The Edge of the Universe: Beware Lest There Be Dragons

by

George W. Collins II

Abstract

In which it is shown that the world is not the way we think it is and what can be done about it. The interpretation of the Universe as a four-dimensional space and its perception by intrinsically three-dimensional humans is explored. Some of the implications of Bell's inequality and the world of the very small are also discussed with a view to trying to understand what we mean by reality. A few of the consequences of prejudicial thinking engendered by our local space-time environment are described with particular attention being paid to a few ubiquitous dragons.

Introduction

Common maps of the Middle Ages depicted the World as flat. The average man who rarely traveled more than twenty five miles from his home had no need of a sophisticated Cosmology. A 'flat' World with a universally defined 'Up' and 'Down' was the only world view he needed to get through the day. The concept of an Earth where 'Down' always pointed toward the center of a spherical world would have offended the common sense of the average man struggling to wrest a living from the soil beneath his feet. Such sophistication was unnecessary for the serf of the Dark Ages. Such sophistication was unnecessary for the educated monk trying to preserve the knowledge of the past while improving the world of his present. To be sure, there were scholars who were aware that the world was round. Columbus' problems stemmed not from the fact that Queen Isabella's advisors thought the Earth was flat, but rather that they knew Columbus had the wrong value for the size. Only later was his life complicated by the fact that his crew, who were mostly prisoners, was convinced that the Earth was flat. Of course, a flat Earth must have an edge and that appeared to be where they were headed. The practical result of the fear of falling off the edge engendered by such ignorance nearly led to Columbus being overwhelmed by a mutiny shortly before they sighted land. Such are the fruits of the mis-perception of the world. For beyond the edge, as depicted on the common maps of that simple flat world, lay Dragons. Not only Dragons, but all manner of beasts and creatures personifying fear and terror, were reputed to dwell there.

As the horizon of man expanded, so did the sophistication of his world view. With the possible exception of the eccentrics of the Flat Earth Society, no contemporary man possessing even a rudimentary education believes that the Earth is Flat. Airline pilots are at home with a geometry of spherical surfaces that a century and a half ago would have been declared invalid by the mathematical establishment of the time. While lengthy flights of airplanes are still largely two dimensional, they are trips confined to the surface of a sphere, not to a Euclidian Plane.

During the 19th century, Georg F.B. Riemann and Nikolaj I. Lobachevski independently discovered perfectly valid geometries which rejected the famous 'fifth' postulate of Euclid. This is the postulate which states that "through a point outside a line only one line can be drawn parallel to the given line". The idea of Lobachevski as expounded by Johann Bolyai is that while the 'fifth' postulate is essential to the development of Euclidian Geometry, it is not a unique postulate. That is, one might assert that "through a point outside a line many lines may be drawn parallel to the given line",or "through a point outside a given line no lines may be drawn parallel to a given line". Lobachevski showed that the geometries which result from these changes in the parallel postulate are consistent and as valid as the geometry of Euclid. We now understand these geometries to be two dimensional geometries done on curved surfaces rather than the flat plane of Euclid. Riemann's geometry, which arises from saying that there are no parallel lines, is equivalent to doing geometry on a closed surface such as the surface of a sphere. Here 'straight lines' are great circles any two of which must cross not once, but twice.

Allowing many 'straight' lines to pass through an external point leads to the geometry of Lobachevski which can be viewed as geometry done on an open surface like a saddle extending to infinity in all directions. Once the unique nature of Euclidian geometry is rejected, it is possible to imagine doing geometry on all kinds of complex surfaces and in higher dimensions.

It has often been said that the primary goal of science is to describe the physical world. Since Mathematics is the 'language' of science, it is of fundamental importance that the geometry of the world be understood. Einstein took the view that the Newtonian force of gravity could be replaced by simpler laws of motion which operate in a space whose geometry is determined by the presence of matter. All the physics of Classical Mechanics is reduced to geometry. This elegant theory, known as the General Theory of Relativity, remains the most accurate description of what Newton called Gravity.

Einstein also emphasized the importance of time in the description of the physical world. The inability to deal with time properly, limited the development of Greek science. Newton's development of the Calculus and the proper description of the concept of limits led to a rapid development of mechanics and the explosive growth of science in general. However, Newton believed that space and time are absolute and the physical world could be viewed as being embedded in an imaginary 'fish-net' and governed by clocks which kept a universal and absolute time. Einstein overturned this notion of 'absolutism' and showed that the measurements of space and time were dependent on the observer. That is, intervals in time and distance between two events in the physical world will depend on who measures them. Since there can be only one set of 'laws' that describe the physical world, it was necessary to modify the description of Newton so that the laws would involve only those quantities upon which all observers can agree. Einstein found that this could be accomplished by modifying the geometry of the physical world while incorporating time in a new and fundamental way. In doing so, he generated a two-fold complexity: first, he replaced the familiar geometry of Euclid with the less well known geometries of Riemann and Lobachevski, and then he elevated time to an equivalence with space. The former seems irrelevant to the casual observer as the round Earth did to the 12th century serf.The latter is just becoming apparent to the average man through the introduction of modern technology.

Let us consider some of the implications of the inexorable intertwining of space and time resulting from Einstein's notion of simultaneous events linked together by light signals. The extreme speed of light (299,700 km/sec) has the effect that very few folks on Earth are inconvenienced by having to wait for information to be carried from place to place by means of a light signal. However, should you place a transoceanic phone call, you may feel the person on the other end of the line is a little slow witted. He seems to take a little longer to respond, even to trivial questions, than he would in person. This delayed response results from your question traveling roughly 42000 kilometers to a geostationary satellite, where it is relayed back to the listener whose reply must then retrace the same path for a round trip total of about 166400 kilometers. Even at the speed of light this will take a little over a half second. Half second delays are quite noticeable in social intercourse - so noticeable in fact that most television networks will not use live dialogue between say a New York Anchorman and a foreign correspondent. The television viewer will hear the Anchorman after a delay resulting from a short trip by the signal of a few thousand miles overland. However, the correspondent's response will be heard about a half second latter during which time a picture of an individual who hasn't even heard the Anchorman - his picture - will be displayed to the viewer. Since not many correspondents are interested in appearing inattentive, slow, or dull, most satellite reports take the form of single run taped segments.

This time delay becomes even more noticeable as the distance traveled increases. During the Moonwalks of the Apollo program, many viewers noticed that everything said by the Houston controllers seemed to be repeated two and a half seconds later. This echo resulted from the controllers statements being picked up by the open microphone in the helmet of the Astronaut and re-transmitted back to Earth and then out to the viewing audience. The round trip distance to the moon is about a three-fourths of a million kilometers and takes light just about two and a half seconds to make the trip. This effect transcends the embarrassing or annoying when one considers the operation of a deep space probe. Several hours of data were lost when Voyager 2 traveled past Saturn and became mis-oriented. Although the correction command was issued speedily upon detection of the error, by the time the command was received the space craft had traveled many miles on its journey and was no longer close enough to the planet to make the desired observations.

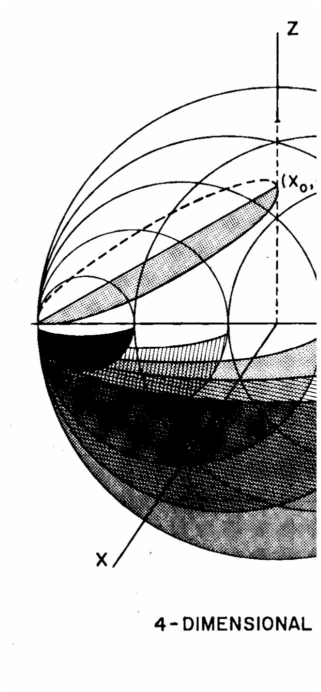
Astronomers have long realized that when they look out into the night sky, they are seeing an image of the past. Light from the bright star Sirius requires eight years to reach the Earth, while light from the Andromeda Galaxy travels for about two million years before arriving. As we look more deeply into space at fainter and more distant objects, we are seeing images of objects in the universe as they were at earlier and earlier epochs. If one were to look deeply enough into space one should see an image of the initial explosion - the big bang - that marked the formation of the universe itself. In actuality, the high density of the early universe limits our view to an epoch when the density of the universe becomes low enough to permit light to travel great distances. The light from this era is sometimes called the primeval fireball and is indeed what Penzias and Wilson found in 1965 while they were testing a very sensitive radio amplifier and receiver. Thus it seems clear that the more deeply we look into space, the earlier an image of the universe and its constituents we see. What is more amazing is that it doesn't matter in which direction we look.

Now we begin to see where our ordinary prejudices for Euclidian geometry can lead. In looking out into space and thus back in time, in principle we should see images of the universe when it was confined to a very small volume - say a point. Yet that point will appear to be spread across the sky. This apparent dichotomy is certainly not the fault of the Universe, but rather is a manifestation of the way we humans perceive the world in which we live. The Universe is all that was, is, and will be accessible to observation. Thus, in a very real sense, the universe exists in time as well as space. In that sense, it is four dimensional in nature and its geometry is non-Euclidian on a grand scale.The situation is not unlike that which you encounter if you take a map of the world and try to flatten it out on to a plane. In addition to cutting the sphere, you will stretch two points (usually the poles) into lines. So our problem of viewing the Universe is two fold; the dimensionality is more than we can perceive and the geometry is not the Euclidian geometry that works so well locally and with which we are so comfortable.

In point of fact, we live in a four dimensional world. Events in our Universe require three spatial coordinates and one temporal coordinate to define their location. Since we only can 'see' in the three spatial dimensions, this makes our task of visualizing the Universe more difficult, but not unimaginable. Let us try to conceptualize a four dimensional sphere. In trying to imagine any multidimensional object, the distance between the various points which make up the object is of paramount importance. For a four dimensional object, this distance will involve four separate and distinct coordinates. In order to attempt to visualize such an object, let us take those coordinates to be the familiar three spatial coordinates and time. The notion of a three dimensional sphere is familiar to everyone. A baseball will do as a specific example. Now consider a continuous sequence of 'baseballs' of ever increasing size. The first is no larger than a point while the last has some finite radius. Now arrange these in order of increasing size along some axis that is not a spatial axis. That is the hard part. You might consider time to be such an axis, but you must be careful to remember that the spatial extent of each 'baseball' does not overlap any other 'baseball' since they are arranged along an axis (time) which is separate from the spatial axes. Figure 1 represents my feeble attempt to represent such a sequence on a two dimensional page. Once you have this much in mind, you have grasped half of the four-sphere. Now repeat the sequence back to a point and you have the whole thing. The 'temporal' spacing of the spheres is important. Each of the initial sequence must be visualized as tangent to the initial point, but since the sequence is arranged in time, the tangent points must be thought of as distinct and separate points. Such a visualization is difficult the first time you try it, but it becomes easier with practice. In order to simplify things somewhat, let us instead imagine creatures that can perceive in just two dimensions. The struggles of these poor folks in dealing with the third dimension will give us some insight into our own problems of comprehending a four dimensional Universe.

In the late 19th century The Rev. Edwin Abbott published a book titled "Flatland" in which he envisioned what existence would be like for such creatures confined to living on a two-dimensional plane[1]. To these 'Flatlanders' there would be no concept of 'up' and 'down' as we know it. Dwellings would be simple polygons, doors would be lines, etc. He even went so far as to speculate what an encounter with a three dimensional being would be like. One day a point would appear in their world and would proceed to expand into a circle of steadily increasing circumference. After a while the sequence of events would be repeated in reverse order. The circle would shrink down to a point and then disappear. An intellectual 'Flatlander' could deduce that a three dimensional sphere had passed by their world even though he could not draw a picture of it to show his fellow Flatlanders. A good deal of Reverend Abbott's essay deals with the trials and tribulation experienced by a Flatlander who has conceptualized three dimensions, while trying to illuminate his fellow residents. However, as a mathematical exercise it is useful and not without parallel in the real world. (For further adventures in "Flatland", the reader should consult a recent article by Martin Gardner[11].)

Figure 1 - This is an attempt to depict a four-dimensional sphere. One can imagine such an object as a continuous sequence of solid spheres which increase in size from some point in the past until they reach some maximum in the present and subsequently diminish to a point in the future. All points of intersection on the drawing must be viewed as distinct and separate points as they exist at different epochs. The 'slice' in the upper left gives some idea of the preceptual problems engendered by viewing parts of the four-sphere at different epochs. Such is the case in the Universe as different epochs are linked by light signals which travel at finite speed



Let us consider how educated Flatlanders might make discoveries about the world in which they live. Could they distinguish whether they lived on a Euclidian Plane or on the surface of an immense sphere where the paths taken by light beams were great circles? In principle, they could measure the number of degrees in a triangle carefully laid out in their world. Should they get 180 degrees, then they would know that at least in the vicinity of the triangle, the local geometry was 'flat' or Euclidian. However, any departure from 180 degrees would signal a departure from Euclidian geometry and they would have to conclude that their world was curved through a third dimension. There are other geometrical tests they might perform to reach the same conclusion, and by these means they could map out the geometry of their world. The fact that their brains would interpret their world as being Euclidian would lead to some conceptual difficulties as they attempted to understand the nature of their Non-Euclidian world on a grand scale. Since these same conceptual difficulties are shared by us three dimensional creatures, let us investigate them in more detail.

The shortest distance between two points is commonly called a 'straight line'. That is a perfectly good name for that concept as long as travel between the two points takes place on a plane. However, should the travel be confined to the surface of a sphere, you would find that the shortest distance between two points would be a great circle. In general, one calls the shortest distance between two points a 'geodesic' regardless of the nature of the geometry of the surface. In the physical world the shortest distance between two points is the also path taken by a beam of light. If this were not the case, it would be possible to travel between two points in less time than that required by light and at a slower speed simply by taking the shorter path. This would violate the principle of causality which says that the order of related events that occur in the Universe must be the same for all observers. To violate Causality is to say that cause and effect cannot be uniquely specified but rather depend on the observer. This would imply that the laws governing the physical world which specify cause and effect would also be observer dependent. This is tantamount to anarchy for the physical world and should it ever prove to be true would, at the very least, send all physical scientists looking for another line of work. Thus we may assume that our Flatlanders will, as we do, perceive their world to be Euclidian-flat and the path taken by light beams to be 'straight lines'.

Let us further assume for simplicity that the large scale geometry of their world is in reality spherical. Looking out from some point in their world, they would interpret what they see as a vast plane when in actuality their line of sight would be confined to the surface of a sphere (see Fig. 2). All lines of sight would be great circles as they are the shortest distance between points on the surface of a sphere. If a Flatlander could see indefinitely into the distance, he would see beyond the antipodal point, right around the Flatland Universe, to the back of his head. This would be the view regardless of which direction he looked. Objects located near the antipodal point would appear magnified along the 'horizon line' and the antipodal point itself would be mapped into a line completely surrounding the observer. In this static picture of their universe no account has been taken of the relative extent of the curvature or the finite velocity of light. In order to make the comparison between the Flatlander's situation and our own more compelling, let us further assume that the Flatlanders occupy a very small 'volume' of their universe and therefore all share the same world view. In addition, let the velocity of light be finite and their spherical universe be expanding like a balloon (see Fig. 3). Now the image of the universe that the Flatlander sees as he looks out from his local spot, is an image of the universe when it was younger and smaller. If at some point in the distant past the contents of this universe were opaque to photons, then that image of the contents would appear as a line - a horizon line - beyond which the observer could not see. He would see this line in what ever direction he looked.

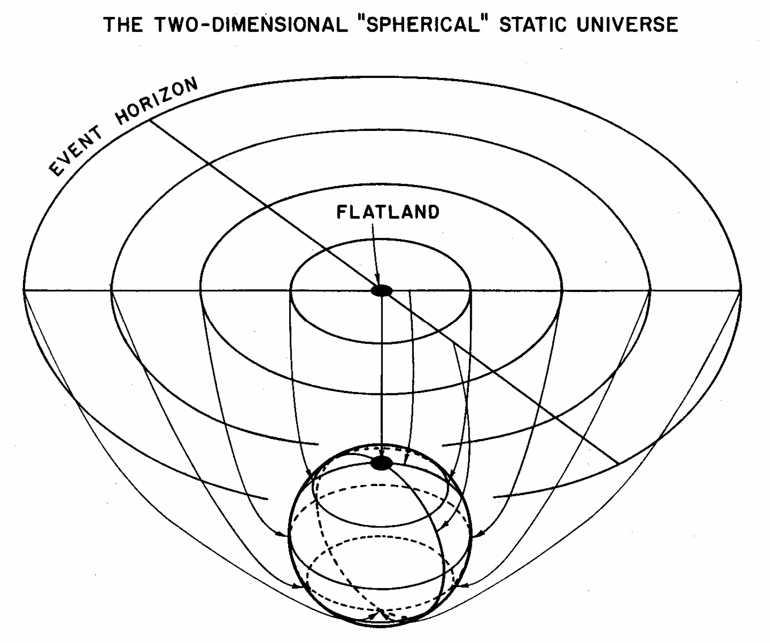


Figure 2 Here we have indicated how a two dimensional spherical universe would appear to the residents of Flatland who think in a Euclidian manner. The arrows indicate where 'latitude' lines would appear to those who perceive their world as flat

Such is the nature of the primeval fireball in our own Universe. But the fireball of our Universe is not as hot as one might expect the universe to have been if it were all packed into a small volume of space. To understand this, consider the effects that the expansion of the universe has on light.

Consider three points on the surface of an expanding balloon; two of these points are initially close together while the third point is located some distance away from the close pair. As the balloon expands all points will move apart but the close pair will always remain closer together than the pair and distant point. Indeed, if the radius of the balloon doubles, so will all distances between points on the surface. The distant point will have to move much further, and hence faster, from the pair than either member of the pair from the other. Thus, an observer on one of the points will see distant point receding from him with a greater speed than nearby points. Specifically, the recessional velocity will be proportional to the distance of the observed point. Such is the case in our own Universe and the velocity-distance relationship is known as Hubble's Law. The galaxies that fill the night sky of our large telescopes appear to be receding from our own local galaxy with a velocity that is proportional to their distance from us.

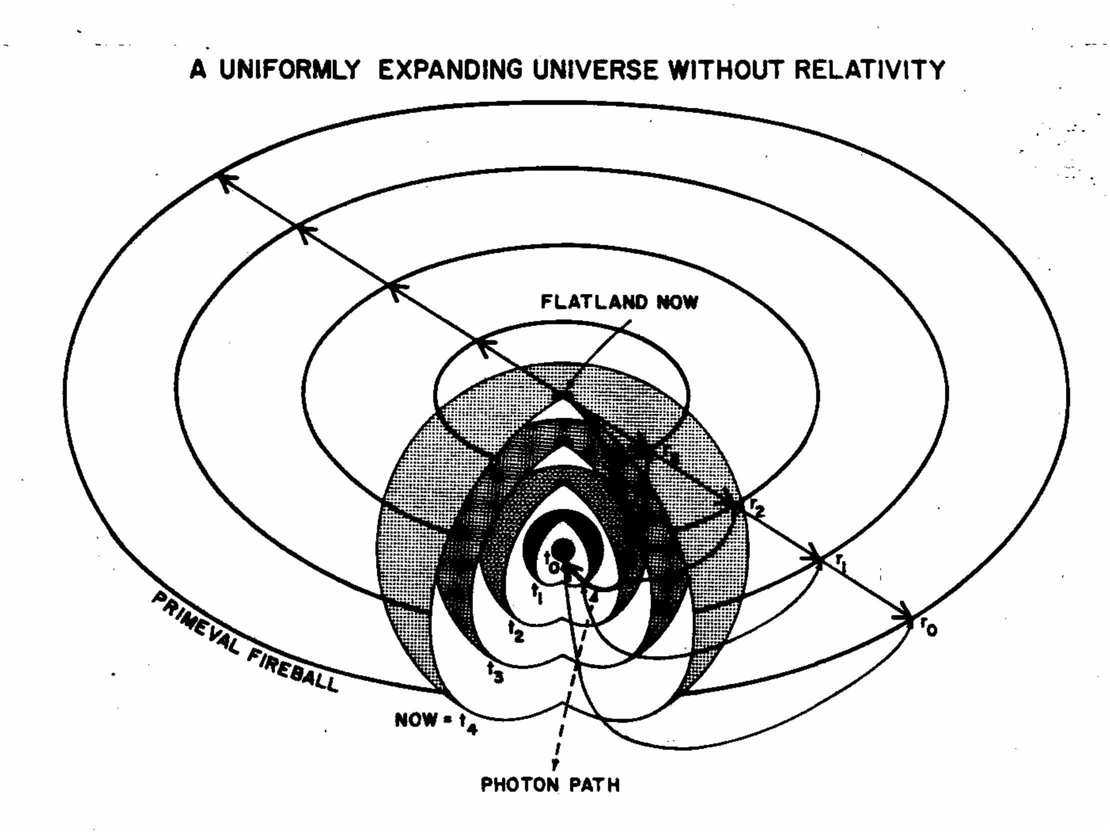


Figure 3 This is similar to figure 2 except now the spherical universe is uniformly expanding in time. Thus different distances observed by the Flatlanders labeled with different values of r correspond to different latitudes on spheres of smaller size as the universe is always seen when it was younger the further away one looks.

It is a well known phenomenon of physics that when a source of wave-like radiation recedes from an observer, he will see the waves to be stretched out or lengthened as compared to an observer moving with the source. This effect causes the light of the receding galaxies of the Universe to be shifted to the red. However, the energy in a beam of light is inversely proportional to the wavelength. So not only is the light of galaxies shifted to the red as a result of the general expansion of the universe, but the total energy is also proportionally decreased. Thus an object that radiates like a body with a particular temperature will, if receding rapidly, appear as an object radiating less energy and hence it would appear cooler. Such is the case with the primeval fireball. Since the source of the light of the primeval fireball is at a great distance in spacetime, the light is subject to a profound Cosmological Redshift and thereby appears very much cooler to present observation. This apparent cooling of the fireball radiation lowers the temperature from about 5000 K to an observed value of 2.7 K. This is the radiation that Penzias and Wilson detected while they were testing their radio equipment.

While the picture of uniform expansion is a relatively simple one leading to some surprising conclusions, there remains one further complication which we shall impose on our Flatlanders. Just as an object thrown in the air slows in response to the gravitational pull of the Earth, so must the expansion of the Universe slow down in response to the matter which makes up the Universe itself. In principle we can detect this effect as the rate of expansion of the Universe would itself appear larger in the past than it does now. This change in the expansion rate makes no fundamental change in our view of the Flatlander's universe. Only the equally spaced spheres of figure 3 are now replaced by spheres which become closer together as time goes on. It remains an open question as to whether or not there is sufficient matter in our own Universe to eventually halt the expansion, but again this does not fundamentally alter our present picture. The primeval fireball still poses a barrier to observation for the Flatlanders as well as ourselves. For it will appear as a Cosmologically Redshifted 'line' all about the horizon. But there is a more fundamental horizon shielded by the fireball. This is the point marking the origin of the universe itself. Beyond this 'Event Horizon' one cannot look, even in principle. A truly two-dimensional mind of a Flatlander might well call this the edge of the universe and wonder what lay beyond it. But this is an il-conceived question akin to asking "What is north of the North Pole ?". Such a question reflects the inability of the Flatlander to grasp the true nature of his world and, by imposing his personal prejudice for Euclidian geometry upon an intrinsically Non-Euclidian Universe evolving in time, be lead astray to thoughts of 'the edge of the universe'. Such problems are felt by many 'three-dimensional' minds in our own Universe. The Universe should be considered a four dimensional world existing in space and time of which we perceive at any instant only a three dimensional 'slice'. Because light travels with a finite speed, the 'slice' is such that we do not see all aspects of the Universe at the same time. The more distant parts are seen at earlier times and the resultant slice is definitely Non-Euclidian. In figure 4, I have placed a dragon beyond the 'Event Horizon' of the Flatlanders universe by analogy with the monsters that lurked beyond the edge of the world on the maps of the Dark Ages.

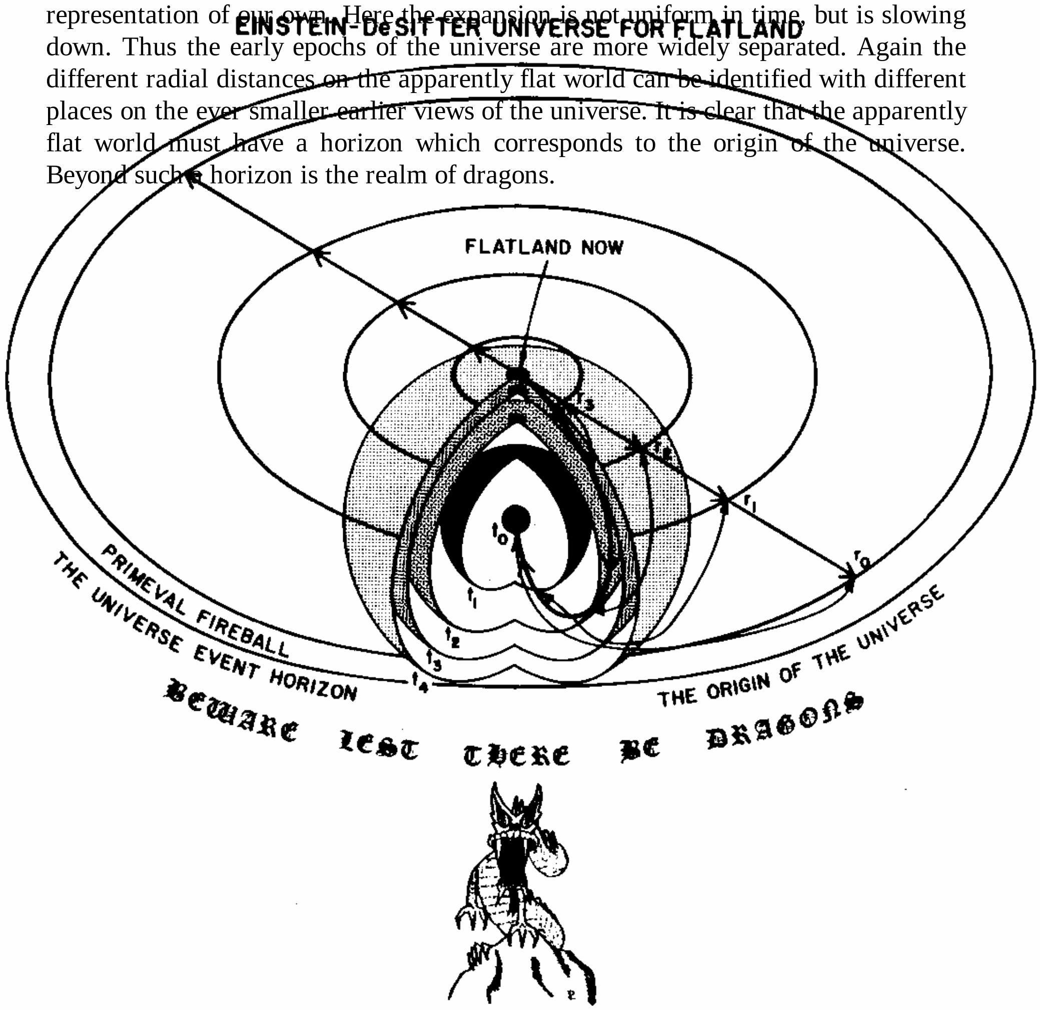


Figure 4 This last figure corresponds closely with a two dimensional representation of our own. Here the expansion is not uniform in time, but is slowing down. Thus the early epochs of the universe are more widely separated. Again the different radial distances on the apparently flat world can be identified with different places on the ever smaller earlier views of the universe. It is clear that the apparently flat world must have a horizon which corresponds to the origin of the universe. Beyond such a horizon is the realm of dragons.

But are the four dimensions of spacetime sufficient to describe our world? Einstein asserted that this was so and for the Universe on the grand scale of Cosmology it certainly appears to be true. But we must not become too confident, as our Universe involves not only the grand scale of the very large, but also the sub-nuclear scale of the very small.

About the turn of the century, Physics began to probe the realm of the very small and found that matter behaved as if there were forces other than the long range forces of Electromagnetism and Gravity at work. In addition, matter itself did not behave in the nice deterministic fashion of classical physics. The discovery by the Curies' of radioactivity and the 'splitting' of the atom by Hahn and Strassmann and subsequent interpretation by Meitner and

Frisch, made it clear that there were at least two other forces in nature in addition to Electromagnetism and Gravitation. These forces, known as the Weak Nuclear force and Strong Nuclear Force, are effective over the short range of the atomic nucleus only and are regarded by many to be 'fundamental' in character. That is, nature can be assumed to be describable in terms of four forces that themselves are not derivable from any other concept.

However, during the 1960's it became increasingly clear that it might be possible to describe both the Weak Force and Electromagnetism in terms of the same formalism. This development culminated in the Weinberg-Salam theory which successfully describes the Weak Force and Electromagnetism as different manifestations of the same force now generally called the Electro-weak Force. Since then, a great deal of effort has been devoted to trying to bring the Strong Nuclear Force into the same theoretical structure. There has been some success in this area and theories known as Grand Unified Field Theories (GUT for short) have emerged. It is clear that while these theories are incomplete they may form a basis for a beginning of understanding of the general unification of all the forces. You may have noticed that Gravity has been strangely missing from the above discussion. To understand why this is so, we must look at the other aspect of the very small - Quantum Mechanics.

Also, about the turn of the century it became clear that certain physical anomalies could be understood if one assumed that energy occurred in multiples of some minimum amount that Max Planck called the quantum. This led to the development of what we now call Quantum Mechanics. The application of Quantum Mechanics to Electromagnetism led to a theory with the imposing name of Quantum Electrodynamics or QED for short. QED has been called 'the greatest artistic creation of the 20th century' by Jacob Bronowski[6]. It is certainly the most successful theory ever devised by man, as it has been found to correctly describe phenomena on the scale of the very large to the very small. It was within the framework of QED that Weinburg and Salam brought about the unification of the weak force. Throughout the 20th century the position of Quantum Mechanics as a correct description of the Physical World has become more firmly entrenched. This, coupled with the strong belief that there should exist a fundamental theory which embraces all of the fundamental forces of nature, has led scientists to suspect that such a theory would be quantum mechanical in form[12]. However, all attempts to develop a Quantum Theory of Gravity have met with only marginal success[8]. Indeed, all attempts to handle Gravity in a unified way, both quantum mechanical and classical, have largely been unsuccessful. Einstein spent the last quarter century of his life searching for such a unification and his failure led many to despair of ever finding such a theory. While Einstein was searching for a classical four dimensional Unified Field Theory, others were considering higher dimensional spaces for such a theory. In most of these attempts the additional dimensions were simply mathematical artifacts not subject to any direct physical interpretation and were not particularly successful.

During the last several years a variety of different mathematical views have been employed toward the goal of unifying the four forces of nature. Underlying all of these approaches has been the notion of symmetry. Symmetry is a concept that most everyone has an intuitive feeling about. It is used as a criterion in evaluating the worth of a work of art of most any kind as well as the form of a physical theory. It appears to be a fundamental property of nature and is all around us. We see it in snowflakes and sunflowers, raindrops and rainbows, and most profoundly in the laws of the physical world themselves. It is the change in the symmetry of the laws, 'symmetry breaking', that forms the foundation for the unification of the electroweak forces. The role of symmetry in modern physics has inspired some to look at the symmetry properties of some of the multidimensional theories developed earlier in the century in hopes of finding a foundation for a quantum theory of gravity which could then be merged with some Grand Unified Field Theory, thus providing for the unification of the all the forces of nature.

About 1919 Theodor Franz Eduard Kaluza developed a theory requiring five dimensions in order to unify electromagnetism and General Relativity. His efforts were published two years later with Einstein's imprimatur. This basically classical theory was expressed in the language of Quantum Mechanics in 1926 by Osker Klein, and since then all such theories have been known as Kaluza-Klein type theories. Modern investigations[10] have shown that seven more 'hidden' dimensions would be required to incorporate the three other forces of nature (i.e. electromagnetism, and the weak and strong nuclear forces). Seven dimensions and the four dimensions of the Cosmlogical Universe would seem to require a theory of eleven dimensions for a unification of all the forces of nature. It is interesting that one can also show that spacetime theories of the form of General Relativity cannot be formulated in spaces with more than eleven dimensions, but this may be only an odd coincidence[10]. How is it that our universe could have such a multi-dimensional character and it escape our notice for so long? It has been suggested that just as the scale for the curvature of spacetime is very large due to the weakness of the gravitational force, so the scale of the curvature of the higher dimensions necessary for the unification of the remaining forces is very small. So small, in fact, that the presence of these dimensions is completely undetectable unless one can probe the domain of the electron itself or possibly even smaller. One can imagine the forces of nature other than gravity producing a curvature of these additional spatial dimensions so as to 'curl' them up on a scale that is beyond current measurement. Such a notion is not as absurd as it sounds. We have become more or less accustomed to imagining the space curvature associated with a black hole[14]. Such an object literally distorts the local geometry of spacetime so that it closes on itself. Perhaps a similar sort of situation exists on a tiny scale yielding multi-dimensional knots which we interpret as particles.

While multidimensional theories may eventually provide a foundation for the unification of all of the forces of nature, we must be very careful in their interpretation. While the four 'dimensions' of Cosmological Spacetime are not directly perceivable by us intrinsically three dimensional creatures, they are observable. That is, we can describe tests and measurements which allow us to unequivocal map out any region of spacetime in our universe. Like the 'Flatlanders',we can perform certain basically geometerical tests which will enable us to quantify the curvature we cannot directly 'see'. Can this be said of the Kaluza-Klein theories? Whether there is an answer to this question is unclear. However, it is clear that if the theory is to have any validity within the framework of the physical description of the real world, it must provide clear and unambiguous signals of the effects of these additional dimensions in the form of measurable phenomena. Einstein is credited with saying 'Experiment is the final arbiter of Theory'. This simple phrase embodies the essence of scientific philosophy. Experiment and observation provide a basis for deciding not only if a theory is wrong, but whether or not a theory matters at all. A mentor of mine, Carl G. Hemple, would repeatedly say that "a theory must make a difference to be a difference". If a theory makes no clear and measurable predications, then it is not worthy of the term theory.

Should the multidimensional theories provide the desired unification of the forces of nature and unique quantifiable tests, do we regard the additional dimensions as real? Reality is another one of those words that carries an intuitive meaning so powerful that it is difficult to question. But if we are to avoid the dragons of ignorance and prejudice, we must be willing to question all concepts which we are to use in understanding the world. However, in order to question the validity of a concept, we must be prepared to define the ground rules by which we will adjudge a concept as valid. Here, once again, Einstein's dictum that 'Experiment is the final arbiter of Theory' serves as a useful guide. We must be prepared to say exactly what we mean by 'reality'[7]. Einstein felt that the fundamental concepts of Physics such as particles and waves had a reality apart from their interaction with the rest of the physical world. It is likely that most scientists would agree with this point of view. However, it is difficult to reconcile this view with his dictum about theory and experiment. Experiments and observations represent the interaction of various abstract concepts with each other. It is only the events which represent these interactions which are observed; not the fields and particles. This may seem like a 'picky' point, but it is important for it serves to focus our attention on what is meant by 'reality'. The point generated a significant debate between Neils Bohr and Einstein in the thirties. In the last twenty years, the argument has re-surfaced in the form of something known as Bell's inequality or Bell's Equation[3]. Recently a series of elegant experiments have tested Bell's Inequality yielding some results that many find surprising. In order to understand some of the implications of Bell's Inequality, it is necessary for us to become very specific about what we mean by 'reality'.

Einstein's notion that the constituents of the Universe are endowed with properties whether or not these properties were measured seems both intuitively and historically reasonable. Denial of such an idea would seem to lead to the philosophical morass of the "if a tree falls where no one can hear it,does it make a sound?" variety. Any physical theory that requires that its constituents have intrinsic properties is known as a 'realistic theory' and virtually all physical descriptions of the macroscopic world are of this type. Such theories make definite predictions. That is , a physical system evolves from an initial state specified by the physical properties of the constituents of the system to a final state which is also determined by the constituent properties. The theory is a program for describing how the system gets from the initial to the final state.

Quantum Electrodynamics departs from this traditional deterministic form in a subtle way. Instead of specifying the final state as a result of initial conditions, QED gives the probability that measurements performed on the system in its final state will yield certain values. It is this aspect of Quantum Mechanics that Einstein was objecting to when he said "God does not play at dice with the Universe". In the famous 1935 paper with Podolsky and Rosen, Einstein showed that within the framework of Quantum Mechanics, a measurement at one point in spacetime could force the result of a different measurement made at another distant point in spacetime[9]. Since this appears to imply some sort of signal propagating from the first point to the second at a rate faster than the speed of light, they felt causality was violated and that therefore Quantum Mechanics was at best incomplete, if not wrong. Since then, the successes of Quantum Mechanics and its generalized cousin QED have proven so effective in describing the physical world, that the probabilistic nature of the theory is generally regarded as unassailable.

In 1964 John S. Bell developed a quantitative form of an experiment suggested by David Bohm[5] in 1951 and showed that 'realistic theories' will result in different predications than those of Quantum Mechanics regardless of the specific form of the 'realistic theory'. That is, the outcome of the experiment depends on the realistic aspect of the theory as opposed to the probabilistic nature of Quantum Mechanics. Here at last is a way to subject the arguments of Einstein, Podolsky and Rosen to test. In the last few years, a series of experiments by Alain Aspect[2] and collaborators in Paris have tested Bell's Inequality in a very thorough and careful manner. They found that the predictions of Quantum Mechanics have been sustained and that 'realistic theories' of the form envisioned by Einstein are not acceptable descriptions of the microscopic physical world.

While the interpretation of these experiments is still a matter of some debate, we can still ask where did Einstein, Podolsky, and Rosen go wrong? The arguments given by EPR are correct as far as they go. That is, the results of the measurement of a system property at one point in space time does appear to force the result of a measurement at another distant point in spacetime meaning that the order in which those measurements are done is not necessarily the same for all observers in the Universe. This would appear to violate the Principle of Causality. The problem seems to be with the notion of cause and effect. While it is true that different observers may see the measurements performed in a different sequence, the outcome of the observations will be the same for all observers. In addition, the probabilistic nature of Quantum Mechanics assures that the specific outcome of either measurement is not predictable ahead of time without knowledge of the result of the other. Thus no information can be transmitted between the two measurement sites. A random signal resulting from a series of successive measurements at one site will merely yield a random signal at the other site. No information can be transmitted by a random signal. It is the transmission of information that contains the essence of cause and effect in the Principle of Causality. Thus it would appear that while our notions of 'reality' may be challenged by Quantum Mechanics, the Principle of Causality survives the test of the French experiments.

How could we be so led astray by such an intuitively reasonable concept as 'reality'? Our experience does not really justify the notion of 'reality', it only seems to. All we sense in this world can be called measurements. What is 'real' to us are sensory impressions resulting from the interactions of components of the Physical Universe with our Physical Being. However, it would be a mistake to suggest that these are the only forms that interactions can take. Such a view could lead one to ask "Is the Moon really there when nobody looks?[13]". One may be confident in asserting that water flows over Niagara Falls, falling trees make sounds, and the Moon is really there whether or not man is present to verify the fact. The interactions that take place between constituents of the Physical World are legion. All these interactions are in a way measurements, myriads of which are directly accessible to observation. It is not the observation by humans which makes the interactions real.To assert otherwise would require one to claim that the sound made by a falling tree and recorded by a tape recorder only became real upon playing of the tape in the presence of a human audience. Such metaphysical nonsense may intrigue some, but in no way can we call such sophistry science. It is just the enormity of interactions among constituents of the Physical World that lend those constituents properties to which we tend to ascribe a reality independent of the interactions that betray their existence. Only in the realm of the very small does the probabilistic nature of the constituents of the physical world become apparent. It is here that we must abandon our macroscopic notion of reality. Once again we have been deceived by our intuition concerning the nature of the physical world.

We have seen that on both the scales of the very large and the very small it is easy to be led astray in our quest for a correct description of the physical world by the impressions of that world gained on a scale of our own existence. We must learn to be wary of those impressions. It is the very nature of the philosophy of science to teach us to be wary, and it is there we should look for guidelines for our quest. During the early part of this century, a group of philosophers known as the "Vienna Circle" developed a philosophical formalism known as Logical Positivism. While many aspects of Logical Positivism have either fallen into disrepute or been reduced to the level of cliche, many of the concepts are extremely useful in coming to grips with the physical world and the scientific disciplines used to describe it. The notion of 'operational definitions' wherein all terms used in science should have their foundation in a series of operational procedures that can be agreed upon, does more than remove confusion among scientists. It also eliminates terms which sound intuitively reasonable but which in reality are poorly understood or ambiguous. The idea that "A theory has to make a difference to be a difference" is central to the essence of science itself. The main objection to Logical Positivism is that it appears to be too conservative. There are those that feel that reducing science to the mere description of interactions in the Physical World removes some of the magic, some of the mystery, some of the fun and beauty from science as they know it. My response would be that the 'magic' and 'mysticism' in the metaphysical meaning of those words should go. However, to say that the logical formulation of a system whose sole goal is the description of the Physical World isn't fun and possesses great beauty is to miss one of the great reasons for being a scientist. Cries of the loss of beauty engendered by Logical Positivism are vaguely reminiscent of Goethe's complaint that science removed the beauty of a rainbow by explaining it. The beauty is in the eye of the beholder and any advanced level of understanding a phenomenon only adds to that beauty; it cannot diminish it.

The conservative nature of modern Logical Positivism only serves to complement the 'healthy skepticism' so necessary for the productive pursuit of science. We have seen that caution is necessary, for our senses may delude us. We require an austere philosophy of prediction and test coupled with an open mindedness to accept the results of careful experiment if we are to avoid the dragons beyond the edge of the Universe. The origin of those dragons which so terrified the crew of Columbus is with us today. They lie in wait for the unwary who prefer to be ruled by their intuition of the macroscopic world while touring the realm of the very large or very small. They are the dragons of prejudice, ignorance, superstition, and absolute certainty, and their enemies are curiosity, logic, and reason. To be involved in science is more than to quest for an objective description of the Physical World; it is to slay dragons.

Acknowledgements

The thoughts contained in this essay have been developing in my mind for many years and there are many colleagues who have contributed significantly to that development at various times. This is not to shift the blame for the contents of the work in any way, as I suspect that many of these thoughts would be rejected by many I call friend. Nevertheless, I must offer thanks to all those who have caused me to think from time to time on these ideas. The comments about Bell's Inequality were most strongly influenced by the excellent article by Mermin, while the article by d'Espagnat initially started me questioning the concept of reality. Specifically, I would like to thank Leon Palmer for providing me with such an elegant and fierce Dragon many years ago and Peter Stoycheff for his excellent rendering of my crude drawings. My deepest gratitude is extended to Carl Hemple for initiating me to the philosophy of science so many years ago.

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