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A Soft Condensed Matter Model for Universal Phenomena

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A SOFT CONDENSED MATTER MODEL FOR UNIVERSAL PHENOMENA

by

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CHAPTER 1

WHAT IS SOFT MATTER?

The physics sub-discipline known as Soft Matter or Soft Condensed Matter is generally considered to have been founded by Nobel laureate Pierre-Gilles de Gennes. In 1991, de Gennes was awarded the Nobel prize for his work with complex forms of matter, at the time, referred to by some as complex fluids, which is a misnomer, since not all soft matter flows. In his Nobel lecture, he referred to this complex matter as "soft matter".[1]

At the time of de Gennes lecture, the primary materials considered as soft matter were polymers, liquid crystals, surfactants, and colloids; and these are still the predominant materials of study in soft matter physics. Bio-materials, such as blood cells, were, also, beginning to be recognized for their "soft properties" (a term which I shall expand upon, shortly). Over the next two decades, great advances were made in the theoretical, computational, and experimental modeling of gels, rubbers, foams, emulsions, microemulsions, amphiphiles (which are similar to surfactants), biological fluids and tissues, and other subclassifications of the above mentioned primary soft matter classifications. During this time, two more classifications of soft matter were introduced—glasses and granular materials. In the past few years, these two material types have grown within the discipline to have nearly as many resources dedicated to their research as the above-mentioned material types.

A vast amount of common materials fall under the umbrella of soft matter; including paints, milk, blood, muscle tissue, ink, soaps, plastics, toothpaste, proteins, glues, foams, sponges, and seemingly countless others.

The major properties that tend to characterize soft matter include:[2][3][4][5]

1. Mesoscopic-sized particles

2. Behaviors and interactions that take place on thermal energy scales (commonly near room temperature)
3. Self-assembly
4. Phase separation
5. Large responses to small stimuli
6. Nonlinear responses to external stimuli
7. Slow response to stimuli
8. Significant contribution of non-equilibrium mechanics to overall behavior
9. Large number of internal degrees of freedom
10. Viscoelasticity

In terms of atoms, soft matter particles have an approximate size range of 10^2 atoms, in the cases of liquid crystals, to 10^9 atoms, in the case of colloids.[2] The size of these particles generally leaves them too large (or having too much momentum) for the quantum mechanical effects that would be experienced at the microscopic level to have an appreciable effect, however they are, also, too small to be taken in the macroscopic view, as they are much smaller than the overall material. This is why soft matter particles are considered mesoscopic, and soft condensed matter physics has a certain amount of overlap with the more general mesoscopic physics.

Possibly the most significant feature of soft matter is exhibition of large responses to small perturbations or weak external forces. For example, rubbers and gels are known well for exhibiting great deformation under small mechanical forces; and a weak electric field can produce significant changes in the optical properties of liquid crystals. This high susceptibility, and large response, to manipulation from external forces is, also, what tends to the nonlinear responses that are frequently observed in these materials. Rubbers, for example, can be elongated by several hundred percent of their initial length. The stress-strain relationship for this deformation cannot be modeled linearly.[2]

The large particle sizes and large distortions following perturbations lead to slow response times. What is meant by slow response time is that; after a perturbation, the material takes significantly longer to return to its unperturbed (or relaxed) state. For simple liquids, response times tend to be on the order of 10^{-9} s, while for certain soft materials, such as solutions of polymers and colloids, response times can be as large as 10^{4} s.[2] These large time scales for response mean that the material spends a large amount of time away from equilibrium, during and following interactions. Thus, non-equilibrium mechanics play a tremendous role in the behavior of soft materials.

The large particles of soft matter very commonly exhibit self-assembly, in which intermolecular forces will cause the particles to aggregate into particularly formed units. This is especially true of surfactants and amphiphiles, which are known to form micelles and reverse micelles. These particles have one hydrophilic end and one hydrophobic end. Depending on the solution, after a critical amount of particles is reached, additionally added particles will either join hydrophobic ends while leaving their hydrophilic ends exposed to the solvent, or they will join hydrophilic ends, while leaving their hydrophobic ends exposed to the solvent.[2]

The majority of soft materials that are fluids exhibit both viscous and elastic properties. This is especially true of polymer solutions, as large particle size and self-assembly can cause much resistance to flow, and the reconfiguring of molecular chains within polymer molecules allows for great stretching while maintaining, and exponentially increasing, restoring forces. These viscoelastic properties and nonlinear responses tend to lead to the shear thickening and shear thinning common of soft materials.

The particles within soft matter are loosely bound; primarily being bound by weak intermolecular forces. These bonds can be broken by energies on the scale of k_bT, with significant changes in many soft materials occurring at T values near room temperature.[4] The combination of this sensitivity to thermal energy, weak binding, and the fact that almost all soft matter is a mixture of multiple particle types leads to soft materials having high internal degrees of freedom and many of them being amorphous in nature. It's because of these features that Brownian motion and entropic interactions are crucial to the modeling of soft matter systems.[5]

Since soft matter systems are almost always solutions, they tend to experience a phenomenon much more common in solutions than in one-component systems known as phase separation. While one-component systems usually only experience phase transitions, homogeneous solutions, particularly those of soft matter, tend to, also, undergo a process in which the material separates into distinct regions of high and low concentration.[2] This is what is known as "phase separation", and like phase transition, it requires a certain combination of temperature and pressure.

CHAPTER 2

UNIVERSAL IMMERSION

There have been many different attempts to model the motions of celestial bodies, the propagation of light, and the seemingly bizarre behavior of small particles. However, many of the most successful theories and models seem to share a common feature. They all seem to elude to the idea that the universe is immersed in something.

First, let us examine light propagation. Not long after James Clerk Maxwell published his famous equations, it became apparent that there was a wave equation associated with the electric and magnetic fields. He and others conjectured that there must be a medium in which the electric and magnetic waves propagate. With light being an electromagnetic wave, it was assumed that light must require a medium through which to propagate. This medium was denoted as "aether". Aether was thought to permeate all of space, allowing for the travelling of electromagnetic waves throughout the universe. Aether was, also, theorized to be responsible for gravity's ability to act throughout space.[6] Immersion ideas related to gravity will be examined further in the next few paragraphs.

Second, we shall investigate gravity. In 1665, Isaac Newton published his law of universal gravitation.[7] This law served the physics community well for hundreds of years, until eventually inconsistencies between the law and empirical observations developed. In 1916, Albert Einstein published his theory of general relativity.[8] This theory alleviated many of the problems that Newton's law of universal gravitation was having explaining certain physical phenomena.

One particular phenomena was the precession of the perihelion of the planet Mercury. Newtonian mechanics predicts precessions of the perihelions of planetary orbits, and does so quite effectively for most planets within the solar system. However, for Mercury, Newtonian mechanics predicts that the perihelion of Mercury's orbit will process by an amount of approximately 532 arcseconds per year, but this turns out to be incorrect. This problem was first observed by Urbain Le Verrier, in 1859. Later, it was shown that the prediction from Newtonian mechanics was off by about 42 arcseconds per year. Newtonian mechanics only considered the two-body system of the Sun and Mercury along with the gravitational interactions between Mercury and the other planets. General relativity, however, introduced a new concept in which space and time were inseparably linked, and this space-time continuum was observably warped by large masses. This moldable spacetime is theorized to pervade all of the universe.[9]

Another phenomena was the bending of light around celestial objects. This, too, was predicted by Newtonian mechanics. But, again, discrepancies between the theory and empirical observation eventually developed. The deflection of starlight predicted by Newtonian mechanics turns out to only be approximately half of the observed angular deflection.[10] The full deflection can be predicted theoretically through the use of general relativity. The first half being accounted for by the now well-known equivalence principle, and the second half being accounted for through the warping of spacetime, near very massive objects.[11]

Third, we will consider the mechanics of galaxies. Again, we find something that was once well explained with Newtonian mechanics, but eventually that explanation has come to require adjustment. The rotational rates (or orbital speeds) of stellar systems such as our solar system are modeled quite well through the use of classical Newtonian mechanics; however galaxies distant from Earth exhibit behavior that would not be expected. The orbital speeds of celestial bodies are expected to steadily decrease as objects are observed that are further away from the galactic center. Through the analysis of the Doppler shifts of light being emitted from stars near the outer edges of these galaxies; it has been observed that the rotational rates of stars near the outer edge are approximately the same as the rotational rates of stars close to the galactic center. The stars in-between, also, shared a similar rotational rate. This unexpected behavior can be accounted for with Newtonian mechanics if the galaxies observed contain much more mass than that which seems to be emitting light. This theorized extra matter has been label "dark matter". It is believed by many to be spread throughout the universe and account for approximately 23% of the mass-energy in the universe.[7]

Another unexpected behavior of galaxies, which was, also, noticed due to Doppler shift analysis, is that they are drifting farther apart, and a seemingly faster and faster rate. This universal expansion is unaccounted for by all theories that preceded its discovery. The current most widely accepted explanation is the presence of an otherwise undetectable energy source referred to as "dark energy". Dark energy is, also, expected to pervade the entire universe, and it is believed to account for approximately 63% of the mass-energy in the universe.[7]

A more recent idea, referred to as "dark fluid", uses negative mass to combine the concepts of dark matter and dark energy into one substance. I shall refer to these three collectively as "dark material".

As can be seen, all of these ideas have a central theme in common. Whether one considers aether, spacetime, dark material, or a combination of the aforementioned; observation and leading theory seem to indicate that the universe is immersed in something.

CHAPTER 3

THE SOFT MATTER MODEL AND HOW IT LINKS THE OBSERVED PHENOMENA

My research has focused on three particular effects related to the theories mentioned in Chapter 2. They are; the velocity and mass changes of relativistic particles, gravitational lensing, and the Casimir effect. In this chapter, I will display how these effects support a soft matter model of the universe.

It has been thoroughly tested that when a high-energy particle is accelerated to ever greater velocities, the increase in velocity does not proceed linearly as predicted by Newtonian mechanics. The particle's velocity will instead increase asymptotically (see Fig. 1).

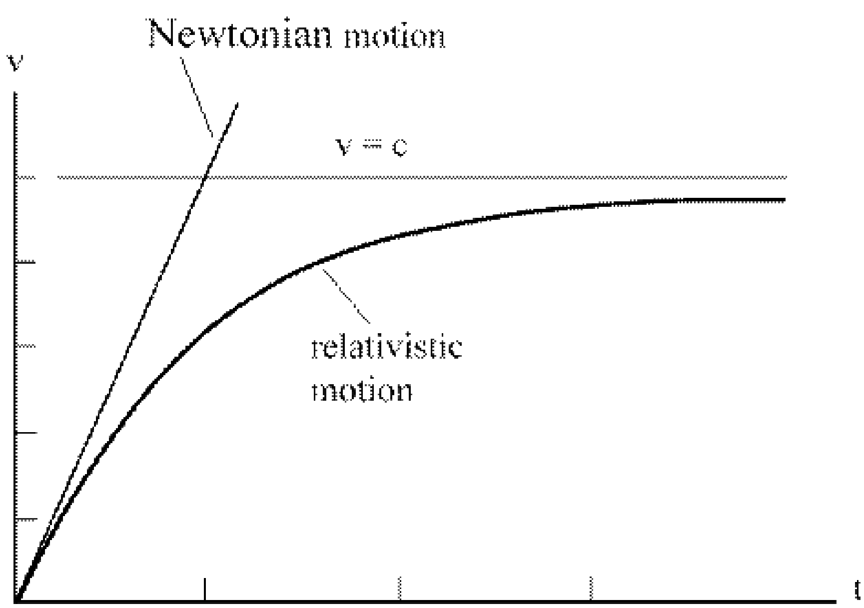

FIGURE 1 The velocity of a particle starting at rest when a constant force is applied.

Fig. 1[12]

Special Relativity explains this phenomenon as being the result of a seemingly magical speed limit that nothing in the universe can exceed. Thus, when a force is applied to a massive high-energy particle, the particle will not accelerate as classically expected, but will instead progressively gain a velocity closer to that of the speed of light in a vacuum. During this progression, one must continually or repeatedly give energy to the particle. As the speed of the particle increases, a smaller and smaller percentage of this energy will go toward increasing the particle's velocity, and a greater percentage will go toward increasing the particle's mass.

In a soft matter model, we consider our particle to be experiencing drag forces as it advances within a fluid. It's expected that the contribution from pressure drag (or form drag) will be more significant than that of viscous drag (or skin friction) to impeding the particle's acceleration.[13] The standard equation for fluid drag can be used in this case;

$$F_D = \frac{C_D \rho A v^2}{2}$$

where F_D is the drag force, C_D is the appropriate drag coefficient, ρ is the fluid density, A is the effect area of the object, and v is the relative velocity between the particle and the fluid.

High speed particles have been observed to gain mass as they accelerate. Qualitatively, it can be stated that the increase in mass is likely due to the "added mass" that the particle gains as it pushes some of the fluid along with it. The amount of mass gained per unit velocity gained increases as velocity increases, as the fluid particles would be pushed farther before being deflected. The relativistically calculated mass gain with velocity is depicted in Fig. 2. The y-axis value (γ) is multiplied by the rest mass to determine the relativistic mass.

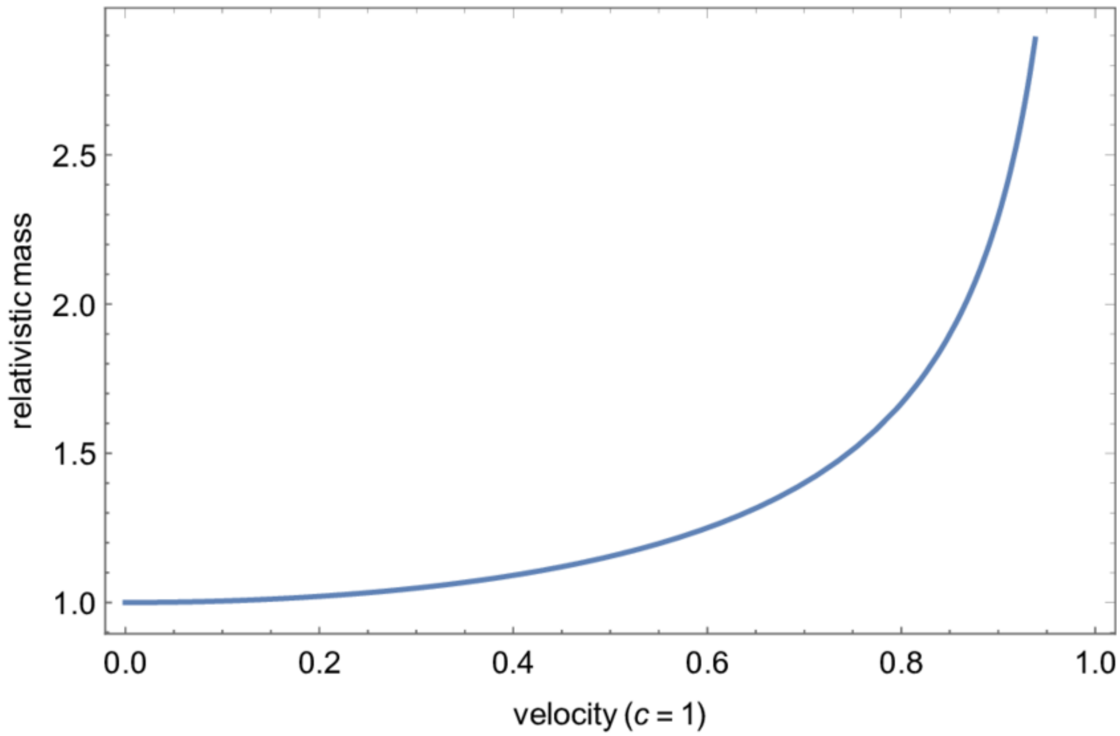

Fig. 2[14] (relativistic multiplier (γ) = $(1 - (v^2/c^2))^{-1/2}$)

An example acceleration from Fermilab, in Batavia, Illinois, is the increase in the kinetic energy of a proton from 400 MeV to 8 GeV, in 67 milliseconds.[15] In Table 1, the values for the energy, mass, and velocity for rest and the two energies have been listed in SI units.

Table 1

	Energy (J)	**Mass (kg)**	**Velocity (m/s)**
Rest	**1.503×10^{-10}**	**1.67×10^{-27}**	**0**
Initial	**2.14×10^{-10}**	**2.38×10^{-27}**	**2.14×10^{8}**
Final	**1.43×10^{-9}**	**1.59×10^{-26}**	**2.98×10^{8}**

Here the equation $E = \gamma mc^2$ has been used to determine the necessary quantities.

With these values we can calculate the proton's change in momentum both classically and relativistically. For a classical proton in a vacuum, the expected momentum change is

$$m_2v_2 - m_1v_1 = m(v_2 - v_1) = (1.67 \times 10^{-27})(2.98 \times 10^8 - 2.14 \times 10^8)$$
$$= 1.4 \times 10^{-19}\ \text{kg}\bullet\text{m/s}$$

And, for a relativistic proton in a vacuum, the expected momentum change is

$$m_2v_2 - m_1v_1 = (1.59 \times 10^{-26})(2.98 \times 10^8) - (2.38 \times 10^{-27})(2.14 \times 10^8)$$
$$= 4.23 \times 10^{-18}\ \text{kg}\bullet\text{m/s}$$

And now, with the assistance of the impulse-momentum theorem, we can calculate the net force that acted on the particle, in each case. We shall consider momentum changes that occur during an equal duration of time.

$$\text{relativistic;} \qquad F_r\Delta t = \Delta p = 4.23 \times 10^{-18}$$
$$\text{classical;} \qquad F_c\Delta t = \Delta p = 1.4 \times 10^{-19}$$

subtracting the classical equation from the relativistic equation yields

$$F_r\Delta t = 4.23 \times 10^{-18}$$
$$- \quad \underline{F_c\Delta t = 1.4 \times 10^{-19}}$$

$$(F_r - F_c)\Delta t = 4.09 \times 10^{-18}$$

$$(F_r - F_c)(6.7 \times 10^{-2}) = 4 \times 10^{-18} \rightarrow \frac{4 \times 10^{-18}}{6.7 \times 10^{-2}} = 6.1 \times 10^{-17} \text{ N}$$

For our soft matter model, this difference in force is the extra force needed to overcome the resistance of the fluid. Thus, it is equivalent to the average drag force.

We shall assume our velocity change to be near linear. This allows us to divide the sum of the given velocities by 2, to determine the proton's average velocity during the acceleration.

$$\frac{v_2 + v_1}{2} = \frac{2.98 \times 10^8 + 2.14 \times 10^8}{2} = 2.56 \times 10^8 \text{ m/s}$$

The effect area is simply the cross-sectional area of the proton. Since protons are understood to be spherical, this can be calculated in the usual way. There is some debate as to the proton's radius, but a recently accepted value is 8.33×10^{-16} (effective charge radius).[16] Thus, the effective area would be

$$\pi r^2 = \pi(8.33 \times 10^{-16})^2 = 2.18 \times 10^{-30} \text{ m}^2$$

Fig. 3 shows the variation of drag coefficient with Reynold's number, for a spherically shaped object. The Reynold's number varies directly with velocity, and inversely with viscosity. Since our fluid has been commonly perceived as a vacuum, we can assume that the viscosity is extremely small.

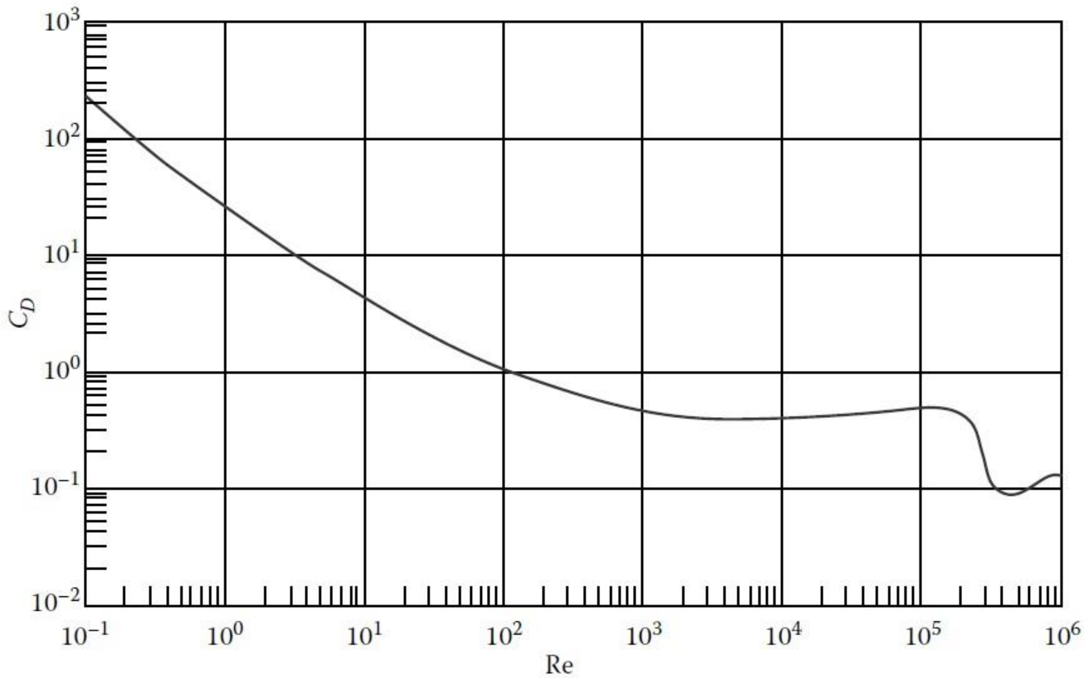

Fig. 3[17]

At Reynold's numbers above 10^6, or in what is known as the transcritical range, the drag coefficient of a sphere levels off at approximately .38. [18] Since our particle has very high velocity and our fluid has extremely low viscosity, we can use this value. Rearranging for density, and plugging in the previous values yields

$$\rho = \frac{2(6.1\ x\ 10^{-17})}{.38(2.18\ x\ 10^{-30})(2.56\ x\ 10^{8})^2} = 2.25 \text{ x } 10^{-3} \text{ kg/m}^3$$

and this appears to be the mass density of the fluid that the universe may be immersed in. While this may seem larger than expected, when compared to other vacuum calculations, this includes not merely the mass of the particles that we have long known of, but, also, the mass of fluid in which they are immersed.

The Casimir effect is an effect that was originally predicted in 1948 by Hendrik Casimir. The effect is an inward pressure that is developed when two parallel plates are brought very close together, while in an apparent vacuum. Casimir determined that this pressure should be present due to the expected fluctuations in fields, particularly the electromagnetic field. These fluctuations, or waves, are free to assume any shape (wavelength) while outside of the gap between the plates, but when in-between the plates, the waves must follow the usual boundary conditions of terminating or having nodes at the boundaries of their enclosure. The fact that this boundary condition only exists on the inside means that far more waves will be present just outside of the plates than those inside the gap between the plates. All of the waves, outside or inside, provide a force against the plates. Since there are less waves between the plates than there are outside of the plates, the total force is greater outside of the plates than it is in-between the plates.[19] Thus, a net inward pressure is generated

Casimir determined that this pressure should be equivalent to

$$\frac{hc\pi}{480d^4}$$

where h is Planck's constant, c is the speed of light in a vacuum, and d is the distance between the plates.

The Casimir effect actually has roots in soft matter, as Casimir, in fact, initially developed the theory to explain the effects of van der Waals forces in colloidal solutions.[20] Fluid analogs to the Casimir effect have been demonstrated, more recently. In particular, a similar effect was observed by Bruce Denardo, Joshua Puda, and Andres Larraza when they suspended two metal plates in ethyl alcohol, and then rapidly vibrated the alcohol's container, to produce surface waves in the fluid. Though in this case, the wavelengths are bound both inside and outside of the plates; there are more allowable wavelengths outside of the plates than inside, and the plates are still drawn closer together, during the vibrations, and recede apart, when vibrations cease.[21]

In a soft matter model, the waves acting on the plates are longitudinal or pressure waves moving through the fluid. Again, we have the same situation that while only wavelengths that feature nodes at the plates may stand inside the plates, we do not have this limitation outside of the plates. We expect that this will, again, lead to an inward directed net pressure. The waves, in this case, travel by way of compressions and rarefactions. When the fluid is compressed near a plate, it's following attempt to expand provides a pressure against the plate. We can evaluate this pressure by using the ideal gas law and assuming that our fluid only contains one type of particle.

$$PV = NkT$$

Inside the plates, the only wavelengths allowable are

$$\lambda = \frac{2d}{n}; \quad n = 1,2,3,\ldots$$

Both inside and outside of the plates, the wavelengths must be at least equal to the mean free path of the particles that constitute the fluid. In this paper, I will not be calculating the mean free path or the minimum wavelength. The key to determining the net pressure, in this case, will simply lie in determining the difference between what is allowable outside of the plates and what is allowable inside of the plates. To analyze the difference, it is beneficial to view the waves as sinusoids. For wavelengths greater than 2d, which can only appear outside of the plates, no significant contribution is expected. This is because the frequencies and wavelengths should be similar to that which we expect from photons, since the predictions of the Casimir effect prove to hold quite well when the cause is considered to be electromagnetic waves. For wavelengths less than or equal to 2d, the effects of those that meet the conditions for standing waves between the plates will be cancelled by equivalent waves outside of the plates. The other waves that may appear outside of the plates will generate varying pressures. Their average cumulative effect will manifest as the net pressure felt by the plates.

We can now substitute mass and density into the ideal gas law and analyze the kinetic energy to determine the mass per particle.

$$P = \frac{NkT}{V} = \frac{MkT}{mV} = \frac{\rho kT}{m}$$

Here, M is the total mass within the volume and m is the mass of an individual particle.
Now, analyzing the energy;

$$NkT = \frac{M\bar{v}^2}{2} \rightarrow kT = \frac{m\bar{v}^2}{2}$$

but from thermodynamics we know that an individual particle gains $\frac{1}{2}kT$ for each translational degree of freedom, and the component of pressure that is perpendicular to the plates is all that we are concerned with. Thus, we need to divide the thermal energy by 3,

$$\frac{kT}{3} = \frac{m\bar{v}^2}{2} \rightarrow \frac{2kT}{3} = \mathrm{m}\bar{v}^2$$

where $\bar{v}$ now refers to the average velocity perpendicular to the plates. Again, we expect the waves in our fluid to behave similarly to electromagnetic waves. Thus, we expect them to propagate with a speed equal to that of light in a vacuum. In order for this to be the case in our very low density fluid, we expect our particles to be moving with a speed near that of EM waves in a vacuum. So, the speed of light in a vacuum can be used here as a fair approximation to our average particle velocity.

$$\frac{2kT}{3} = \mathrm{m}\bar{v}^2 = \mathrm{mc}^2 \rightarrow \frac{2kT}{3c^2} = m = 3.07 \text{ x } 10^{-40}$$

Here we have used 3K, the accepted approximate temperature for the vacuum of space. This mass is smaller than any known particle, which is what was to be expected.

Using the effective pressure and particle mass, we can determine how much, on average, the density of the fluid at the outside boundary of the plates exceeds that of fluid on the inside boundary.

$$\rho = \frac{Pm}{kT} = \frac{hc\pi}{480d^4}\,\frac{3.07x10^{-40}}{k3} = \frac{9.67\ x\ 10^{-45}}{d^4}$$

This difference in density is very small, as we would expect. Comparing this to the density found in the previous discussion, we see that the density change due to the waves is much smaller than the normal density of the fluid. This is similar to compression waves in known materials. It should be noted that this formulation does have the problematic feature of increasing without bound as the distance between plates reduces to zero; a feature that is shared with the usual formulation of pressure due to the Casimir force.

Light has been observed to experience an altered direction of travel as it passes near a very massive object. This effect has been termed as Gravitational lensing. Gravitational lensing is currently explained most accurately by Albert Einstein's theory of General Relativity; in which it is explained as being a combined effect of the equivalence principal and the warping of space-time. Through this theory, Einstein determined that the angle of deflection could be calculated using the formula[22]

$$\theta = \frac{4GM}{Rc^2}$$

where G is the gravitational constant, c is the speed of light in a vacuum, M is the mass of the object, r is the radial distance from the object's center of mass, and θ is in radians. This equation has proven quite accurate when dealing with light passing near the Sun; in which case, r is replaced with the solar radius and M the solar mass. This yields

$$\frac{4(6.674\ x\ 10^{-11})(1.99\ x\ 10^{30})}{(6.96\ x\ 10^{8})(3\ x\ 10^{8})^2} = 8.48 \text{ x } 10^{-6} \text{ rad}$$

For a possible soft matter explanation of this phenomenon, we consider our fluid to be compressible and gravitationally interactive. Thus, under the effect of a large gravitational source, notable compression should occur. This compression should affect the refractive index of the fluid, with a likely positive correlation.

We begin by acknowledging that the bending of light's course is the general function of a traditional lens, and we should be able to model the effects of our fluid as though it were replaced by a traditional lens. Our fluid will condense around a mass. A beam of light will bend as it goes around the very massive object and through our fluid. The beams deflection will have reflective symmetry about the midpoint of the bend. Thus, we must only analyze the first half of the bend and double our result. The deflection of the beam may be continuous, but we need only consider the total deflection between the entering beam and the midpoint of the bend. The total deflection is equal to that that would be obtained if the beam had passed through a convex spherical lens, into a material of the appropriate index of refraction. The total deflection in the second half of the bend is equal to that that would be obtained if the beam had passed through a concave spherical lens, out of that previously entered material. These similarities mean that we can model the entire deflection as though it were due to a thin lens having been placed at the center of the bend. For this I will make use of the well known thin lens formula[23]

$$\frac{1}{d_o} + \frac{1}{d_i} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Due to the symmetry of the situation, R_1 and R_2 are of equivalent magnitude. R_1 is positive due to convexity and R_2 is negative due to concavity. n_1 equals 1, since the outside medium is a vacuum. With these things in mind, we can substitute, rearrange, and solve for n_2.

$$\frac{d_i+d_o}{d_i d_o} = (n_2 - 1)\left(\frac{2}{R}\right) \rightarrow \frac{R(d_i+d_o)}{2d_i d_o} = n_2 - 1$$

$$\frac{R(d_i + d_o)}{2d_i d_o} + 1 = n_2$$

Arguably the most well studied example of gravitational lensing, and the first to be confirmed, is the deflection of light from the Hyades star cluster, around the edge of the Sun. We can use information for light emanating from the Hyades star cluster and being focused on Earth to calculate a value for n_2, which will be the index of refraction for our fluid nearest the Sun.[24]

$$n_2 = \frac{6.96x10^8(1.5x10^{11} + 1.4510^{18})}{2(1.5x10^{11})(1.45x10^{18})} + 1 = 1.00232$$

where we have used the distance between Hyades and the Sun as our object distance (d_o) and the distance between the Sun and Earth as our image distance (d_i).

Currently, there is no universal relationship between mass density and refractive index, though many experiments have shown a positive linear relationship between the two. There is a very simple relation between refractive index and relative permittivity (also known as dielectric constant). It is[25]

$$n = \sqrt{\varepsilon_r}$$

where ε_r is the relative permittivity. The reason for invoking this relation is the possibility that the permittivity of our fluid may vary with particle density. So, as our fluid condenses near very massive objects, the permittivity increases. For our n_2 value

$$n_2 = \sqrt{\varepsilon_r} \rightarrow n_2{}^2 = \varepsilon_r \rightarrow (1.00232)^2 = 1.004645$$

$$\varepsilon = \varepsilon_r\varepsilon_0 = (1.004645)(8.85 \text{ x } 10^{-12}) = 8.89 \text{ x } 10^{-12}$$

Using the Clausius-Mossotti relation, we can also examine the expected average polarizability per unit volume.[24]

$$3\varepsilon_0\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right) = N\alpha \rightarrow 3(8.85 \text{ x } 10^{-12})\left(\frac{1.004645 - 1}{1.004645 + 2}\right) = 4.1 \text{ x } 10^{-14}$$

Here N is the particle density and α is polarizability of an individual particle. Through the structure of our equations, we can see that refractive index increases as permittivity increases, and permittivity increases as particle density increases. Thus, it is plausible and expected that the condensation of our fluid will lead to a greater index of refraction.

CHAPTER 4

SUMMARY AND FUTURE WORK

This brief exploration has shown how a soft material can account for a few of the observed physical phenomena. Further analysis is expected show how a universe filled with this material can account for many more observed phenomena. It should be noted that, though I repeatedly stated "immersed in", previously in the paper, "composed of" may be a more appropriate term. The greater theory that the ideas presented in this paper are leading into is what I will refer to as a "variable composition" theory. I plan to, eventually, complete a model in which all observed objects in the universe are actually amalgamations of the constituent particles of the complex fluid that fills the universe. These amalgamations can then progress as waves within the fluid. As the amalgamations progress, their constituent particles are constantly being interchanged with the "rest fluid" or unbounded fluid. Other variable composition theories would include string theory and various other quantum field theories. These are in opposition to what I would term as "constant composition" theories; which would include all classical physics, relativity, and much of quantum mechanics. It should, also, be noted that the material discussed does not necessarily have to be a fluid. This is because it technically does not need to flow; it only need be able to support wave motion.

There are several issues to be investigated further. Two of these are the makeup of the material and the compressibility of the material. In this paper, I considered a homogeneous material of one particle type, however the material could be heterogeneous and/or consist of multiple particle types. If the material in the observable universe is in a compressed state, even in regions without a perceived amalgamation, then this could be a cause for the universe's continued and accelerating expansion. Other issues that will be later theorized include greater detail about the electric and magnetic properties of the material and the roles of binding forces such as gravity and the strong force. A better understanding of the electromagnetic properties of the material may lead to an explanation for the speed at which light propagates through an apparent vacuum, an explanation for why this speed seems to be a universal speed limit, and a solution for how this speed can be exceeded.

Future research will, also, include a deeper investigation into the presence of traditional soft matter properties within the material. Common soft matter behaviors such as Brownian motion, non-equilibrium mechanics, self-assembly, and non-linear response may account for much of the strange particle behavior that is noticed on the subatomic level.

One current problem with the theory that will need to be addressed is the apparent lack of a drag effect while not accelerating. In this paper, I was able to calculate the force of drag due to a particle's acceleration, however a drag force would be expected to be present, so long as the particle has non-zero velocity. Though, this may be explainable through the conservation of energy as the amalgamation moves through the material as a wave.

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