The Properties of Space

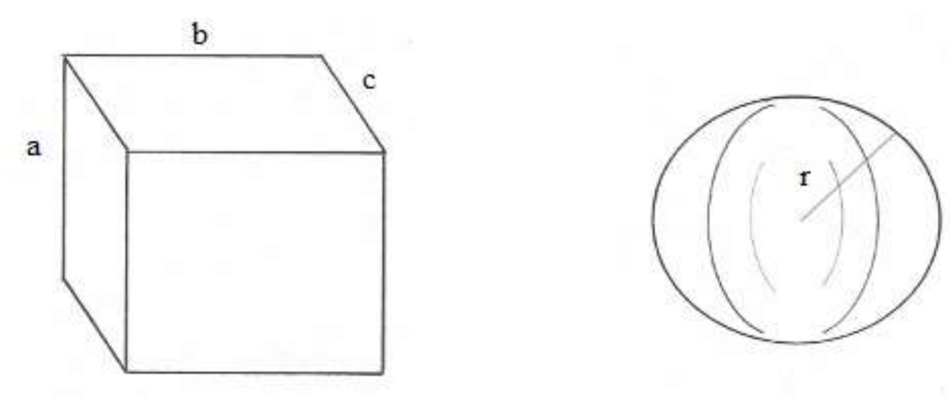
The conventional wisdom is that space is property-less. To our natural senses, space appears empty, but that does not conclude that it is featureless. Just because “outer space” is mostly devoid of dense matter does not exclude it from having physical properties. It's properties may not be those that we attribute to matter, but unknown, or not well understood, properties still to be discovered and defined. Space contains energy in transport and in storage, specifically, radiation is energy moving around. Space also contains matter, which is a form of energy in accordance with Einstein’s equation –

$$E = mc^2$$

Space accommodates these two forms of energy differently and this constitutes part of this essay. Before proceeding further on this philosophical subject it is necessary to be clear on what exactly is space. Webster's dictionary defines space in several different ways. Some of the relevant ones are:

a) “A region beyond the Earth's atmosphere.”
b) “Physical volume independent of what occupies it.”
c) “The infinite extension of the three-dimensional field of everyday life.”
d) “A blank or empty area.”

The second definition “Physical volume independent of what occupies it” will be adopted for the purpose of this essay. Space is all around and everywhere, within us and without us. Space usually connotes an emptiness, but this essay will focus on the general definition of any volume, whether it contains matter or not. So the most general definition of space is just a volume. This is it's first property, that is, that it contains some volume, figure 1.



Volume = abc

Volume = $4/3\pi r^3$

Figure 1. Volumes of Space

Any volume also has a location, such as my room. The space of my room travels with me, as the Earth rotates, around the sun and around the galaxy. Or did the space of my room stay behind, and my room with it's contents and I, move through new and different volumes? That brings up the issue of absolute or relative space. That is a question for philosophers to ponder. For the time being, the volume has an arbitrary location that can be defined however we chose. If the volume is to have a location; a location relative to what? At the present time, we define location relative to our home planet, Earth. It is moving through space relative to the sun. The sun is moving through space, as is the galaxy. I suppose we could place an immovable buoy somewhere in deep space and call it zero location. But how would we know that it was stationary? Suppose further that we placed sensors on it, like accelerometers or some other internal sensors, to detect it's motion or lack of. According to Einstein's General Theory of Relativity, these sensors could not tell the difference between gravity and uniform motion. If there was an absolute stationary ether, then the dilemma would be solved. Perhaps the old ether concept should be resurrected and re-defined as a location reference. The alternative to no absolute reference is that we are adrift. We do not know where we are, nor where we are going, except that we are spaceship Earth. The volume of a space can be defined with certainty, but only a relative location and an unknown velocity.

Einstein stated in 1920 ".......To deny the aether is ultimately to assume that empty space has no physical qualities whatever..........According to the General Theory of Relativity, space is endowed with physical qualities: in this sense, therefore, there exists an aether......."

Space is the realm through which we traverse to get from point A to point B. These points are relative to some reference, but not to any absolute location. There is no absolute home location that we have discovered yet. We are adrift in some huge unknown with no absolute reference location that we can call a starting place or an ending place. We do know some things about this huge imaginary volume that we call the universe. We would like to know more. The character of this hypothetical ether, and the question of absolute location reference are two intertwined issues that will someday be resolved and added to the properties of space.

These volumes can be imaginary or real, but they do have a property of containing fields that support the transmission of energy and waves. So in this sense, space does have some measurable quantities, which are volumes and field strength, but maybe not location. As soon as we define volumes, then we can talk about densities. If energy is contained within that volume, then there will be an energy density. The energy can be electric, magnetic, EM waves, cosmic particles, gravity, or something else.

We have no direct natural sensory capability to observe space except as the absence of any perception, so we naturally conclude that it is empty. We can measure a volume with a meter stick and define a certain space of interest, but what is inside that volume we cannot "see". Without any sound, or temperature, or weight, or light, or taste, or smell, we come to the conclusion that it is a void. But is it? Our senses filter the physical world. There can likely be something there that we are “blind” to. So how can we measure the properties of space? If we cannot measure it, then the common scientific reasoning is that it does not exist. But space does exist and it has some properties, so to measure these properties it is necessary to come up with some instrument that can convert the energy in space to something within our field of view. This has already been done to some extent and this article will attempt to illuminate them. It will go on to further explore our lack of knowledge about space in general.

<u>**Known Properties**</u>

Does space have a temperature? The answer is no, because temperature is a property of matter, specifically, the internal kinetic energy of particle motion on a statistical basis. Temperature is the interaction of radiant energy with matter. A temperature cannot be assigned to a volume, so temperature is not a property of space. Because radiation and matter interact, therein lies a clue for possible detection mechanisms of unknown properties of space.

Is space homogeneous, that is, the same everywhere? Well, we don't know because we have not been everywhere. The theory of gravity, whether Newton's or Einstein's, or others, indicates that this particular property of homogeneity may be similar in a local area, but varies on a cosmological scale. That begs the question of “why should that be?” We also do not know if radiant energy propagates uniformly everywhere, but much of our physics hinges on the assumption that the speed of light is constant in a vacuum.

Are the properties of space the same in all directions i.e. isotropic? This is still largely unknown, but it may be the same for some properties, like the speed of light, and not for others. For those properties of space still to be discovered concerning homogeneous and isotropic, the safe answer is unknown, but probably not. We do know that space contains fields, and we also know that the field strength varies with location. The fields under consideration here are electric, magnetic, and gravity fields. There may be others still undiscovered. The concept of fields, and field strengths, concludes that the properties of these fields are not the same in all directions. Fields are energy of some sort because they can exert a force on things. Even though fields are not material things, they interact with matter. Fields fill space. The various fields jointly coexist in the same volume, so this begs the next natural question "Do they have a relationship"? For now, we can safely conclude that space is not homogeneous nor isotropic as it relates to fields. Energy permeates all of space in a non-homogeneous and non-isotropic density. If the various fields have a relationship, then we would certainly like to know the nature of those kin-ships. Electric and magnetic fields can and do interact as radiation. Gravity is still an unknown.

There are some properties of space that are known with some clarity. The first is the speed of light, or radiation in general, in a vacuum of 2.99×10^8 m/s. The qualifier here is “in a vacuum”. If matter occupies that space, then radiant energy can interact with it to slow down, even to zero for opaque and absorptive materials. Transparent materials, like water, glass, and diamonds, slow down light speed. They impose a resistance to the speed, but a better term is impedance, because white light is composed of various frequencies and a prism separates out the frequencies, or colors. The obvious next question is "Does space have some frequency properties?" More on this later.

Space must also have some impedance to all electromagnetic radiation in general because of the known speed limit. Otherwise, why would not radiation travel at infinite speed? What causes this impedance? There is something there that we have not detected yet that places a limit on the speed of light.

Another known property is the universal gravitational constant $G = 6.678 \times 10^{-11}\ Nm^2/Kg^2$. This is actually a coefficient that appears as a constant in the gravitational law of Newton's –

$$F_g = G \frac{m_1 m_2}{r^2}$$

That coefficient makes the mathematics work with consistent dimensional units. A coefficient in an equation is really a "fudge factor" that speaks of our lack of knowledge as to the real physics. This gravitational constant, G, does appear to be ubiquitous everywhere, in all directions, and doesn't care if matter occupies the space or not. It is not sensitive to what material occupies a volume. We have not observed anything that shields gravity, so gravity may be a property of space. According to Professor Dicke, interpreting the null result of the Eotvos experiment, gravity is a property of space, not of mass.

Two other properties are –

Permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ Wb/Am (magnetics)

Permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$ (static electricity)

Both of these are modified by materials in the path, so the qualifier of "free space" is included.

Since space freely propagates radiant energy, then the Plank's constant ($h = 6.62 \times 10^{-34}$ J·s) may be a property of space on an atomic scale. It is a very small number in units of energy, Joules, multiplied by time, s. This is called action. It is the energy content of a small quantum of radiant energy divided by it's frequency. Being a constant, and of very small numerical value, and not related to matter, it could be considered to be a property of space that is frequency dependent.

The cosmological constant, if it is proven to exist and a number can be agreed upon, will be a property of space. Eistein introduced it in 1917 to make the universe static and not collapse under gravity. He abandoned it in 1932 after Hubble proposed an expanding universe based on the Doppler red shift of light from distant galaxies. The cosmological constant is now back in vogue along with the aether, but wrapped up with "dark energy", "dark matter", "vacuum energy", and "zero point energy", all of which are still speculative. That is why they are in quotes because they are as yet undefined. If the frequency shift of light toward the red end of the spectrum is interpreted another way rather than receding motion, then much of our understanding of the universe has been all messed up.

Motion

Empty space does not appear to impede motion of material objects, so it's friction properties are zero, or close to it, at least when speeds are very much lower than the speed of light. When approaching that upper limit of c = 3 x 10^8 m/s, or even a fraction of that speed, more energy is needed to keep moving faster. At the limit of c, matter cannot exist. It must all be converted to radiant energy. Space has some strange property of converting matter and energy when motion is involved. Space, or some property of it, appears to impose that upper universal speed limit on radiant energy. It is not mechanical friction. It is not a material property. It is some unknown property of space that operates on radiant energy that keeps the conservation of energy principle within bounds.

Can space move? That sounds like a stupid question. There is some speculation that space is expanding. That is motion, even if just stretching. If space is expanding, then some density properties should be detectable as changing. If it is moving, then relative to what? Is this motion uniform such that we cannot detect it's non-varying velocity with physical measurements? If space is expanding, then it’s velocity is not uniform in all directions and it may be accelerating, in which case something should be measurable.

Matter

Space accommodates matter and energy, but in different ways. It concentrates material into clumps of dense matter, but spreads energy. It is not clear how this can be consistent with the laws of thermodynamics and the concept of entropy. Accretion of matter into clumps is a property of matter, we believe, not of space. The role of space is to store matter in a volume. Space functions as a de facto storage manager that disallows two solid planets to occupy the same volume. It maintains some separation. If it did not, then the entire solar system would collapse into the sun. How is it that matter manages to come together, yet maintains a separation distance that appears to be based on size and motion?

At low speeds (<< c) matter is not distorted to any significant degree. At high speeds, matter appears to contract in the direction of motion in accordance with the special theory of relativity. Or does the perception of space contract, depending on one's frame of reference? In reality, neither matter nor space change shape. It is just the measurement of that dimension that changes because of the time for a light signal to travel from the far end of the object to the near end.

In high school physics, we learned that no two objects can occupy the same volume at the same time. This is partially true, because later in college chemistry, we learned that fluids can mix and occupy identical volumes. Solids can also diffuse into each other given sufficient time and elevated temperature. This is the principle for hardening of steel with carbon atoms that migrate into the iron crystal matrix. There may be a small volume change. Space has few, if any, restrictions on what kind of matter can occupy it's volume. Simply put, any object can occupy any volume without catastrophic consequences if the existing resident is willing to move. The bottom line is that space stores matter in a volume. The volume occupied is a property of the matter. Space is there just for the ride and does not interfere with the storage function.

Matter does not displace space. The space volume still exists with matter as the occupant, but the matter can modify the properties of the space away from a vacuum. The presence of matter can modify the magnetic permeability and the electrical permittivity, and slow down the speed of light, but appears to have no effect on gravity. Matter appears to be transparent to gravity.

In another context, outer space is not totally empty. It contains about one molecule of hydrogen or helium per cubic centimeter of volume between star systems. In intergalactic space, the estimate is one molecule per 10 cm^3. Could it be that the few molecules in deep space interact with light photons and slow them down causing a downward shift in frequency toward the red? This would be in addition to the red shift of white light climbing away from a gravity mass. This could be one of the frequency properties of, not empty space, but deep space with a small amount of dispersed gaseous molecules. Energy interacts with matter "selectively", based on frequency.

It has been postulated that mass nay not be the source of gravity, but rather energy is. This is allowed by $E = mc^2$ where matter and energy are somewhat equivalent by the ratio of the light speed squared. If energy is the source of gravity, then it has a dual function of also being the transmission mechanism for the force of gravity. Space accommodates this.

Energy

The concept of energy grew out of the study of heat and work during the boring of cannon. It was later expanded to other forms, i.e. potential, kinetic, chemical, electrical, and gravity. Space can store energy in fields. The fields in mind are magnetic, electrical, electromagnetic (radiant energy in transport), and gravitational. These fields may or may not be real, but have shown to be a useful abstraction to understand these phenomena.

Matter and energy can co-jointly occupy the same space, with some qualifications about shielding. Matter and energy are not mutually exclusive as relates to space.

Space does not carry acoustic energy, matter does.

Energy is a fundamental quantity of nature. All life, all change, all destruction, is sourced from energy. This concept of energy has only been in the human understanding for less than 200 years. All communication is also a form of energy exchange, and this happens within space. What role space plays in this process, specifically radiant energy transfer, remains mysterious.

Given the equivalence of mass and energy, can energy have some inertia properties, or some other equivalent sort of mass properties, like gravity?

Can energy sources attract each other, or alternately, repel? That is an intriguing question. The current model of the atom is mostly empty space. Electrons orbit a volume around a tiny nucleus. Further, the nucleus, which accounts for the majority of the atoms' mass is composed of even smaller particles called quarks that have high energy and little mass. They move around very fast, nearly the speed of light. Consequently, this supports the theory that matter is not really hard. The ultimate reality, purported by some, is that everything that we perceive, including matter, is really just energy.

If mass is mostly composed of energy, 98% being the current estimate of the strong force holding the nucleus together, then mass attraction perceived as gravity could really be an energy reaction. The energy, being a wave phenomenon with a frequency, goes positive and negative and could also be polarized. Hence, it could be possible to filter and rectify this energy wave producing the theoretical possibility of negative attraction.

Finally, there is the issue of the red shift. A decrease in frequency implies an energy loss. Where does the energy go after being withdrawn from the spectrum of light? Another unknown that is looking for an answer.

Time

Time is a conundrum for those who dwell on the instantaneous passage of it. Time is a relative duration of an interval between two or more events and is only relevant to the description of motion. If there is no motion, then there is no displacement. When the displacement is zero, then the numerator of the velocity equation, ds/dt, is zero and the denominator of the time interval is irrelevant. It does not exist and becomes superfluous. Time is a human invention. It is an illusion adorned with the quality of a fundamental physical quantity. Nevertheless, we can still discuss the time interval in the context of spacial properties.

The changes in the properties of space over time, if any, are largely unknown. The conventional understanding is that the universe is expanding based on Hubble's observations of the red shift of distant galaxies. If the universe is expanding, then three ponderable questions immediately arise. The first is "Does space expand along with the matter"? The second is "What is the universe expanding into"? The third is "What properties of space change with thinning of it's density"? These three questions are somewhat interweaved and not totally independent. The crucial question is if space itself is expanding. If the matter of the universe is expanding, then it is thinning. The energy density of space must be decreasing, unless we accept the strange concept that a vacuum, as it stretches, releases some energy that just "pops" into existence as light, matter, or something else. A study of it's properties over time should be observed to change. What to observe to change is up for grabs, but frequency is one parameter that we can measure very small changes in. Given that distant light sources i.e. galaxies, require light years for their energy to reach us, does the passage of time cause a decrease in frequency from the source? Time and frequency are two parameters intimately connected. Frequency is real, time is a human invention.

Consider the possibility that light can lose energy over time when the transit distances are very large. If it did not lose energy, then it would be 100% efficient and appear to violate the second law of thermodynamics. The energy loss would appear as a lowering of frequency. This makes sense in that light sources further away display a larger red shift because they have a longer transit time. The red shift can then become a measure of distance rather than speed.

Fields

Classical physics cannot explain the origin of fields satisfactorily. The origin of magnetic fields is still unknown, but is theorized with magnetic dipoles and granular domains. Michael Faraday invented the field concept to explain magnetism and motion without contact. He observed the iron filings as visual evidence of something in space that caused particles to line up, but he could not feel comfortable about force without contact. He suggested in a letter to Richard Phillips in April, 1846, that space may have some elasticity. He was relying on an analogous concept with matter that transmits acoustic energy. The elasticity may be zero, infinite, or something in between of some nature that is still unknown, that allows the propagation of electromagnetic energy via fields. He called it an ether.

If the ether stiffness were zero, then light would travel at infinite speed. The stiffness nature of this ether (or stiffness of space) is still an unknown. If space had some stiffness, then that would provide for some resistance to energy transfer and light speed would be limited. Radiant energy has a frequency, so we need to consider impedance, rather than resistance. Impedance to motion is analogous to stiffness for static material properties. If space had zero impedance, then again, there would be no speed limit for light. If space had infinite impedance, then nothing would move. Impedance is a parameter that changes with frequency. The concept of impedance allows for energy transfer most efficiently if the impedance from source to receiver is a favorable match.

Einstein had something to say about space, time, and fields. Space is modified by the presence of matter. So space, in this context, is not homogeneous nor isotropic, and it cannot be stable with time because matter is always on the move.

Space, therefore, controls motion by virtue of the variation of the gravity field. Einstein's general theory of relativity is based on the principle of equivalence in which gravitational mass and inertial mass are the same. The modern interpretation of this is that gravity is not a force, but rather an acceleration. The mass then no longer senses the presence of another mass, but instead senses the curvature of the space-time field. The mass responds to this field with an acceleration. The logical conclusion must be that mass and space communicate.

The question then raised is, "What is the nature of this curved space-time field"? It cannot be a thing because it changes. It must be a property that changes. The process of this changeable property is another unknown. How does the mass detect the presence of another mass (or this curved field) and know which way to move? In other words, what is the communication mechanism? These same questions can be posed for charged particles in electric fields, and ferrite materials in magnetic fields.

So Einsteins's general theory does not answer the question of how masses communicate, but rather rephrases the question. Since mass is another form of energy, then masses responding the each others' presence is really energy entities communicating via energy exchange. This suggests that there is an unknown transduction method for this conversion of which we have no knowledge. Energy itself is an abstract concept that we have invented to explain natural processes, but it is calculable from measurable quantities in ways that we have defined.

Speaking of motion, a rock can detect the presence of another rock and moves. Einstein termed this “spooky action at a distance”. The universal law of gravitation tells us that both rocks experience an attractive force, never repulsive. Not only can a rock detect anothers' presence, but also it's direction and size. This is some form of communication through space, whether occupied with matter or not. It suggests that a rock has some form of primitive consciousness. The attractive force is a property of matter, but the communication is an energy transfer through the intervening space, and a property of the space. The future discoveries of the properties of space must explain how this process occurs. This will lead to a better understanding of gravity. As for now, we know much about nothingness, but not enough.

Unknown properties

The unknown properties of space that are open for investigation are –

1. Impedance, specifically, what limits the speed of light?
2. Frequency. This question is a natural consequence of the fact that empty space allows for the transmission of electromagnetic energy at widely ranging frequencies. What are it's natural frequencies? Where does it filter? Where does it amplify?

3. What are the spacial and temporal variables?
4. Does space play a role in the matter, energy, and motion transduction?
5. How does space accommodate communication between rocks, or anything else?

From a manufacturing and practical perspective, there is variability in all measurements and processes. Nature is chaotic also. On a microscopic scale, nature is stochastic. This means that measurements and processes are governed by statistics, based on thermodynamics and quantum theory. Physical laws vary on a microscopic level and possibly also on a macroscopic level that we call measurement uncertainty. The variability may be below our capability to resolve. We should be open to the possibility that there is no absolute certainty in physical laws below a level of accuracy. The investigations into the properties of space are likely to open that door.

Victor Wowk, P.E.
Albuquerque, New Mexico
June 2021