Cherished Assumptions and the Progress of Physics

Jonathan J. Dickau
Independent Researcher/Science Writer

Abstract

For Physics to progress or advance, cherished assumptions about reality and the universe must give way to new notions that allow a better understanding. Ideas from sciences of the past seem quaint or misguided to modern scientists, and today's Science will undoubtedly be seen to contain untruths or half-truths by folks in the future. However; we cannot know which assumptions are erroneous, without sufficient time for exploration and comparison. Scientists learn more by devising experiments that – if performed with care and precision – will reveal which assumptions are wrong. Unfortunately assumptions are hidden by nature, as when we assume ideas are true we take their reality for granted; we believe in them. Beliefs must be carefully separated from what we learn through observation or test by experiment. In Cosmology, there is an additional challenge as scientists cannot experiment with or observe some of the cosmos' wonders up close, and must be content with observation at a distance. Thus; a number of explanations aptly fit the same evidence. Perhaps we need to be more playful with our assumptions. There will always be frontiers in Physics, horizons we cannot reach and must speculate about instead. It is best, therefore, to be aware that any of our cherished assumptions could be wrong, and to remember the assumptions we do not know we have made might be an even greater problem.

Introduction

To understand the universe, individuals make assumptions about the nature of reality, and then calibrate their measuring rods to the actual dimensions of the world at large. This is literally true for all human children. In a Scientific American article [1], Judy DeLoache explains that this culminates in a breakthrough into symbolic thinking around age 2½ – which is when their grids are calibrated to the dimensionality of 3-d objects and space [2]. This ties in with observations of Alison Gopnik and other cognitive development researchers, that young children are like little scientists – cleverly devising ways to test reality and isolate assumptions by varying one thing at a time, just as adult experimenters do [3]. But this same modality, playful exploration with careful variation, is also seen in the methods of the world's top scientists. In a lecture I attended at the 10th Frontiers of Fundamental Physics symposium (FFP10); Nobel laureate Doug Osheroff echoed this view and suggested we should let theory guide us to the right question or experiment – which will reveal what is truly real – while not assuming that theorists are exactly correct in the details of their models [4]. Making advances in Science often requires us to suspend belief in common assumptions and to examine things playfully but systematically ourselves – so we can learn what is really there.

When I attended the 2nd Crisis in Cosmology conference, September 2008 in Port Angeles, WA; I was struck by the fact that – in one subject area after another – the presenters gave several equally plausible ways to explain the same observations [5]. This showed me that changing one or two key assumptions allows us to understand cosmological data differently from the mainstream or concordance view, but have equal fidelity of agreement with both local and distant observations and measurements. This insight is in stark contrast with the accepted view that the basic facts about Cosmology are known and we need only grapple with minor issues. The accepted view is flawed according to Paul Steinhardt, one of the Inflationary Universe theory's founders – in a lecture I attended at FFP11 in Paris and in Scientific American [6]. Problems exist with the theory, in Steinhardt's view, as assumptions made along the way lead to unintended consequences or unobserved phenomena and many of these side-effects appear for all types of inflationary universe. While we await more advanced detectors which will reveal the gravitational wave spectrum in greater detail, we cannot say for certain that inflation is the mechanism which gave us the present day cosmos, or know which assumptions to change. So we must be cautious even when assuming a cornerstone of modern cosmology, and keep looking at alternatives.

I assert that superior sciences of the future (or those of advanced civilizations elsewhere) arise from a progression of ideas or viewpoints, not merely better answers. Assumptions are stepping stones to cross the waters of a somewhat fluid reality, best taken up playfully and tentatively, and not regarded as more real than what nature reveals. Nature is full of surprises, where our best guesses at natural law are bound to be seen by future eyes as convenient assumptions explaining parts of reality well, but ultimately leaving other facts unexplained. Yet each stepping stone in a progression of ideas treated as facts is a new observation post, a different viewpoint that gives us fresh perspective and allows us to better triangulate the actual location of the knowledge we seek. Often, people end up looking for new truths where answers once were (maybe because it is easier to get funding) rather than where the answers are. Osheroff addressed this in his lecture during FFP10, at UWA near Perth, Australia in 2009 – with this suggestion. It is far better to look for something undiscovered, unexplained, or poorly understood, "in an area of the parameter space that is not already well explored." Simply put; it is better to look in new places, if new answers and new understanding are what you hope to find. For Physics to advance; we must set assumptions aside, think for ourselves, and playfully imagine what might yield the reality we observe, if things are different from what is presumed true.

Questionable Assumptions and Alternatives

When calling assumptions into question, we must consider how replacements or alternatives can provide an understanding with greater fidelity to what is observed in the laboratory or cosmos. Sometimes; curious evidence that stands in conflict with what we know from other data, reveals flaws in our thinking or the existence of a bigger picture, a greater truth of which our limited 'knowledge' is only a special case. But often, playing with ideas in theory suggests that a greater truth exists, as with Einstein and the study of gravity. Newton's 'Law of Gravitation' is remarkably accurate within certain bounds or barring complications demanding Relativity. If an object and observer share the same local frame of reference and neither is a supermassive object, we don't need a more complicated formula. Einstein's version reduces to the Newtonian form then, which is easily solvable. But his more general formulation gives meaningful insights where Newton's equations fail, though sometimes it yields equations we cannot solve. One lecturer at FFP10, Mikhail Kovalyov, suggested this is a general pattern in Physics, where equations fully or accurately representing the Physics of a given interaction are often nonlinear – but as a rule they are insoluble [7]. However; by making some simplifying assumptions, or restricting the range of motion to bounds where the behavior is known or understood – we obtain nice linear equations to solve, so we can plug in numbers from data and obtain meaningful results.

Only when we have soluble equations allowing us to compare predicted values with actual data can our models be tested. The danger is in forgetting that simplifying assumptions were made, and creating a self-fulfilling prophecy where the assumptions are later seen as predictions or validations of the theory. This is tautology, a common logical fallacy, but an example is easy to find. Friedmann, LeMaitre, Robertson, and Walker did something remarkable by allowing Einstein's Field Equations to be soluble, as they would otherwise be intractable. But if a homogeneous and isotropic universe at the largest scales is a simplifying assumption they made to do that, it is fallacious to also see it as a prediction of the theory. Nor am I certain this is what we observe. I think the large-scale structure of the universe may be fractal (e.g. – between 2-d and 3-d, or 3-d and 4-d) [8], and that dimensionality is different at small and large scales, or when comparing the early universe with the present day or distant future, but I am not alone. That the dimensionality of spacetime evolves over time – and can assume fractional values – is a feature of Causal Dynamical Triangulation [9] and Quantum Einstein Gravity [10], aptly demonstrated by computer simulations. But quite a few physical theories under serious consideration ask us to see extra dimensions or dimensional reduction (as in holographic universe and 2-d gravity [11] theories) as realistic possibilities – or assume they are physical realities.

Can empty spaces have a particular dimensionality at all? This is a very common assumption indeed. The idea that the universe is 10-dimensional at the smallest scales is fundamental to String Theory; while Classical Mechanics is based on the notion the universe is 3-d with one dimension of time. Relativity is set in a 4-d spacetime (Minkowski space) that exists independent of objects and observers, but some question whether it is realistic to make this assumption. Loop Quantum Gravity researchers [12], and others who prefer a background independent formulation, challenge the idea that space began with a particular dimensionality – magically having the right number and arrangement of dimensions. Constructivists assert that the opposite is true; a space has no particular dimension until a sufficient array of constructed objects and well-placed observers allows us to make a determination of its dimensionality. And adherents of the Machian view [13] assert we must apply this notion to cosmology, where the stars, planets, and all other bodies contribute to an ongoing relativistic triangulation of the universe – dynamically determining its dimensions – and shaping space by having mass, by moving, and simply by occupying space. Instead of assuming any particular spacetime geometry is a given, therefore, perhaps we should assume it emerges from a deeper reality or has evolved to become what it is now.

The idea of emergent dimensionality has seen a resurgence from efforts to combine String Theory with Twistors, coming out of a meeting of minds between Roger Penrose and Edward Witten – exciting several researchers including Nima Arkani-Hamed [14]. A similar generative property comes via a different route, as we move from real and complex numbers (with one real and one imaginary component) into quaternions (with 3 imaginaries) and then octonions (with 7)[15]. Quaternions possess a non-commutative algebra and geometry, while octonions are also non-associative, which corresponds in ascending degree to a forced ordering of operations. This property is the same as procedural evolution, in my view, evoking process theoretic notions. Simply stated; working in these algebras requires us to handle terms in a specific order or sequence – in a process-like manner – and spaces corresponding to these higher algebras tend to evolve [16]. This escapes notice because people assume that higher-order dimensions are just like lower-order dimensions – only with more of them. It is untrue. The geometry and topology of higher dimensions are far more interesting and complex. If we consider the spheres, and the filled spheres or balls, it is usually imagined that adding more dimensions provides more space – more area or volume – as their number is increased. Instead; the maximal hyper-volume occurs at around 5.257-d and the maximal hyper-surface at around 7.257-d [17]. Higher dimensions are more compact, up to the Leech lattice in 24-d – the most compact known regular arrangement.

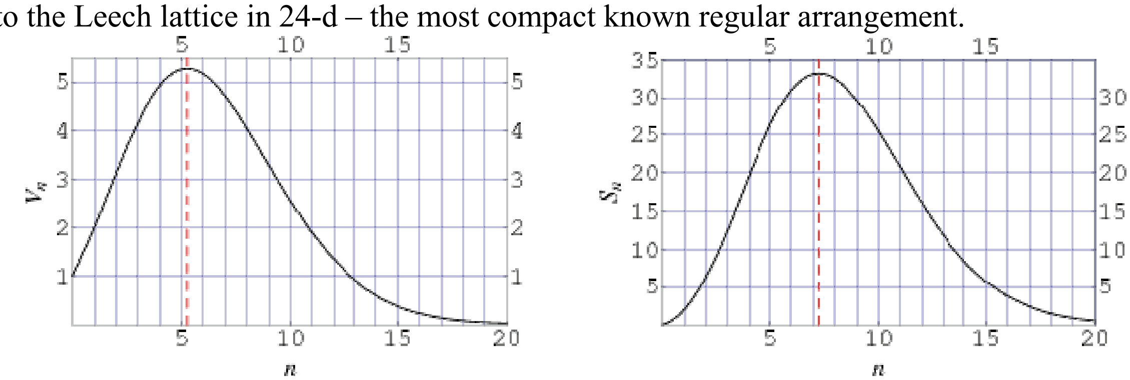

Figure 1 – A 5-d filled sphere or ball's **hyper-volume** (V_n) is maximal, but **hyper-surface** (S_n) is maximal for 7-d spheres.

This means that we can have only so many outward-facing axes at once, and extra dimensions must be curved or twisted, inward facing, or have a minimal extent. So the notion that adding more dimensions makes spaces more spacious is incorrect beyond the first five or seven steps. Admitting higher dimensions can exist forces us to re-think notions of size, locality, and distance, in radical ways. What is inside or outside what becomes a matter of perspective, or orientation, and locality and distance must be more flexibly defined. Imagine that what appear to be surfaces are actually the insides of things – that the universe is inside out. This idea follows from the accepted notion that the center of the Big Bang is actually everywhere at once, and perhaps from higher-dimensional embedding, but it has intriguing consequences. Things appearing to happen at a distance could, paradoxically, be local – or vice versa – given that perspective. This relates to ideas recently proposed by Joy Christian to explain the entanglement and apparent action at a distance (non-locality) observed in Bell's theorem, Hardy, and GHZ experiments – in a locally realistic framework – using geometric algebra and assuming a higher-dimensional space [18]. He asserts that those quantum correlations show we reside in a 4-d 3-sphere embedded in an 8-d 7-sphere, a quaternionic subspace of octonionic space. His work exploits oddities introduced by complex topologies of the higher-order geometries involved, but it has sparked intense debate on FQXi forums, sometimes becoming quite different from a civil intellectual discussion. While it has some enthusiastic supporters, Christian's explanation for Bell's experiments is by no means satisfactory for everyone, and it has some serious detractors.

The idea that the underlying geometry of space and time influences our reality must be taken seriously, regardless of the debate's outcome. Exactly what that geometry might be is far less certain. Whether Christian is correct is not as important as the open exploration of ideas and possibilities resulting from his work – which has been enlightening for me – but the controversy generated likely shows there is something worth examining we might have overlooked, which could yield some exciting new Physics. The heated debate forced both sides to examine assumptions about what is most fundamental, and caused a lot of hidden assumptions to be made explicit, but it also raised awareness about little known areas of Math that have a lot to offer Physics. I already appreciated the almost magical properties of the quaternions and octonions [19], for example, and I think that they will play an important role in the Physics of the future, but from the online discussion I learned details of their intimate connection with the 3-sphere and 7-sphere, and the extraordinary attributes of those figures, which ignited a fresh round of research for me. I think learning is more about how our knowledge and understanding grow over time, than it is about what is learned in particular. Things once on the horizon look different up close, and there are new horizons to see from there, but those horizons are still distant. Questioning the truth of a particular idea can be misleading, or perhaps even irrelevant, as any viable model that captures aspects of reality in a novel way offers perspective we did not have before – and this is useful. Yet we must be careful not to favor our models over what is real.

For me; the relevance of the online debate and discussion was mainly the insights into the geometry and topology of higher-dimensional spaces that assist my research into the origin of dimensionality – a subject of interest for quite a few years. I have considered the possibility that the early universe might be octonionic, in its geometry, and I think this could confer certain geometric properties which influence today's reality. It makes sense to me, and I plan to run some computer simulations of the universe's origin starting with this assumption, but regardless of the results I will still have to wonder what came before that. Was it a higher or lower-dimensional space? Or is there such a thing as a dimensionless space? I am at heart a constructivist, and a process theoretic view of the universe is appealing to me, so I think it is natural for geometry to evolve. However; in Physics we must look to physical processes that drive the evolution of a system – as a causative agent. Any discussion of dimensional evolution due to purely geometric considerations must be accompanied by a treatment of the physical forces driving, or corresponding to, the changes in spatial geometry. Ideally, our conceptual models should support this process, by allowing us to extract the type of information we are looking for; which brings me around to another questionable assumption – the way we look at thermodynamic entropy.

Entropy is often equated with disorder, but this can be misleading, and assuming it is a general rule sometimes gives the wrong answer. When researching entropy for a paper; I found the website of Chemistry professor Frank Lambert [20], and later the papers of Physics professor Harvey Leff [21], which offer a radically different view. In their formulation; entropy is defined by the dispersal of energy and/or the spreading of energy and substance within a sample, rather than a chaotic disorganization of orderly arrangements over time. Leff has suggested we can think of the symbol ***S***, used in equations to represent entropy, as shorthand for spatial and temporal spreading. In molecular entropy, we examine the number and utilization of microstates (coexisting and equally likely possible configurations of molecules within a sample). In this context, Leff suggests we can think of increased entropy as both spreading into available states and increased sharing among those states. I find this view more enlightening than the assumption that "entropy is a measure of the disorder of a system." This description was used by cosmologist Sean Carroll in his Scientific American article spelling out an alternate mechanism for inflation [22], but his premise follows more directly from the metaphor of Leff and Lambert. Briefly stated; the Spontaneous Inflation theory of Carroll and Chen suggests entropy is the driving force behind inflation, where it causes things to become more spread out over different directions in time as well as space, such that some universes' timelines appear to run backwards from our own. This sounds precisely like 'spatial and temporal spreading' to me, making it simple to explain.

But entropy is *not* altogether simple, as an exact description often requires non-linear equations. Stated differently; entropy embodies a host of non-linear properties, or processes, because boundary conditions confining a system to linear regions change over time and energy feeds back. Many exciting and paradoxical things are observed when we expand our purview to include non-linear behaviors of systems. Perhaps this is what prompted the Scientific American Editors to say that "nature breaks the 2^{nd} law of thermodynamics," in their description on the cover about an article by J. Miguel Rubi that discusses non-linear entropy in the mesoscale regime, which lies between microscale and normal sized or macroscale phenomena [23]. I think their statement reflects more a sense, though, of how greatly cherished the assumption is – that entropy's increase is synonymous with the increase of disorder. In his article; Rubi carefully explains that the 2^{nd} law (which states that entropy tends to grow) is precisely and exquisitely preserved, thermodynamically speaking, even in instances where we observe an increase of order within a system and know entropy increases as well. In fact; Rubi's work depends on the fact that the 2^{nd} law ***is*** observed – as the effective degrees of freedom of a system increase due to non-linear properties – and it derives much of its strength therefrom. Any confusion about breaking the 2^{nd} law results solely from the mistaken assumption that entropy is disorder.

Finally; it is important to question the assumption that objects and phenomena are independent or discrete. The illusion of separateness is compelling, but it now appears that no two things are completely separated and no system is isolated. Maybe we should ask if there are things at all – and see all entities as a collection of processes that have a separate existence because energy flows in a loop or circuit. This process theoretic view suggests the notion of a computing universe, but not only the kind where the universe and everything in it is a computer. It hints at a much more organic and holistic view of reality. The point is that reality and the universe are unified – existing as a congruent whole. Rather than seeking a route to the unification of fundamental forces and entities, scientists should observe how nature is already unified, and highlight the unity that is already there, or the unifying concepts already in play. Two papers by Dieter Zeh come to mind [24], where he states that there are no particles and quantum transitions are an illusion, contrasting these observables on the surface with the deeper connectedness of the global wavefunction, which persists whatever interactions take place. This notion is bolstered by recent research showing that the wavefunction may be a literal, rather than figurative, entity [25]. The idea that things are connected behind the scenes, and spread into each other, appears factual. They are connected more directly too, and all things form a congruent whole. There are no truly isolated systems, as everything is part of its environment and also helps to create that environment. I think this assumption will stand the test of time.

Concluding Comments

I have highlighted questionable assumptions in this paper, and suggested alternatives we need to consider, but I think even erroneous ideas can help the progression of knowledge and understanding to continue. Assumptions are nothing but ideas we treat as-if true, to calibrate or test our understanding of reality. Making assumptions, and then educated guesses that become beliefs, is something all human beings must do to learn. But when we treat our beliefs as though their reality is independent of nature's truth, they can harden into dogma and inhibit our search for scientific knowledge. A belief is only a feeling of certainty that something is true, but no matter how certain we are or how deeply we feel something – reality exists independent of our mental and emotional states. Therefore; we must be willing to set beliefs or assumptions about reality aside, and play with alternatives, to understand the cosmos better. The danger lies in thinking we already know what is going on, and do not need to learn more to understand things. A mental inertia known as the Einstellung effect sets in, where people believe in and attempt to adjust old models or methods rather than adopt a new model, even when it offers distinct advantages in terms of improved understanding and predictions. Some believe this has happened in Cosmology, where the concordance view is a hodgepodge of adjusting factors. Others say the same thing about the Standard Model of Particle Physics and its minimally supersymmetric cousins. If we plug in all of the right constants, we can use renormalization to get the correct strengths for the fundamental forces and masses for subatomic particles, but does this really explain anything?

Perhaps those values come from something behind the surface reality that would exist even if our universe did not. Scientists point to the symmetry groups (SU(3) x SU(2) x U(1)) as a representation of the underlying order, but I must ask 'from what palette of choices did nature select that combination and why?' Is there an even deeper reality it derives from – like fundamental entities of Mathematics? Did the Standard Model arise from the number families (real, complex, quaternion, and octonion) and their respective (normed division) algebras? Maybe E8 holds the key. Perhaps it is the Monster Group, the Mandelbrot Set, or all of the above we should look to for answers. I would rather adopt and then set aside any number of assumptions, than believe String Theory or the Standard Model is the only game in town. Data from the last several years has narrowed the list of candidate solutions to consider, in Cosmology, Particle Physics, and elsewhere. But some data calls for new ideas in Cosmology and raises questions about the Standard Model as a final answer, despite the recent Higgs discovery. We have learned more about the cosmos in the past 10 years than in the previous 100. We live in exciting times where knowledge grows very fast, and we must struggle to explain what we are learning. The whole face of Physics has changed, but many cherished assumptions persist, despite the fact they do not accommodate what we now know. A large segment of the public still holds views from the 19^{th} century, and denies basic realities of Quantum Mechanics while clinging to devices which depend upon it to operate, so societal time lag is part of the problem. But men and women of Science should know better, or be more playful, and be willing to set cherished assumptions aside.

This again brings the discussion around to how play is essential for learning, both for young children and for scientists [26]. Young children's playing is very much like the activity of experimental scientists, where they formulate and carefully test theories about how things work. This insight came to be called the 'theory theory' – as Gopnik explains in her

Scientific American article [3] – but it has been verified experimentally. Young children are not afraid to try one idea after another, but they are cleverly careful to vary things in a systematic way – in their playing – that isolates the variables, and allows assumptions to be sifted or sorted. It appears that the advancement of Science, especially in Physics, requires individuals to continue this playful approach into adulthood – as the most esteemed scholars also appear to be the most playful. Richard Feynman's book "What do you care what other people think?" [27] was a recent gift, and this gifted man's work epitomizes the playful approach to Science. He suggests we should not take assumptions about reality too seriously, and should instead think for ourselves. This is in stark contrast to the kind of learning that involves memorizing a bunch of facts – and it is fundamentally better. Thinking things through, to determine for yourself what makes sense, avoids the danger of memorizing other people's assumptions that are presented as facts – but are untrue.

Anton Zeilinger's lecture at FFP11 emphasized the need for playful exploration to foster research progress, warned of the dangers of regarding even great ideas (like Einstein's corpuscular theory of light which won the Nobel Prize) as facts, and cautioned against compelling researchers to be focused on producing results. He was colorfully candid about how he advised his employers on this matter, as a champion of the need to experiment, but I have heard other top Physics researchers stress the need to remain open minded and playful with ideas about reality and how the universe works, to make rapid or significant progress. Research is more about looking, and finding out what is really there, than it is about finding something specific you are looking for. So assumptions we make along the way – about what we might find – must be tempered by the knowledge of what is actually found, or what is there when measurements are taken. We must be willing to throw off our shackles, as even assumptions that help us to find exciting new information must be set aside if the new data shows an assumption is false, or has limited applicability. This is the essence of progress. The scientific method has served us well, in the realm of experimental Physics, but some of its lessons should inform us on the more basic level of how we learn about reality. Scientists need to be child-like, in their openness and willingness to play with ideas as-if they were true, to test those ideas under a variety of conditions, and to try other ideas as well – seeing if they also allow us to make sense of things. Those who can be the most like little children shall understand all in the heavens and on Earth.

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Figure 1 graphs from mathworld.wolfram.com articles for “Ball” and “Hypersphere”

Early-stage learning

Object constancy – The essential insight that objects can (and do) continue to exist even when they cannot be seen or touched sets the stage for all future learning.

Observation, exploration, and comparison – Observation is the first road to understanding. Once children become mobile, exploration and comparison allow triangulation – which enables them to learn how to navigate safely, and to formulate concepts of size and distance.

A breakthrough allows symbolic thinking – Judy DeLoache observed that children before age 2½ display dimensional confusion, where they will talk to a photograph, attempt to get into toy cars or chairs, or try to wear shoes that are much too large [1]. Once this confusion disappears, though, she observes that children acquire a rapidly increasing ability to think using symbols. I speculate that the ability to distinguish dimensionality (the difference between 2-d and 3-d objects, for example) is crucial to learning symbolic thinking [2].

Exploration generalized becomes experimentation – Once the concept of exploration is expanded a bit, the notion of taking up a new position, observing from that new place, and comparing the view, becomes a formula for experimentation of all kinds. The metaphorical equivalent of taking up a new position is to make assumptions or postulates – theories about reality – and playing or experimenting is how we see where those ideas take us.

Comparing Newton's and Einstein's gravity

Using Newton's Law of Gravitation, the gravity of a massive spherical object like the Earth is seen to emanate from its center, but if we use Einstein's formulation instead – this is seen as an approximation. Using Einstein's equations, we find that the gravitational lines of force do not converge to a point at the center, but take us a distance away – because gravity bends the fabric of space – to the Schwarzschild radius, which is defined as:

$$r_S = \frac{2Gm}{c^2}$$

where:

r_S is the Schwarzschild radius	G is the gravitational constant
m is the mass of the object, and	c is the speed of light in a vacuum

For an object the mass of our Sun, r_S is a few kilometers, where for the Earth, it is only about 0.85 cm. This small distance is the maximum discrepancy introduced into Earth-based trajectory calculations by using Newton's equations instead of Einstein's, so the difference is trivial here – except for a small volume at the Earth's core which is apparently in an extra-dimensional space. But what if we could cram Earth's mass into that volume?

For sufficiently dense supermassive objects, such as the core of a large dying star, a point is reached where – because of the concentration of mass – a Black Hole is formed. This can be understood simply as what happens when enough of the matter is squeezed into a volume inside the Schwarzschild radius, so that the force of gravity exceeds the strength of nuclear binding forces which would otherwise prevent further collapse. Any matter or energy within that radius disappears behind the Black Hole's event horizon – as even light cannot escape – though some of it will eventually come back out as Hawking radiation.

Entropy reframed

Frank Lambert states "Energy of any type disperses from being localized to becoming spread out, if it is not constrained," [20] and asserts that this principle is the basis for the 2nd law and thermodynamic entropy – refuting the notion that entropy is disorder. His work, detailed at entropysite.oxy.edu has had great impact on Chemistry education, where the great majority of introductory and intermediate texts have abandoned the 'disorder' metaphor, and many have adopted his view that entropy is an expression of the dispersal of energy.

Harvey Leff first presented entropy as a 'spreading function' to the Physics community in 1996, and published a lengthy paper in Foundations of Physics in 2007 [21] expanding on this idea, but it has gained traction much more slowly in Physics than in Chemistry. A five-part series recently published in The Physics Teacher further elucidates how this approach can improve our understanding of entropy, and attempts to bring it to a broader audience. In the last installment, the disorder metaphor for entropy is again 'roundly rejected.'

Note: To regard thermodynamic entropy as 'spreading' gives a direct geometric interpretation and implications are explored in a Prespacetime paper I co-authored with Ray B. Munroe [28].

Evolving Geometry and Abstractions

Taking a step one unit in length brings you one unit away from your point of origin, but where is that exactly? For a one-dimensional journey – an excursion on a line – you have arrived at either +1 or –1, assuming you started at 0. In general, people assume a positive direction and see the negative as unphysical, but the choice is completely arbitrary, and saying you have traveled one unit on a line implies both choices as possibilities – so the information we have is ambiguous, after only one step.

What about 2-d, 3-d, or higher-dimensional excursions, the geometry implied by transiting a unit of distance, and so forth? In general terms; $r = 1$ defines a unit sphere, but it can be a sphere of any dimension. The two points on a line in the above example constitute what is called a 0-sphere. For excursions on a plane – in a 2-d space – we call the resulting figure a circle, or 1-sphere. In a 3-d space, the figure defined by $r = 1$ is a conventional or ordinary sphere – a 2-sphere. The 3-sphere is an odd-ball, though, as it has a Möbius-like surface.

The spheres answer the question "where can a step of one unit take us?" and this depends upon degrees of freedom, or the dimensionality of space. Things get interesting for higher dimensional spaces, and for spaces whose dimensionality is undetermined. We begin life's journey not knowing the dimensions of the world, though, until – by exploring – we gain perspective. One can see a circle in its entirety from above, but this perspective does not exist for those constrained to observe from the circle's 2-d frame of reference. Nor does being above a sphere or ball allow us to see its entire surface, as it is 3-d like us. The abstraction learned by seeing a circle from off the page allows us to grasp that a sphere's surface can also be continuous, but only if we explore and observe can we actually see the other side. I am curious. Let us go look, or spin the ball around, and see what is there!