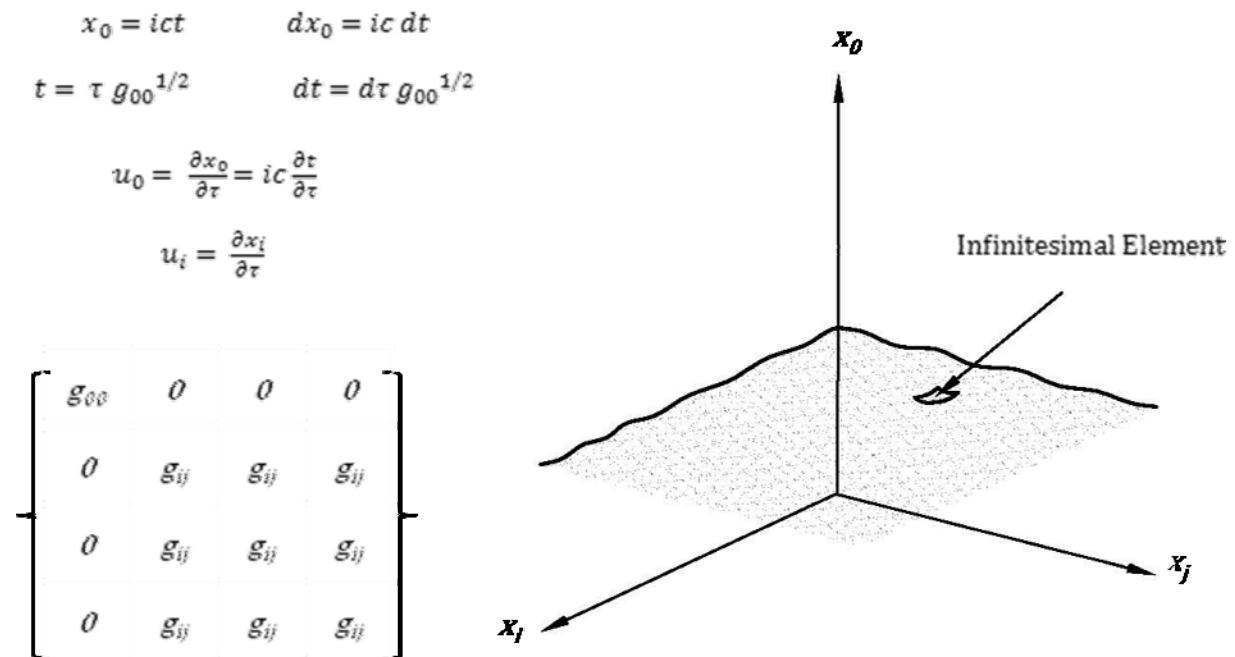
The goal of this study is to start from empty spacetime, and theoretically attempt to construct matter. Empty spacetime itself must be the most basic building material from which all things are constructed. Yet, how does one construct something from nothing? The proposed solution is to introduce concepts from physical chemistry and surface tension to space and time. Spacetime is modeled as a continuum of space held together by a multi-dimensional membrane of time. From this simple mathematical construct, a veritable universe of particles and waves can be manufactured from nothing except spacetime curvature.

Ordinary continuum mechanics describes well the behavior of bulk fluids. However, understanding the behavior of fluid interfaces and small-scale interactions requires concepts from physical chemistry and surface tension. Examples of ordinary small-scale interactions governed by surface tension include the quantized size of water droplets, corpuscular formation, wavelets, adhesion, meniscus formation, and capillarity. By analogy, it is suggested here that including surface tension in the treatment of spacetime may provide new ways of relating general relativity, quantum mechanics, and atomic particle physics.

## 2. Membrane geometry

Consider an arbitrary, non-relativistic distribution of matter contained within a small volume of spacetime. If time and position of each point mass are plotted relative to a set of nearby clocks and coordinates in space, the resulting mass distribution would align in time and take the form of a fabric or membrane. An example of a matter distribution relative to time and two coordinates of space is shown in Figure 1. The distribution of non-relativistic matter is dispersed over the two-dimensions of space and concentrated in a thin increment of time. The matter distribution forms an interface in time. The same plot can be constructed relative to any two coordinates of space.





**Figure 1.** Geometry of an arbitrary matter distribution in a small volume of spacetime displaying membrane-like properties

Consider the same matter distribution from a relativistic perspective. At the start of most physics problems/experiments, clocks are typically set to zero. At the instant clocks are set to zero, the distribution of an arbitrary volume of relativistic matter also would appear as a fabric or membrane. Each point in the fabric would correspond to a particle of mass with space-like, time-like, or light-like trajectories. Constant resetting clocks to zero can be achieved by a reference frame moving along a time-like hypersurface such that all points remain separated by space-like intervals. Such a reference frame is shown by the metric in Figure 1 and is referred to as a *synchronous* frame. The synchronous frame can be found by appropriate transformations for any distribution of matter [3]. In the synchronous frame, the time component of the metric,  $g_{00}$ , approaches unity,  $g_{00}=1$ . Surface tension allows for small perturbations in  $g_{00}$ .

The interface of matter in time for an observer can be treated as a boundary layer to which physical chemistry of surfaces and membrane mechanics can be applied. In four dimensions, the distribution of matter is more difficult to visualize. Matter is dispersed in the continuum of space and held together by a multi-dimensional membrane at the interface with time.

### 3. Surface tension

Each dot along the planar fabric in Figure 1 depicts a point mass. Due to equivalence of matter and energy, each point in Figure 1 also is a concentration of energy. Let the Greek symbol Koppa<sup>1</sup>,  $Q$ , represent surface energy per unit area. A fundamental theorem of physical chemistry of surfaces is that surface energy of an interface is mathematically equivalent to surface tension. A crude

<sup>1</sup> In the study of physical chemistry, the Greek letter gamma,  $\gamma$ , is typically used to represent surface tension. To avoid confusion with the Lorentz factor in theoretical physics assignment of a new symbol was necessary. The forgotten Greek letter Koppa,  $Q$ , was chosen. Before being adopted and then omitted from the modern Greek alphabet, the letter Koppa,  $Q$ , had its origins in ancient Hebrew. The ancestor Koppa symbol was drawn as the sun on the horizon and it signified light and the edge of time. Thus, Koppa seemed a fitting parameter to describe tension at the boundary of time. In the Roman alphabet, Koppa corresponds to the letter  $Q$ .

mathematical derivation showing the equivalence of surface energy and surface tension is shown in Table 1 below.

Table 1. Classical and Multi-Dimensional Surface Tension

3D Space	4D Spacetime
$\text{Surface Energy} = Q = \frac{\text{Energy}}{\text{Area}}$	$\text{Surface Energy} = Q = \frac{\text{Energy}}{\text{Volume}}$
$\text{Surface Tension} = \frac{\text{Force}}{\text{Width}} = \frac{\text{Energy} / L}{\text{Area} / L} = Q$	$\text{Surface Tension} = \frac{\text{Force}}{\text{Area}} = \frac{\text{Energy} / L}{\text{Volume} / L} = Q$

where  $L$  is a space-like increment of length,  $Q$  is free surface energy per unit area (3D) or per unit volume (4D), and  $Q$  is also surface tension. Surface energy is equivalent to surface tension. In ordinary three dimensional membrane problems, surface energy has units of  $\text{J/m}^2$ , which is equivalent to surface tension with units of  $\text{N/m}$ . For a multi-dimensional membrane in spacetime, surface energy has units of  $\text{J/m}^3$ , which is equivalent to surface tension with units of  $\text{N/m}^2$ .

Stable existence of an interface requires that the surface energy be positive; were it negative or zero, fluctuations would lead to continuous expansion of the interface and eventual complete dispersion [1]. Surface tension forms a contractile skin which gives rise to membrane-like behavior. It is important to note that a physical membrane is not required in spacetime, rather matter/energy need only be organized in a surface for an observer. Spacetime surface tension may be the fundamental force of nature, which acts to keep matter and energy together within the construct of general relativity. Analogous to general relativity [2], surface tension tells spacetime how to curve, and spacetime curvature tells surface tension (energy/matter) how to flow.

#### 4. Fluidity

Spacetime is generally assumed to exhibit fluid-like properties. For an ideal fluid, shear stresses are zero.

$$Q_{ij} = 0 \quad \text{for } i \neq j$$

It follows from traditional mechanics that if shear stress is zero everywhere, then surface tension must be uniform in all directions. The Cauchy stress tensor for spacetime surface tension is given by,

$$Q_{ij} = Q\delta_{ij} \quad (1)$$

where  $\delta_{ij}$  is the Kronecker delta symbol.

#### 5. Equations of motion

The equations of motion are derived here using figures drawn with time and two coordinates of space to aid in visualization. Equations are constructed in manner to include the hidden third dimension of space for full four-dimensional treatment of spacetime.

An infinitesimal element of spacetime membrane is taken from Figure 1 and represented at larger scale in Figure 2. In order to account for potential curvature of spacetime, the element is modeled as a curved manifold such that stresses are not co-linear. Surface tension is assigned to four sides of the element.

It should be noted that the infinitesimal element of spacetime can be moving through space and time at some arbitrary four velocity,  $u_0$  and  $u_i$ . All lengths and forces in the equations of motion are taken in the material reference frame moving with the *membrane* itself. To understand that which would be experienced for an observer in a spatial/inertial reference frame, Lorentz transformations apply.

Dynamic equations of motion are derived by summing surface tension acting on the infinitesimal element in various directions and setting the result equal to the change of momentum with proper time,  $\tau$ . Forces acting in a spatial direction are summed as follows,

$$\begin{aligned}\sum F_{x_i} &= -Q dx_j dx_k \cos \alpha_i + Q dx_j dx_k \cos \alpha_i + \frac{\partial Q}{\partial x_i} dx_i dx_j dx_k \cos \alpha_i \\ &= \frac{1}{c^2} \frac{\partial}{\partial \tau} (Q u_i) dx_i dx_j dx_k\end{aligned}$$

where  $\alpha_i$  is the small angle between planar spacetime and perturbed spacetime, and  $c$  is the speed of light. In the foregoing equation, traditional mass has been replaced with surface energy using the relation for energy per volume,  $Q dx_i dx_j dx_k = mc^2$ .

Recognizing that for slight curvatures, the cosine of a small angle is approximately equal to one,  $\cos \alpha_i \approx 1$ , reduces the equation of motion in the spatial direction to,

$$\frac{\partial Q}{\partial x_i} = \frac{Q}{c^2} \frac{\partial u_i}{\partial \tau} + \frac{u_i}{c^2} \frac{\partial Q}{\partial \tau}$$

The last term in the equation above is the change in surface tension with time. In physical chemistry of surfaces, change in surface tension with time is associated with gradual fluctuations in temperature and is typically assumed to be negligible for short duration and small scale events. The change in surface energy over cosmic scale events is likely of importance and may be the subject of future studies. Omission of the time rate of change of surface energy further reduces the equation of spatial motion of spacetime to,

$$\frac{\partial Q}{\partial x_i} = \frac{Q}{c^2} \frac{\partial u_i}{\partial \tau} \quad (2)$$

The dynamic equation of motion through time has a different appearance. Summing forces in the time direction yields,

$$\begin{aligned}\sum F_{x_0} &= 2Q dx_j dx_k \sin \alpha_i + \frac{\partial Q}{\partial x_i} dx_i dx_j dx_k \sin \alpha_i + 2Q dx_i dx_k \sin \alpha_j + \frac{\partial Q}{\partial x_j} dx_i dx_j dx_k \sin \alpha_j \\ &\quad + 2Q dx_i dx_j \sin \alpha_k + \frac{\partial Q}{\partial x_k} dx_i dx_j dx_k \sin \alpha_k - P dx_i dx_j dx_k \\ &= \frac{1}{c^2} \frac{\partial}{\partial \tau} (Q u_0) dx_i dx_j dx_k\end{aligned}$$

where  $P$  is an applied external volumetric force acting on the fabric of spacetime. If both sides of the equation are divided by differential volume,  $dx_i dx_j dx_k$ , and the change in  $Q$  over an infinitesimal distance and time is assumed small with respect to  $Q$ , then the equation of motion in the temporal direction reduces to,

$$2Q \frac{1}{dx_i} \sin \alpha_i + 2Q \frac{1}{dx_j} \sin \alpha_j + 2Q \frac{1}{dx_k} \sin \alpha_k - P = \frac{Q}{c^2} \frac{\partial u_0}{\partial \tau}$$

For small angles of curvature, basic trigonometry provides that  $\sin \alpha_i \approx dx_i/2r_i$  where  $r_i$  is the radius of curvature of the surface in the  $i$ 'th coordinate. For a thin membrane, the following relation holds,

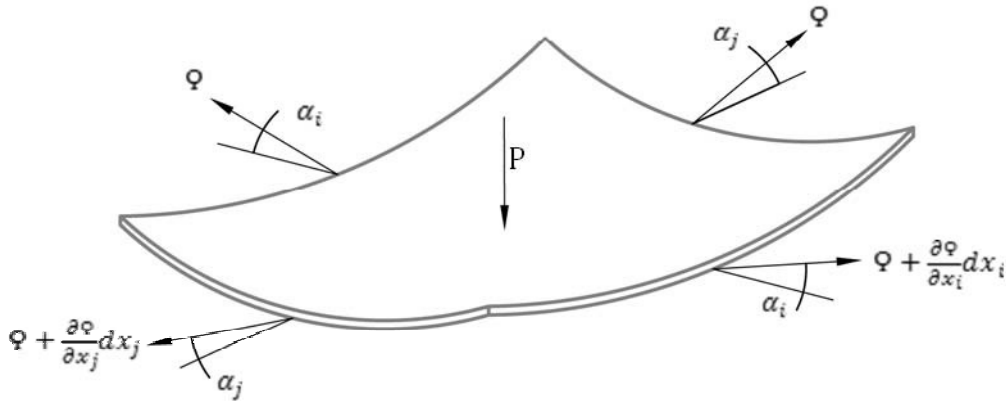
$$\frac{1}{r_i} = \frac{\partial^2 x_0}{\partial x_i^2}$$

By substituting this relation into the dynamic equation of motion in the temporal direction and noting that  $u_0$  is  $\partial x_0/\partial \tau$ , one obtains,

$$2Q \frac{dx_i}{2dx_i} \frac{\partial^2 x_0}{\partial x_i^2} + 2Q \frac{dx_j}{2dx_j} \frac{\partial^2 x_0}{\partial x_j^2} + 2Q \frac{dx_k}{2dx_k} \frac{\partial^2 x_0}{\partial x_k^2} - P = \frac{Q}{c^2} \frac{\partial^2 x_0}{\partial \tau^2}$$

which reduces to the following expression,

$$\frac{\partial^2 x_0}{\partial x_i^2} + \frac{\partial^2 x_0}{\partial x_j^2} + \frac{\partial^2 x_0}{\partial x_k^2} - \frac{P}{Q} = \frac{1}{c^2} \frac{\partial^2 x_0}{\partial \tau^2} \quad (3)$$



**Figure 2.** Surface tension about an infinitesimal element of spacetime membrane

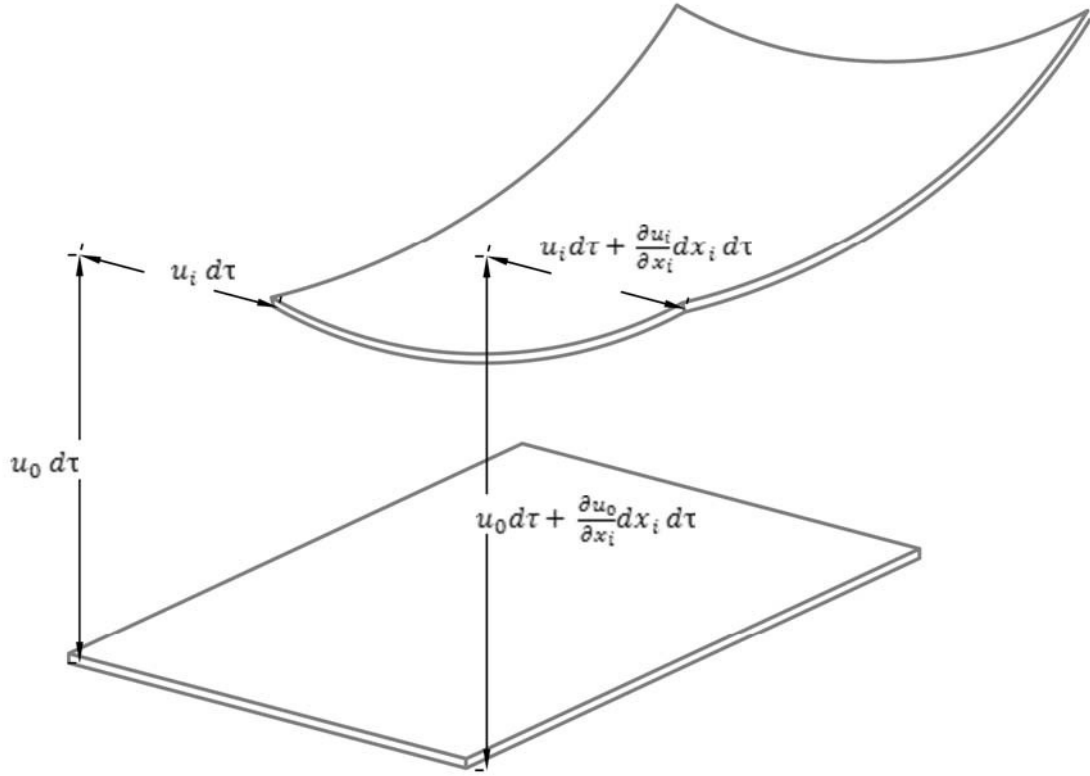
## 6. Strain-displacement

Displacement and strain of an infinitesimal membrane of spacetime is shown in Figure 3. Here again, the infinitesimal element of spacetime can be moving through space and time at some arbitrary four velocity,  $u_0$  and  $u_i$ . Displacement in time and space is shown as an upward and right hand translation in the figure. Excellent derivations of strain-displacement equations for membranes can be found in common engineering texts [4, 5, 6, 7]. However, the differential unit of time in these derivations is assumed to be unchanging, set equal to 1, and dropped from equations without mention. Equations for strain-displacement are re-derived here in order to better account for changes in perceived time.

The strain-displacement tensor is the Lie derivative of the metric on space and represents the rate of geometric change of a Riemannian manifold [8]. In this derivation, it represents the dynamical change in the metric as observed from a synchronous frame. There are several definitions of strain-displacement. Here the Green-Lagrange strain,  $\epsilon$ , is used, as defined by [4],

$$\epsilon d\tau = \frac{ds^2 - ds_0^2}{2ds_0^2} \quad (4)$$

where  $ds_o$  is an infinitesimal space-like increment at some time  $\tau$  and  $ds$  is the same space-like increment at time  $\tau+d\tau$ . The differential increment of proper time  $d\tau$  has been added to the definition of Green-Lagrange strain to be rigorous.



**Figure 3.** Displacement and strain of an infinitesimal element of spacetime membrane

Referring to Figure 3, the initial length of the infinitesimal fabric of spacetime may be taken as,

$$ds_o^2 = dx_i^2$$

The length of the element at time  $+d\tau$  may be found using the Pythagorean theorem since an imaginary time coordinate is being used in a Gaussian normal (i.e. material) reference frame.

$$ds^2 = \left( dx_i + \frac{\partial u_i}{\partial x_i} dx_i d\tau \right)^2 + \left( \frac{\partial u_0}{\partial x_i} dx_i d\tau \right)^2$$

Expanding the above equation yields,

$$ds^2 = dx_i^2 + 2 \frac{\partial u_i}{\partial x_i} dx_i^2 d\tau + \left( \frac{\partial u_i}{\partial x_i} \right)^2 dx_i^2 d\tau^2 + \left( \frac{\partial u_0}{\partial x_i} \right)^2 dx_i^2 d\tau^2$$

In membrane mechanics, in-plane strains,  $\partial u_i / \partial x_i$  are typically very much smaller than the out-of-plane membrane displacements, so the second order term,  $(\partial u_i / \partial x_i)^2$ , is omitted leaving,

$$ds^2 = dx_i^2 + 2 \frac{\partial u_i}{\partial x_i} dx_i^2 d\tau + \left( \frac{\partial u_0}{\partial x_i} \right)^2 dx_i^2 d\tau^2$$

Substitution of the above equations for  $ds_o^2$  and  $ds^2$  into (4) for the  $i$ 'th component in strain results in,

$$\epsilon_{ii} d\tau = \frac{2 \frac{\partial u_i}{\partial x_i} dx_i^2 d\tau + \left(\frac{\partial u_0}{\partial x_i}\right)^2 dx_i^2 d\tau^2}{2 dx_i^2}$$

which reduces to,

$$\epsilon_{ii} = \frac{\partial u_i}{\partial x_i} + \frac{1}{2} \left(\frac{\partial u_0}{\partial x_i}\right)^2 d\tau \quad (5)$$

A similar derivation can be performed to include shear strain-displacements, with the following result obtained [4]. Equation (6) represents a more complete form of the strain tensor for any  $i$  and  $j$ ,

$$\epsilon_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \frac{1}{2} \left| \left( \frac{\partial u_0}{\partial x_i} \right) \left( \frac{\partial u_0}{\partial x_j} \right) \right| d\tau \quad (6)$$

In the principle direction of strain, traction and transverse strains are null.

$$0 = \epsilon_{00} = \epsilon_{i0} = \epsilon_{0j} \quad (7)$$

As an aside, the metric tensor for space-like separated particles in the synchronous frame for the surface tension model can be found by rearrangement of (4),

$$(1 + 2\epsilon_{ij}d\tau) ds_o^2 = ds^2$$

Note that the difference in the squares of space-like increment is invariant; the same principle strains can be obtained starting in either an inertial or material reference frame. The strain tensor is covariant, symmetric, and torsion free. The quantity enclosed by parenthesis is somewhat analogous to the Schwarzschild metric except for the positive sign. It is noted that the sign is a convention. Had this derivation been conducted such that surface tension was positive (compression), the sign in the above equation would change.

## 7. Constitutive relations

If spacetime is homogeneous, isotropic, and linearly elastic, then the constitutive relations between stress and strain are represented by Hooke's laws, given by [5]

$$Q_{ii} = \frac{E\Delta x_0}{1 - \nu^2} (\epsilon_{ii} + \nu\epsilon_{jj})$$

where  $\nu$  is Poisson's Ratio,  $E$  is Young's Modulus, and  $\Delta x_0$  is membrane thickness. In the mechanics of thin shells, Young's Modulus is multiplied by membrane thickness,  $\Delta x_0$ , because surface tension acts over the membrane thickness. According to special relativity, length contraction occurs only in the direction of motion and is not associated with a complimentary dilation in height. Consequently, Poisson's Ratio should be taken as zero,  $\nu = 0$ , for spacetime. Hence, the constitutive relations take the form,

$$Q_{ii} = E ic\Delta t \epsilon_{ii} \quad (8)$$

The constitutive relations for the off-diagonal shear terms with  $\nu = 0$  would appear as [5],

$$Q_{ij} = \frac{E \, ic\Delta t}{2} \epsilon_{ij} \quad (9)$$

### 8. Analogous Klein-Gordon

In the proposed model of spacetime, perturbations in the coordinate of time,  $x_0$ , given by (3) exhibit wave-like properties consistent with the Klein-Gordon equation of quantum mechanics. Setting external pressure,  $P$ , equal to zero in (3) and evaluating the result in 1-dimension, yields the familiar wave equation given by,

$$\frac{\partial^2 x_0}{\partial x_i^2} = \frac{1}{c^2} \frac{\partial^2 x_0}{\partial \tau^2} \quad (10)$$

In (10), waves in the membrane of spacetime propagate with a constant speed of light,  $c$ , independent of wavelength and frequency. Since the wave equation was derived for a membrane rather than bulk fluid, the resulting waves travel along hypersurfaces and would exhibit properties of polarization. Electromagnetic radiation behaves in exactly this way.

The equation of motion in the time direction given by (3) has another immediately recognizable solution. The solution is the familiar equation of Young and Laplace which is found when temporal acceleration is zero,  $\partial^2 x_0 / \partial \tau^2 = 0$ , given by,

$$\frac{\partial^2 x_0}{\partial x_i^2} + \frac{\partial^2 x_0}{\partial x_j^2} + \frac{\partial^2 x_0}{\partial x_k^2} = \frac{P}{Q} \quad (11)$$

where  $P$  is the applied external volumetric force perhaps best described as encapsulated mass/energy. The Young and Laplace solution is the equation for a corpuscle, which at its lowest energy state is a sphere. The Gauss-Bonnet theorem states that the integral of Gaussian curvature over the surface area of a corpuscle has distinct quantized solutions; this theorem provides for torus and other higher energy corpuscular geometries. Equation (11) suggests three "polarizations" of corpuscular geometry can exist in spacetime; each set of solutions is found by omitting one of the spatial curvature terms.

### 9. Analogous Schrödinger

Using the constitutive relationship (8), substituting strain (5) for surface tension in the equation of motion (2) yields,

$$E \, ic\Delta t \left( \frac{\partial^2 u_i}{\partial x_i^2} + \frac{\partial u_0}{\partial x_i} \left( \frac{\partial^2 u_0}{\partial x_i^2} \right)^2 d\tau + \frac{1}{2} \left( \frac{\partial u_0}{\partial x_i} \right)^2 \frac{\partial}{\partial x_i} (d\tau) \right) = \mu \frac{\partial u_i}{\partial \tau}$$

where  $Q/c^2$  has been replaced with mass density per unit volume,  $\mu$ . Here, the thickness of the fabric of spacetime,  $\Delta t$ , is assumed constant. It is proposed that the second higher order term on the left side of the equation can be assumed small compared to the other terms. The third term on the left side of the equation has to do with the curvature of spacetime. For flat spacetime, the third term can be omitted. The above equation can be re-arranged to the familiar dispersion equation of quantum mechanics,

$$E \, ic\Delta t \frac{\partial^2 u_i}{\partial x_i^2} = \mu \frac{\partial u_i}{\partial \tau}$$

Young's Modulus and the thickness of the fabric of spacetime are unknown constants. If  $Ec\Delta t$  is set equal to  $\hbar/2$ , it follows,



$$-\frac{\hbar}{2\mu} \frac{\partial^2 u_i}{\partial x_i^2} = i \frac{\partial u_i}{\partial \tau} \quad (12)$$

which is analogous to the non-relativistic, one-dimensional Schrödinger equation. The spatial component of the four velocity replaces the probability wave equation in the Schrödinger equation. Surface tension (matter/energy) within the manifold of spacetime and the corresponding strain (Lie derivative) over space, which is the time rate of change of the manifold to varying tension, move in accordance with a Schrödinger-like equation.

### 10. Analogous Heisenberg

In the foregoing derivation of the analogous Schrödinger equation, the constants  $Ec\Delta t$  were set equal to  $\hbar/2$ . If this assignment of constants is reinserted into the constitutive relationship (8), the following result is obtained,

$$Q_{ii} = i \frac{\hbar}{2} \epsilon_{ii}$$

It is worth noting that the units of surface tension,  $Q$ , are energy per infinitesimal volume and the units of dynamical strain are the inverse of proper imaginary time. This equation holds for a change in surface tension and a change in strain, such that one can write,

$$\Delta Energy \Delta \tau = \frac{\hbar}{2} \quad (13)$$

which has some similarity to the Heisenberg uncertainty principle where the equal sign would be replaced with a greater than or equal sign. Aspects of the uncertainty relation are embedded within Hooke's law for the mechanical medium of spacetime.

### 11. Analogous Weyl

It follows from the fluidity of spacetime (1), the constitutive relationship (9), and the shear strain (6) that,

$$\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} + \left| \left( \frac{\partial u_0}{\partial x_i} \right) \left( \frac{\partial u_0}{\partial x_j} \right) \right| d\tau = 0 \quad (14)$$

This equation governs the free rotation of geometries manufactured of spacetime which classically represents an eddy and bears some resemblance to the Weyl equation. Rotation itself does not cause stress or strain (change in mass/stored energy) in the membrane of spacetime but does cause a deformation of time thereby altering geodesics. Free rotation may lead to other particle-like geometric solutions in spacetime such as vortices. There are three possible particle-like vortex solutions to (14): unstable, short lived rotational vortices, stable irrotational vortices with field lines ending at a corpuscle, and a stable pair of oppositely rotating irrotational vortices entangled in time.

### 12. Discussion

The main-stream view of quantum mechanics is based on the Copenhagen interpretation where wave functions have no physical analog, rather quantum mechanical waves are purely mathematical probabilities. The present surface tension model is not the first to suggest a physical interpretation of quantum wave equations. The Copenhagen interpretation edged out a deterministic geometric theory originally proposed by de Broglie and further revised by Bohm, known as pilot wave theory. Pilot wave theory explained that point-like particles moving along hidden fluid-like waves can provide a foundation for quantum mechanics. De Broglie could not explain the fluid-like waves which Einstein called "ghost waves". Still, physicists striving to better understand quantum mechanics continue to

look at pilot wave theory even today [9]. The present study proposes the fluid medium suggested by de Broglie may be the metric of spacetime itself under the influence of surface tension.

The present surface tension model is not unique regarding the importance of membrane geometries in attempting a physical explanation for quantum mechanics. In modern string theory, hidden dimensions are conjoined by strings and membranes in a multiverse [10]. The eigenstates of these geometric constructs, specifically including "branes", seem to have the correct constraints to match the spin, mass, and number of particles in the Standard Model. The present work attempts to explain how spacetime might exhibit membrane-like behavior and suggests, as one solution, how string-like entangled micro-vortices are fixed by Dirichlet boundary conditions to the fabric of spacetime. Surface tension may provide a mechanism for how strings, branes, and Dirichlet boundary conditions arise in spacetime. This paper represents only an introduction. Much work remains to compare results with string theory and the Standard Model.

### 13. Conclusions

From surface tension, the membrane of spacetime can take on many fundamental shapes such as waves, corpuscles, menisci, vortices, agglomerates, and foams. It is suggested that these basic shapes can be arranged in atoms, molecules, and matter. In other words, everything in the universe may be manufactured from the fabric/membrane of spacetime itself. Matter and energy are connected in a virtual membrane at the interface of observed time.

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