Travellers...
GUIDE

ONE

TIME
TRAVELLING
16K21

Travellers... **GUIDE** ONE

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INDEX

INTRO-DUCTION

THE ROTATING CYLINDER MODEL IS BASED ON A CONCLUSION OF GENERAL RELATIVITY THAT SHOWS ROTATION OF MATTER CAUSES A DISTORTION IN SPACE-TIME. THIS DISTORTION CAN BECOME POWERFUL ENOUGH TO ACTUALLY TWIST TIME AROUND A ROTATING CYLINDER. WITH THE RIGHT AMOUNT OF MASS AND SPEED, A PATTERN OF WHAT ARE REFERRED TO AS "CLOSED TIME-LIKE CURVES" CAN BE CREATEDNAVIGATING THROUGH THIS PATTERN OF CLOSED TIME-LIKE CURVES WILL PERMIT TIME TRAVEL TO BOTH THE FUTURE AND THE PAST WITHOUT VIOLATING THE LAWS OF MATHEMATICS AND PHYSICS.

TO UNDERSTAND TIME CONTROL USING ROTATING CYLINDERS REQUIRES SOME UNDERSTANDING OF GENERAL RELATIVITY. AN OVERVIEW OF THE "GENERAL THEORY OF RELATIVITY" HAS BEEN INCLUDED AS A SEPARATE ARTICLE IN THIS ISSUE OF THE SPACE-TIME JOURNAL. IT ALSO REQUIRES A BASIC UNDERSTANDING OF SPACE-TIME PHYSICS, INCLUDING THE IDEAS OF SPACE-TIME DIAGRAMS, LIGHT-CONES AND CLOSED TIME-LIKE CURVES. FOLLOWING IS A BRIEF REVIEW OF THESE TOPICS.

REVERSING AT SUB TIME LIGHT SPEEDS

AN OVERVIEW OF CLOSED TIME-LIKE CURVES

An article by Dr. David Lewis Anderson

Originally Published in THE SPACETIME JOURNAL,
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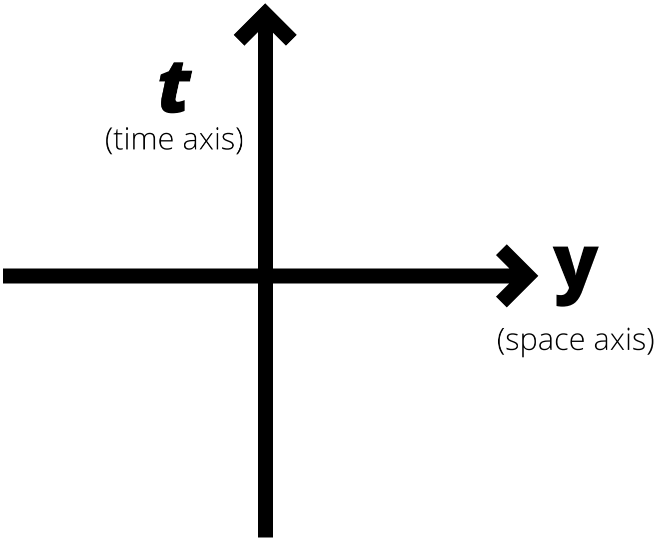
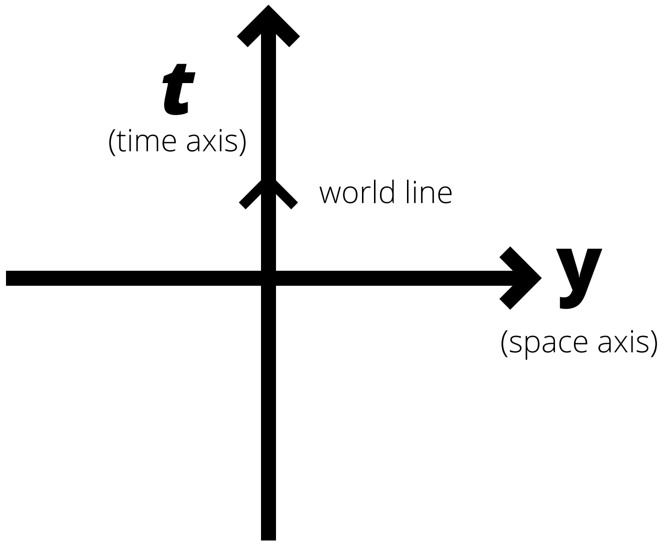
In this series of articles we will show a solution using a rotating cylinder model that demonstrates how time travel is possible within the context of general relativity. This solution clearly permits time travel and communication not only to the future, but also to the past. Most important, it will show how reverse time travel can be achieved without having to travel faster than the speed of light. The advanced computer simulations we have run at the Time Travel Research Center have confirmed this model as a valid approach for actual time travel to the past.

A COMMON TOOL WE USE TO DISCUSS SPACE-TIME IS THE SPACE-TIME DIAGRAM. THIS DIAGRAM PLOTS THE POSITION OF A PARTICLE AS IT MOVES THROUGH SPACE-TIME. BY CONNECTING ALL THE PLOTTED POSITIONS, A LINE CALLED THE "WORLD LINE" OF THE PARTICLE IS CREATED.



Simplified Space-Time Diagram
with One Space Dimension



Simplified Space-Time Diagram
for Particle at Rest

The illustration to the right shows a simplified space-time diagram with just one space axis (y) representing motion through one space dimension, and one time axis (t) representing motion through time.

Lets look at the example of a particle starting at rest on the origin of the y and t axes. If the particle does not move over time in the space dimension (y) it will not move off the time axis (t). So for a particle at rest in some observers' frame of reference, its space-time diagram for that observer is a vertical world line. This is illustrated in the space-time diagram to the right showing a particle at rest.

The path the particle follows, whether it moves in the space dimension (y), time dimension (t), or both represents what we call its world line. The world line represents the path the particle follows in space-time as a whole. If the particle moves in the space dimension (y), its world line tilts away from the vertical as is illustrated in the space-time diagram of a particle moving at constant speed shown to the left. Straight (un-curved) world lines like this represent un-accelerated particles (i.e.) particles experiencing no forces.

If a particle experiences acceleration, its world line will curve away from the vertical time axis. If the same particle experiences deceleration, its world line will curve back towards the vertical time axis. The resulting world line will be curved as is illustrated in the space-time diagram of an accelerating/decelerating particle on the left.

In order to make a space-diagram more meaningful in has become common practice to normalize the axis to a specific standard. Each unit on the time axis (t) is set to a second and each unit on the space axis (y) is set to one light-second. A light-second is the distance that light can travel in one second, which is 300,000 kilometers. This normalization of axes is illustrated to the left.

Since photons travel at the speed of light, this means that the world line of a photon is tilted away from the vertical time axis by and angle of 45 degrees, or 300,000 km/sec. If we accept a speed limit of the speed of light as is general believed, the area between the world lines of the photons represents the area where all possible world lines must be contained. The illustration to the left shows that the paths of all possible world lines will never tilt more than 45 degrees away from the vertical.

LIGHT CONES

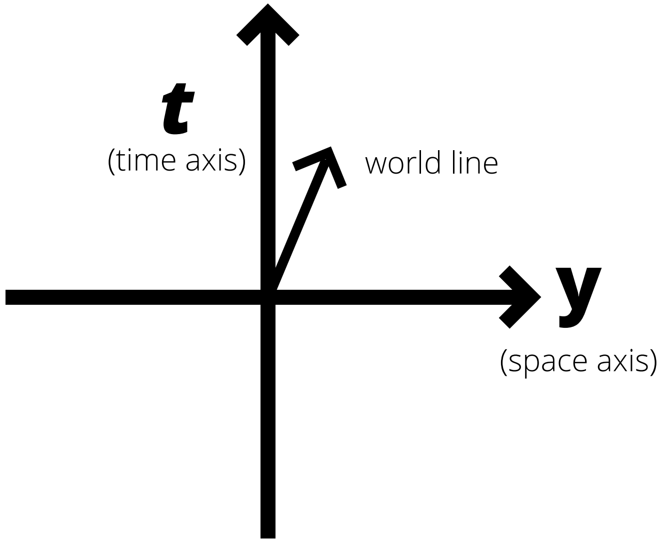
As we recall, a true space-time diagram would have the time dimension plus three space dimensions. But again, this can be extremely difficult to both draw and visualize. But by adding another dimension, our 45° area around the time axis wraps around the time axis and also upward and downward becoming a three dimensional "light cone." This light cone with two space dimensions is illustrated below.

LIGHT CONE WITH TWO SPACE DIMENSIONS

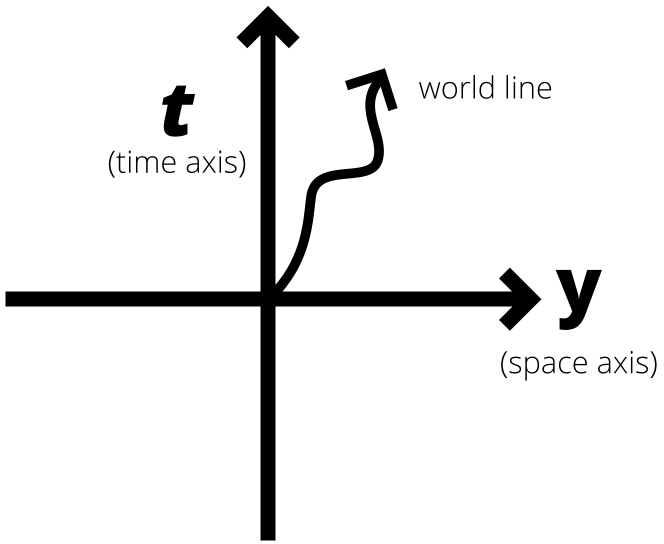
Lets call the point in space-time located at the origin of all three axes (x=0, y=0, and t=0) the Here-Now. Then all points in the upward region are located in the future of Here-Now. Also, all points in the downward region are located in the past of Here-Now. From Here-Now a particle can travel to any other point in the future light cone by traveling at a speed less than the speed of light. Also, any particle inside the past light cone can travel to Here-Now by traveling at less than the speed of light.

In this diagram the present is represented by the point where the two cones meet in the middle (i.e. here-now). Since we generally assume that we are restricted to at most the speed of light, the cone above here-now represents the only possiblecone above here-now represents the only possible "future".

The distance between any two space-time points on a world line on this space-time diagram is defined as:

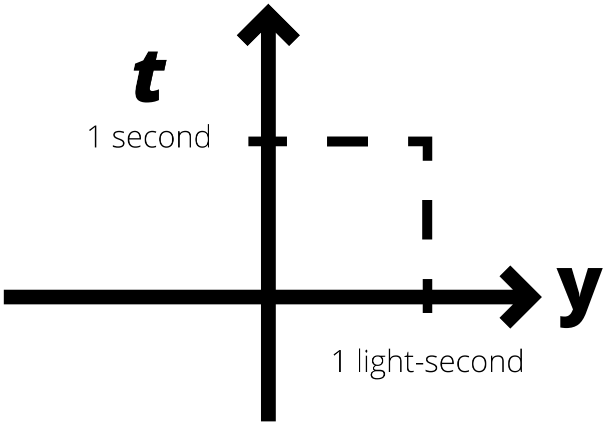


Simplified Space-Time Diagram for
Particle Moving at Constant Speed



Simplified Space-Time Diagram for
Accelerating/Decellerating Particle

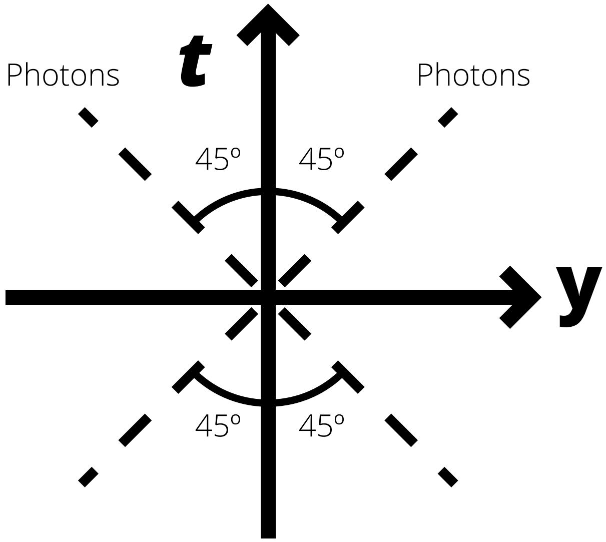
IN REALITY, A TRUE SPACE-TIME DIAGRAM WOULD HAVE FOUR DIMENSIONS INCLUDING THREE SPACE DIMENSIONS AND ONE TIME DIMENSION. THIS TYPE OF DIAGRAM IS VERY DIFFICULT TO ILLUSTRATE AND VISUALIZE. WHEREVER POSSIBLE WE USE A SIMPLER CONVENTION TO ILLUSTRATE CONCEPTS IN SPACE-TIME.



Simplified Space-Time Diagram for Accelerating/Decellerating Particle

Axis Scale Normalization

1 second (***t*** axis)= 1 light-second (**Y** axis)
1 second (***t*** axis)= 300,000 kilometers (**Y** axis)



Space-Time Diagram
showing Possible World Lines

SPACE-TIME INTERVALS

The future cone represents those areas where "ds" is positive and "t" is also positive. The past cone includes space-time points with "ds" positive and with "t" negative.

Those volumes outside the two cones represent what is sometimes called "Elsewhere," since they are events for which the metric "ds" is imaginary. For one event to influence another event, it is necessary that the event that is to provide the influence lie in the past cone of the event being influenced.

We typically refer to three different types of space-time intervals. These are commonly called time-like, space-like and light-like.

On our space-time diagrams a time-like displacement is one with an angle to the time axis of less than 45°. A time-like displacement represents an object traveling at a speed of less than the speed of light. Time-like intervals have positive ds values.

TYPES OF INTERVALS

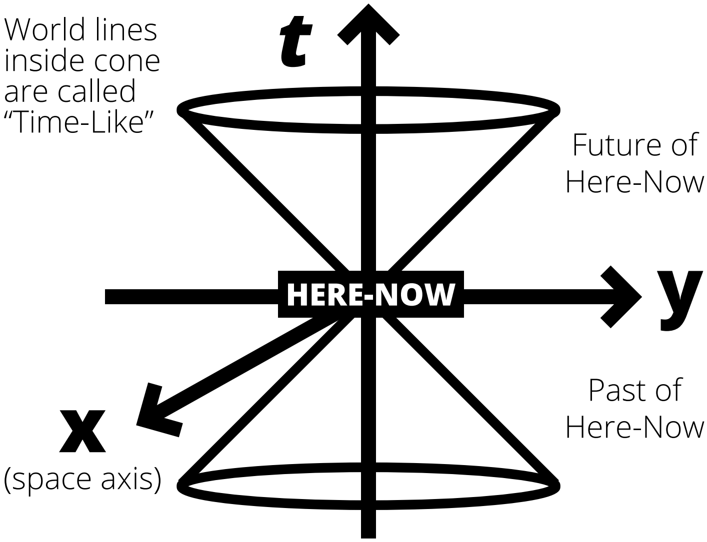
A light-like interval is one that makes an angle of 45° to the time axis. Light of course travels on light-like intervals.

The third possibility is a space-like interval, which represents a line that makes an angle of more than 45° to the time axis. Space-like intervals have negative ds values. Events joined by ke intervals have negative ds values a space-like interval can never influence each other, nterval is one that makes an angle of 45° to the time axis. Since that would imply a flow of information at speeds faster than the speed of light.

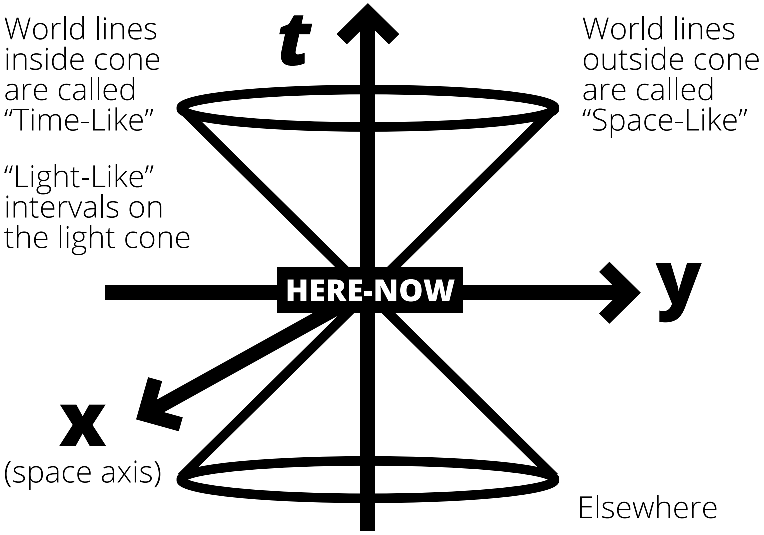
Its very important to note that every point in space-time has its own, and potentially differently-oriented light cone.

Space-time diagrams can also be used to represent world lines that travel into the past instead of the future. As shown in the illustration to the right a world line can loop back on itself. In this example the world line curves back and comes close to itself.

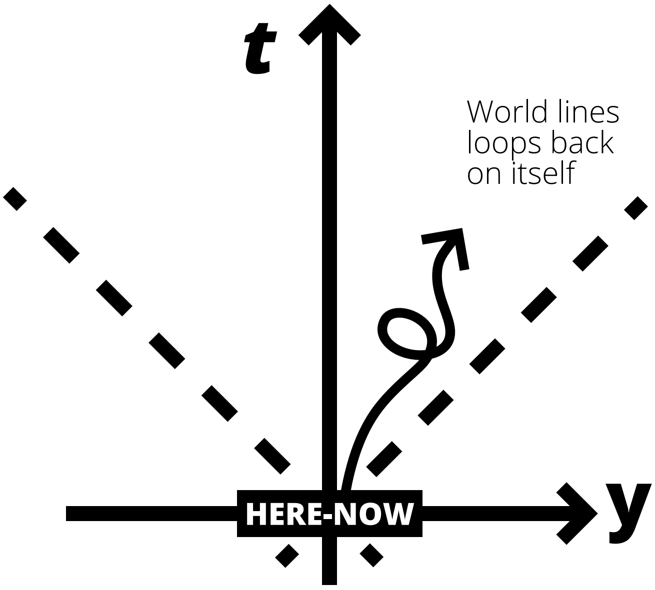
On a world line it is important to remember that the direction



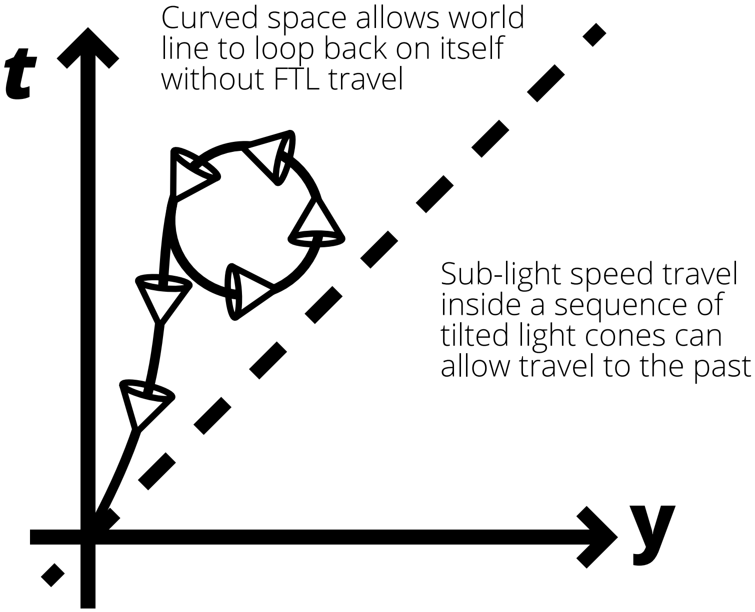
Light Cone With
Two Space Dimensions



Types of Space-Time Intervals



World Lines Moving to the Past



Tilted Light Cones in Curved Space Permits Reverse Time-Travel at Sub-light Speeds

WORLD LINES MOVING TO THE PAST

of the world line is in the direction of the local future of the particle. Events happen in a sequence and direction of the world line. If the particle is a living person then memories would also be formed in the direction of the world line.

A subtle implication of this "loop back" is that it is only possible by both moving through space and also exceeding the speed of light. As soon as the loop bends more than 45 degrees away from the time axis the particle must be traveling at a faster than light speed.

CLOSED TIME-LIKE CURVES

So how can reverse time travel be possible at sub-light speed? By understanding and using curved space-time. There are two important points here that we will use later to show how reverse time travel is indeed possible at sub-light speed.

First, general relativity shows that space-time can be curved by heavy gravity. Second, every point in space-time has its own light cone. In a curved space-time it is possible to "tilt" or "tip over" light cones. With a sufficient amount of space-time curvature a particle or person could continue to move into their own local future at sub-light speed but actually travel along a world line that loops back on itself as shown in the illustration.

This loop back is commonly referred to as a closed time-like curve, a concept introduced by Kurt Gödel in 1949.

This world line could carry the particle or person backwards into time without violating the laws of mathematics and physics... and without having to travel faster than light!

Lets now take detailed look at a rotating cylinder model that could create a curved space-time like this, permitting time travel to the future, the past, and back again.

THE ROTATING CYLINDER

In 1974 Frank Tipler published what appeared to be the construction details for a time machine. His paper even concluded with the quote, *In short, general relativity suggests that if we construct a sufficiently large rotating cylinder, we create a time machine.*

Tipler was continuing to build upon the study of rotating cylinders and the relation of general relativity that actually been around for decades. References can even be found for literature on rotating infinite cylinders dating back to 1932. However, Tipler was the first to publish his work in a respectable scientific journal and show a solution free of singularities and other problems associated with black hole models. Tipler was also the only scientist at the time to show a solution that violated causality.

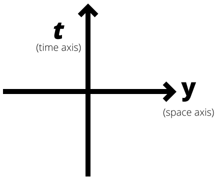
What does this rotating cylinder look like? Let's take a look. The one result from general relativity that we will be using is that the rotation of matter causes a distortion in space-time that results in the tipping over of light cones. The rotating, infinite cylinder is a method that can be used to artificially produce the tipped-over light cone effect creating closed time-like curves.

HOW DOES IT WORK

The best way to picture a rotating cylinder would be to take a piece of material ten times the mass of the Sun and compress it into a long, thin, super-dense cylinder. Then spin the cylinder up to a few billion revolutions per minute. The cylinder must rotate with a surface speed of at least half the speed of light. This is necessary to create centrifugal forces that will balance the gravitational attraction of the super-dense material used to construct the cylinder to prevent collapse or explosion.

By moving around the surface in a carefully plotted spiral course one could travel through time into the past. One could also make the return trip back to the original time of departure. The integrity of this model holds on paper and it

AN OVERVIEW OF CLOSED TIME-LIKE CURVES



Simplified Space-Time Diagram
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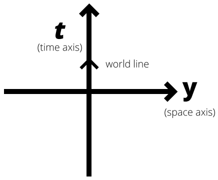

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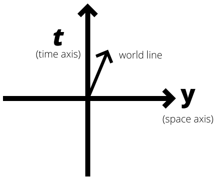

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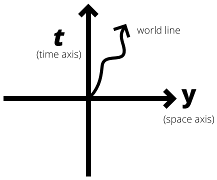

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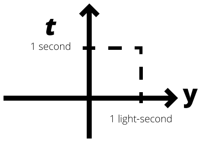

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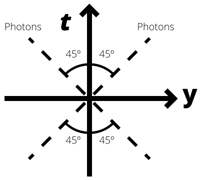

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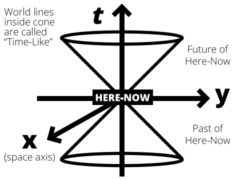

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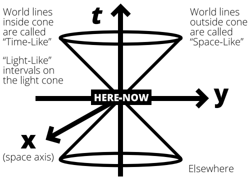

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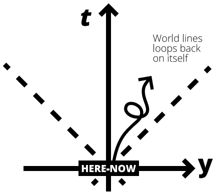

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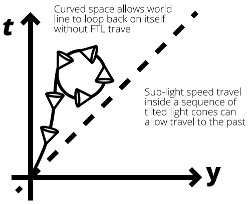
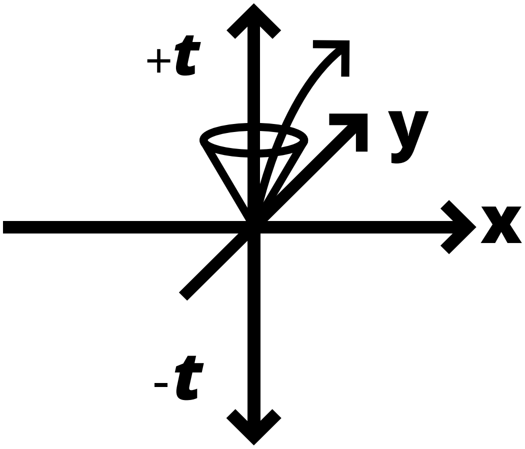


Tilted Light Cones in Curved Space
Permits Reverse Time-Travel at
Sub-light Speeds

REVERSING
TIME
AT SUB-LIGHT SPEEDS

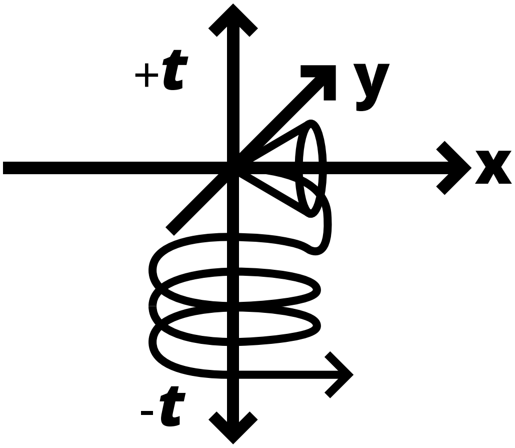
Far form the cylinder Space-Time is normal as illustrated by the “un-tipped” light cone to the right.

Sub-light speed can only result in travel in a positive time (+***t***) direction.



Near the cylinder the Space-time curvature is strong enough to tip light cones more than -15 degrees.

In this curved space a sub-light speed spiral path is possible allowing travel backwards into time.



CLOSED TIME-LIKE CURVE FORMATION USING A ROTATING CYLINDER

does not violate the laws of mathematics and physics.
General relativity shows how rapid rotation can actually twist space-time creating and allowing movement through closed time-like curves into the past. This is again accomplished at sub-light speed travelling through a series of tipped light cones in curved space. One method to artificially produce closed time-like curves is to use a rotating, super-dense cylinder.

We will use the diagram titled "Closed Time-like Curve Formation using a Rotating Cylinder Model" to illustrate how this works.

The rotating cylinder will spin along the vertical time axis shown in the illustration.

The gravitational effects on space-time curvature are weaker distant from the cylinder but grow stronger the nearer one approaches the cylinder.

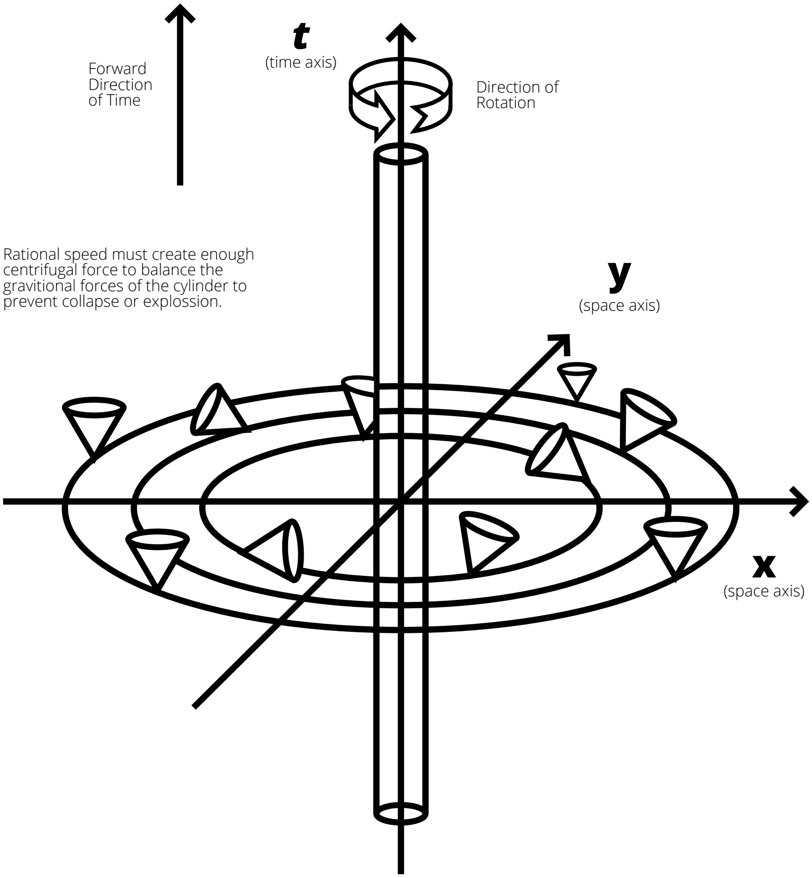
BACKWARDS IN TIME AT SUB-LIGHT SPEEDS

At a distance from the cylinder the resulting curvature of space-time is small and the light cones are upright pointing almost directly in the positive time (+t) direction. This is the typical orientation for any point a normal or flat space-time. The closer one approaches the rotating cylinder the stronger the space-time curvature which can be illustrated by the tipped over light cones. The effect of the rotating cylinder is to curve space-time, which can be illustrated by the light cones that tip further in the direction of rotation as we come closer to the cylinder.

The light cones closest to the cylinder are tipped more than 45

CLOSED TIME-LIKE

USING ӘИITATOЯ CYLINDER MODEL



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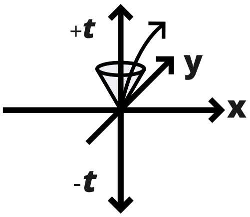

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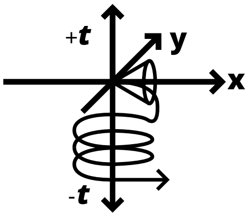


degrees. This is far enough that part of the inside of their cone actually is tipped through the x,y plane and into the negative time (-t) direction.

With part of our future light cone now tipped into the past we now are in a region where the roles of space and time interchange and time itself is twisted around the cylinder.

To travel back in time the time traveler would approach the cylinder and carefully navigate into a region of high space-time curvature. Following a helical path around the cylinder the time traveler would spiral down into the negative time (-t) direction. Notice that the time traveler's motion only needs to be a sub-light speed and stays completely within the local future of his light cone.

By navigating a course that always moving into his local future the time traveler can follow a path at sub-light speeds that will carry him backwards into time where he can steer away from the cylinder and then exit in his own distant past.

Time travel to the future, time travel to the past… even travel to the past and return to the future. This is all possible within the laws of mathematics and physics.

Within general relativity are secrets that will allow us to unlock the possibilities of interstellar travel and time travel.

- Explore how to navigate the Cylinder for forward and reverse time travel.
- Examine some detailed mathematical models of the rotating cylinder Model.
- Study some other interesting implications and uses of the rotating cylinder.

CRYSTAL TIME-TRAVEL

WHAT CRYSTALS ARE

Crystals are living entities and not objects. They exist in two states: closed (dormant) and open (active). They are commended open by the mind or a series of sound vibrations. They hold a lot of information about our own crystal line form (the human body). And this information leads to a better connection to the soul and the spirit.

There are two forms of crystals: organic (those we have available at this time) and genetic (those we will use in the future or those found in the time chamber of the AA site).

The organic crystals are programmed to lead toward understanding on how to create, grow or import genetic ones.

Crystals respond to mental command (telepathic communication) and also to sound vibrations, such as Tibetan bowls and other toning devises. They are very receptive to certain frequencies, more specially the frequency of love unconditional.

Genetic crystals are designed, grown or created for specific functions, such as: data processing, energy broadcast, energy fields, propulsion systems, healing, scanning and sensing devises…

Cooper is very conducive for such energy in its technological aspects. Such technologically engineered crystals were what was

THEIR IMPORTANCE AND HOW CAN BE USED

used once on Atlantis and we will at some point in time find again a way to use them, so that we may stop polluting the Earth and better the quality of life. We can access through them or tap into an unlimited and abundant source of intelligent energy (photon energy), which is already present, but not harvested.

- In order to be used properly, a crystal need to be encored into the Earth, so that it can draw energy from the Earth, open up and create generations of energies . Creating a vortex of energy such as this can then be used for a number of sacred activities such as space and time travel.

I was introduced to such technology by a friend and personal guide of mine from the planet Chiron. I was curious to interact with extraterrestrials and upon my request, he explained to me that I have many friends in other dimensions and it is easier for a human being to visit another civilized planet or dimension, then for extra terrestrial to visit us here, because human beings are not so receptive and most human are not very welcoming of them.

He further explained how to create such vehicle for inter dimensional travel. I have since performed almost 200 initiations and I am getting more and more comfortable in this process. Every human being as the right and ability to space travel, but the scientific community has not caught up with it yet. Albert Einstein was the first scientist I know who was doing that to gather information from the higher planes. he was a visionary person who expended our understanding of time, space, energy and matter.

"I felt that I was granted clearance and that my request was to be approved."

In order to space travel (or time travel for that matter), one does not need to create a very complex and sophisticate machine such as a spaceship, but one can create a vehicle out of its own energy. When we see an extraterrestrial spaceship up in the sky, most of the times it is not as physical as it appears to be. When a ship enters into the atmosphere and the stratosphere it takes on a physical manifestation, but most of them are made out of thought forms.

In order to create an inter dimensional vortex, and a thought form vehicle, the process goes as follow:

First, one needs to gather a group of people (five or more) who have

“The next thing I saw was the planet Saturn a few seconds later.”

a similar intentionality, to tele-transport into another dimension. It can be done alone, but it is never recommended. Those five people or more need to be very clear and intended on doing just that. they need to be clear and it is not recommended to use alcohol or drugs or even doing this after a big dinner. They need to find a place that is private, empowered and energized. Such can be done with the presence of a central crystal or in the absence of it the participant need to invoke and visualize a crystal in their mind's eye. The physical presence of the crystal makes it easier, but it is not fundamental. In the absence of such crystal, I have used my own energy to bring the group to the predetermined destination. When a large crystal is used, the crystal is programmed for a specific destination and screen the participants, so that, if one is not ready, the person as to leave the circle rather then potentially prevent the energy of the group from departing.

This was first introduced to me for scientific research, to go and gather information in other realm of existence or future times where advanced technologies are already in place and retrieve it to find practical applications here and now on Earth. But I found that the people I knew where more interested in tourism, so this creative vehicle took on a relaxed form rather then taking a clear scientific direction up until now may be.

The process is experienced on the visionary realms and it become more and more clear as we become more adept to it. We will later find out how to take our physical body (all the molecules that makes up our physical body) with us in this process, as the Wing-Makers did or will do it the creation of the time capsules.

So, the groups is gathered in a private location and ready to do that work. They decide that they may go to Pleiades or Chiron or the fifth density... and then they start on a visualization (with their eyes closed) where they begin to envision, to formulate a spaceship made up of their own energy which connects them. When all are in a semi trance state and feel the newly created ship enveloping them, the crystal is opened, the energy is released and the group depart their bodies.

A few minutes later they start to experience the vibration of the dimension they have reached. The first time they usually experience simple patterns, like geometric forms, deep feelings, or random visions. But as they become more experienced they can actually see the realms they have attained and interact mentally with guides and beings from those realms. When going with a specific task the time is utilized to achieve the goals of obtaining the information, but on a touristic voyage the information received is very personal to each participants. I sometime, undertook trips with a specific goal of researching a specific information and often getting there I was sent elsewhere in the universe where I could find what I was looking for.

After 30 to 45 minutes I usually brings the groups back to share the experiences they have received before returning on a second journey. The second time doing this is always more powerful for first timers. Most people on their first journey will be reluctant to come back to their bodies because they are always very comfortable in reaching the higher planes, so it usually takes a few more minutes for all to return, if they have not fallen into sleep.

This is different then astral travel in that we seek to reach a plane of reality higher then the forth dimension (which is still a level that is unresolved) and reach the fifth or above (where the knowledge is found and integrated). The energy of the group makes the visions a lot stronger and directed then someone doing this alone projecting into the astral planes.

Through this vehicle I have had a chance to visit many planets and dimensions. I have being invited to visit great ship made of light, met amazing beings and found additional meaning to my existence as a part of a greater , lager energy. I realized that I was to become an antenna to the spirit world and at some point to share those gift with all who are receptive to such potentials. To explore the universe would take a trillion lifetimes just to begin, so we take it one step at the time, one moment at the time and follow the guidance of our spirit and guides.

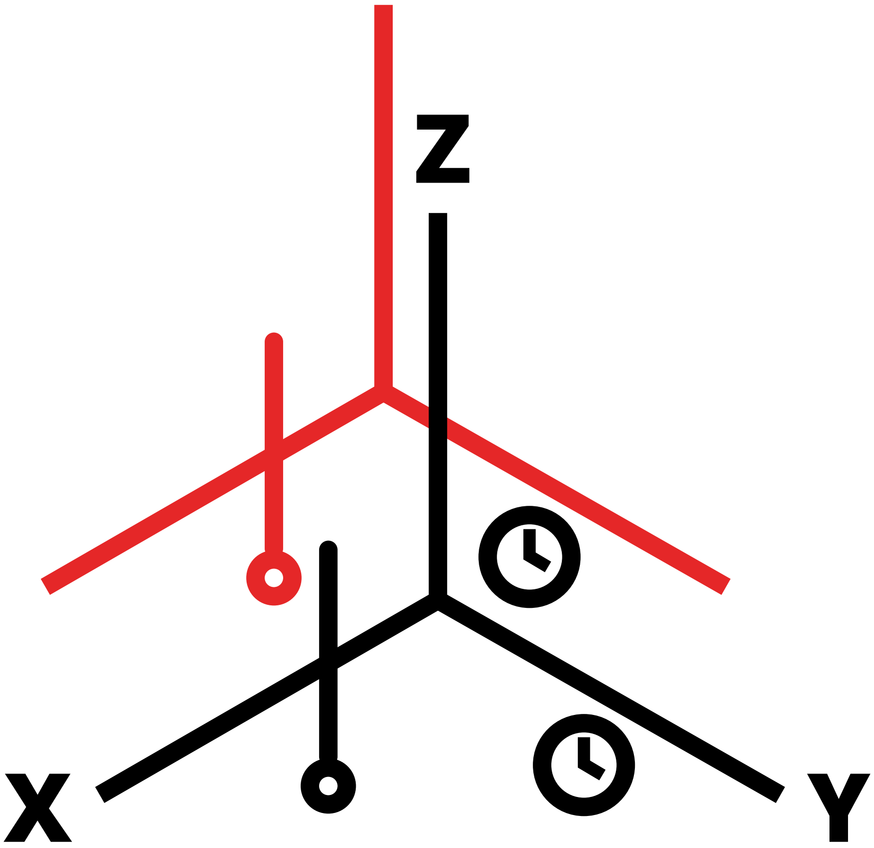
“I was sent elsewhere in the universe where I could find what I was looking for.”

LI OR
PRINCIPLE
SYMMETRICAL COMPREHENSIBLE FOUR-DIMENSIONAL SPACE-TIME

The space-time continuum of our universe that emerged at the end of the inflationary epoch had three spatial dimensions and one temporal dimension. The three spatial dimensions were to prove crucial for the development of life and Mind. Three dimensions are not inevitable; the string landscape of possible universes allows them to have up to nine spatial dimensions. Our space-time is also symmetrical with respect to translation and rotation in space, translation of time, and symmetrical with respect to all kinds of motion; all frames of reference in it are equally valid for physical measurements.

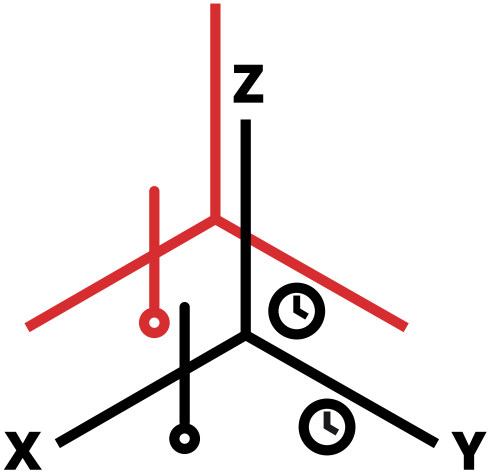
When Einstein published his General Relativity Principle in 1916,(8) he showed gravity to be a consequence of the symmetry of space-time. Einstein based his gravitational model on a generalized symmetry of space and time which states that all frames of reference for making physical measurements, whether accelerated or not, are equivalent; this symmetry in turn implied the existence of the gravitational force.(9) The generalized symmetry of Einstein's model included three specific and simple space-time symmetries.(10,11) The first of these was the continuous symmetry of translation of space; the space of our universe was the same no matter which way one moved in a straight line; any point in space was equivalent to any other point in space for physical measurement. The second was the continuous symmetry of our space under rotation; any circular motion in space also resulted in the physical equivalence of any point in space with any other. The third was the continuous symmetry of translation of time; any point in time was equivalent to any other point for physical measurement. These three symmetries, together with the symmetries of uniform and accelerated(12,13), are crucial to epistemology and Mind. They allow Mind to reliably measure the characteristics of our universe, regardless of their location in space and time. If these symmetries did not exist, we would have to re-verify the models of physics at every point in space and time to establish their generality; this would be an impossible task.(14,15)

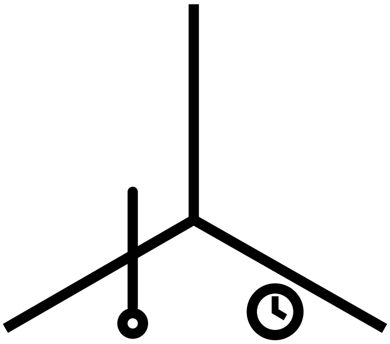
In 1918, the German-American mathematician Emmy Noether, stimulated by her role in checking the mathematical formulation of Einstein's gravitational model, published another general model of the physics of our universe.(16,17,18,19) Her model showed that, for every continuous symmetry in the models of physics, there must exist a conservation principle, and conversely for every conservation principle, there must exist a continuous symmetry. Using her model, Noether showed that each of the three continuous space-time symmetries of Einstein's model implied a conservation principle of physics. The symmetry of spatial translation implied the conservation of linear momentum(20) which is critical in the expulsion of heavy elements during a supernova explosion. The symmetry of spatial rotation implied the conservation of angular momentum,(21) which maintains planetary orbits and the rotation of galaxies. And the symmetry of translation of time implied conservation of energy(22) by which stars lose mass as they radiate energy, according to Einstein's model, and eventually it causes a few to explode as supernovas, expelling the elements needed to make planets, life and Mind. These conservation principles were all previously developed independently of these space-time symmetries. It was Noether's model showed the deep connections between them; the previous experimental confirmation of the conservation principles in turn confirmed



SYMMETRY OF SPATIAL TRANSLATION
Moving a thermometer in a straight line in any direction has no effect on it’s meassurements’ validity.

SYMM





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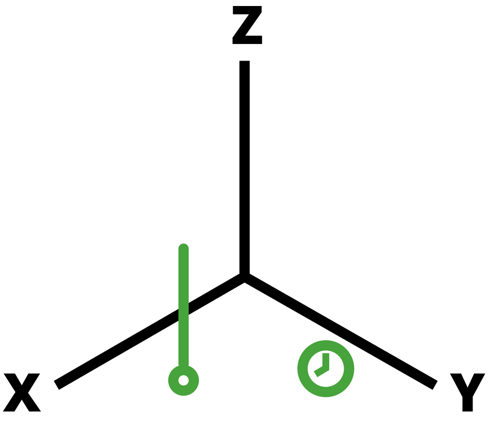
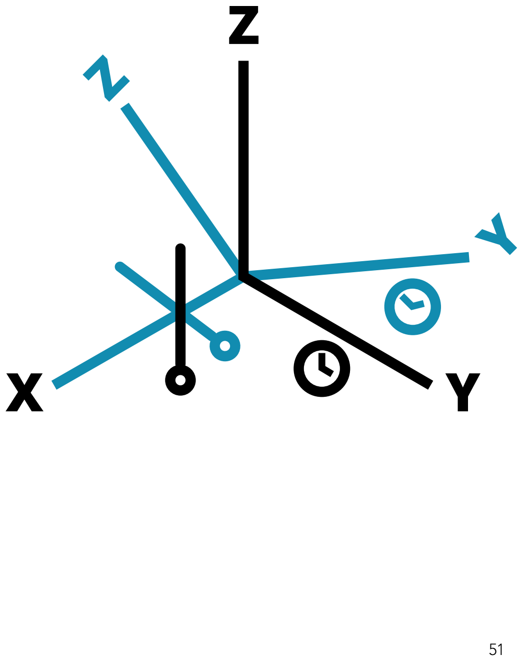
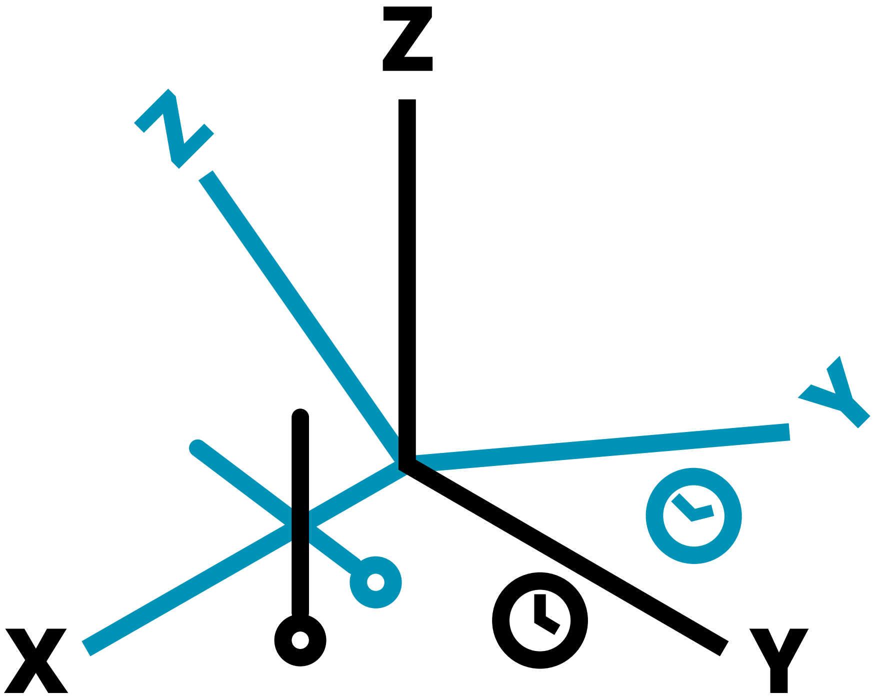






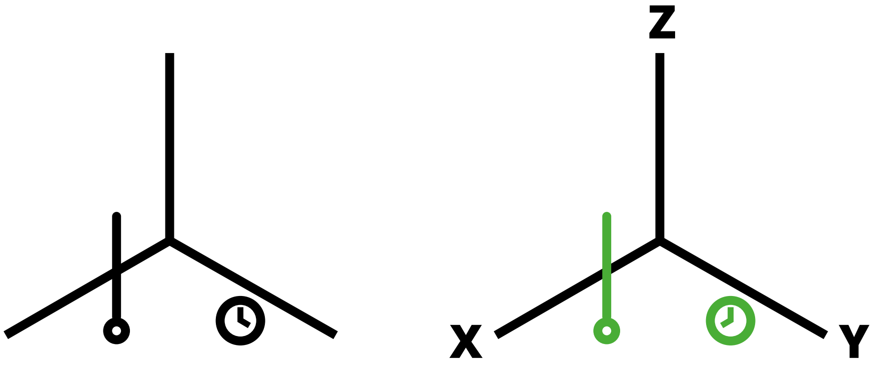
SYMMETRY OF SPATIAL ROTATION
Rotating a thermometer to any angle has no effects on it's meassurements' validity.

THEIR IMPORTANCE, AND HOW CAN THEY BE USED

the validity of the three symmetries.
Marcus Vitruvius Pollio, the Roman architect of the 1st Century BC told us that the reflective symmetry of classical temples was symbolic of the bilateral symmetry of the external parts of the human body;(25) we call this somatic symmetry.
In traditional Chinese architecture, the axis of symmetry defined and celebrated the pathway or route of visitors or officials along which they approached the central architectural event of a building or building complex, such as a religious image, the office of a provincial governor or the imperial throne;(26) we call this ceremonial symmetry.
In our Casina, the enclosing exterior elements and many of the interior elements are symmetrical about the north-south axial plane. We intended this simple reflective symmetry to symbolize and celebrate the profound space-time symmetries that allow Mind to obtain its knowledge of our universe; we call this epistemic symmetry.

EPISTEMIC SYMMETRY

Epistemic Symmetry. This orthographic drawing shows the South Elevation (top) and the North Elevation (bottom) of the Casina. They show the reflective symmetry of the external building elements about the Casina's north-south axial plane (red line). This simple symmetry symbolizes and celebrates three of the epistemic symmetries of our space-time; the symmetry of spatial translation, symmetry of time translation and symmetry of spatial rotation. It is through these crucial symmetries that Mind is able to measure and model our universe.



SYMMETRY OF TIME TRANSLATION
A thermometer’s meassurements made at different points in time are equally valid.

THE ORIGIN OF MASS

WHAT'S THE ORIGIN OF MASS?

Nobel Lecture, December 8, 2004
by Frank A. Wilczek
Massachusetts Institute of Technology
(MIT), Cambridge, USA.

EVERYDAY WORK AT THE FRONTIERS OF MODERN PHYSICS USUALLY INVOLVES COMPLEX CONCEPTS AND EXTREME CONDITIONS. WE SPEAK OF QUANTUM FIELDS, ENTAN.GLEMENT, OR SUPERSYMMETRY, AND ANALYZE THE RIDICULOUSLY SMALL OR CONCEPTUALIZE THE INCOMPREHENSIBLY LARGE. JUST AS WILLIE SUTTON FAMOUSLY EXPLAINED THAT HE ROBBED BANKS BECAUSE “THAT’S WHERE THE MONEY IS,” SO WE DO THESE THINGS BECAUSE “THAT’S WHERE THE UNKNOWN IS.” IT IS AN AMAZING AND DELIGHTFUL FACT, HOWEVER, THAT OCCASIONALLY THIS SOPHISTICATED WORK GIVES ANSWERS TO CHILD. LIKE QUESTIONS ABOUT FAMILIAR THINGS. HERE I’D LIKE TO DESCRIBE HOW MY OWN WORK ON SUBNUCLEAR FORCES, THE WORLD OF QUARKS AND GLUONS, CASTS BRILLIANT NEW LIGHT ON ONE SUCH CHILD-LIKE QUESTION: WHAT IS THE ORIGIN OF MASS?

When Einstein published his General Relativity Principle in 1916,(8) he showed gravity to be a consequence of the symmetry of space-time. Einstein based his gravitational model on a generalized symmetry of space and time which states that all frames of reference for making physical measurements, whether accelerated or not, are equivalent; this symmetry in turn implied the existence of the gravitational force.(9) The generalized symmetry of Einstein's model included three specific and simple space-time symmetries.(10,11) The first of these was the continuous symmetry of translation of space; the space of our universe was the same no matter which way one moved in a straight line; any point in space was equivalent.

HAS MASS AN ORIGIN?

That a question makes grammatical sense does not guarantee that it is answerable, or even coherent. The concept of mass is one of the first things we discuss in my freshman mechanics class. Classical mechanics is, literally, unthink-able without it. Newton’s second law of motion says that the acceler-ation of a body is given by dividing the force acting upon it by its mass. So a body without mass wouldn’t know how to move, because you’d be divid-ing by zero. Also, in Newton’s law of gravity, the mass of an object governs the strength of the force it exerts. One cannot build up an object that gravitates, out of material that does not, so you can’t get rid of mass without getting rid of gravity. Finally, the most basic feature of mass in classical mechanics is that it is conserved. For example, when you bring together two bodies, the total mass is just the sum of the individual masses.

This assumption is so deeply ingrained that it was not even explicitly formulated as a law. (Though I teach it as Newton’s Zeroth Law.) Altogether, in the Newtonian framework it is difficult to imagine what would constitute an “origin of mass,’’ or even what this phrase could possibly mean. In that framework mass just is what it is — a primary concept.

Later developments in physics make the concept of mass seem less irreducible. Einstein’s famous equation E=mc2 of special relativity theory, written in that way, betrays the prejudice that we should express energy in terms of mass. But we can write the same equation in the alternative form m=E /c2. When expressed in this form, it suggests the possibility of explaining mass in terms of energy. Einstein was aware of this possibility from the beginning. Indeed, his original 1905 paper is entitled, “Does the Inertia of a

Body Depend on Its Energy Content?" and it derives m=E /c2 , not E= mc 2 . Einstein was thinking about fundamental physics, not bombs.

WHAT MATTERS FOR MATTER

Having convinced ourselves that the question of the origin of mass might make sense, let us now come to grips with it, in the very concrete form that it takes for ordinary matter.

Ordinary matter is made from atoms. The mass of atoms is overwhelmingly concentrated in their nuclei. The surrounding electrons are of course crucial for discussing how atoms interact with each other — and thus for chemistry, biology, and electronics. But they provide less than a part in a thousand of the mass! Nuclei, which provide the lion's share of mass, are assembled from protons and neutrons. All this is a familiar, well-established story, dating back seventy years or more.

Newer and perhaps less familiar, but by now no less well-established, is the next step: protons and neutrons are made from quarks and gluons. So most of the mass of matter can be traced, ultimately, back to quarks and gluons.

QCD: WHAT IT IS

The theory of quarks and gluons is called quantum chromodynamics, or QCD. QCD is a generalization of quantum electrodynamics (QED). For a nice description of quantum electrodynamics, written by an MIT grad who made good, I highly recommend QED: The Strange Theory of Electrons and Light, by Richard Feynman. The basic concept of QED is the response of photons to electric charge. Figure 1a shows a space-time picture of this core process. Figure 1b shows how it can be used to describe the effect of one electric charge on another, through exchange of a "virtual" photon. [A virtual photon is simply one that gets emitted and absorbed without ever having a significant life of its own. So it is not a particle you can observe directly, but it can have effects on things you do observe.] In other words, Figure 1b describes electric and magnetic forces! Pictures like these, called Feynman diagrams, may look like childish scribbles, but their naïve appearance is misleading. Feynman diagrams are associated with definite mathematical rules that specify how likely it is for the process they depict to occur. The rules for complicated processes, perhaps involving many real and virtual charged particles and many real and virtual photons, are built up in a completely specific and definite way from the core process. It is like making constructions with TinkerToys®. The particles are different kind of sticks you can use, and the core process provides the hubs that join them. Given these elements, the rules for construction are completely determined. In this way all the content of Maxwell's equations for radio waves and light, Schrödinger's equation for atoms and chemistry, and Dirac's more refined version including spin—all this, and more, is faithfully encoded in the squiggle [Figure 1a].

"It's sucha a mess that physicists have pretty much given up on trying to describe all the possibilities and their probabilitites in detail."

At this most primitive level QCD is a lot like QED, but bigger. The diagrams look similar, and the rules for evaluating them are similar, but there are more kinds of sticks and hubs. More precisely, while there is just one kind of charge in QED—namely, electric charge —QCD has three different kinds of charge. They are called colors, for no good reason. We could label them red, white, and blue; or alternatively, if we want to make drawing easier, and to avoid the colors of the French flag, we can use red, green, and blue. Every quark has one unit of one of the color charges. In addition, quarks come in different "flavors." The only ones that play a role in ordinary matter are two flavors called u and d, for up and down. [Of course, quark "flavors" have nothing to do with how anything tastes. And, these names for u and d don't imply that there's any real connection between flavors and directions. Don't blame me; when I get the chance, I give particles dignified scientific-sounding names like axion and anyon.] There are u quarks with a unit of red charge, d quarks with a unit of green charge, and so forth, for six different possibilities altogether.

And instead of one photon that responds to electric charge, QCD has eight color gluons that can either respond to different color charges or change one into another.

So there is quite a large variety of sticks, and there are also many different kinds of hubs that connect them. It seems like things could get terribly complicated and messy. And so they would, were it not for the overwhelming symmetry of the theory. If you interchange red with blue everywhere, for example, you must still get the same rules. The more complete symmetry allows you to mix the colors continu.ously, forming blends, and the rules must come out the same for blends as for pure colors. I won't be able to do justice to the mathematics here, of course. But the final result is noteworthy, and easy to convey: there is one and only one way to assign rules to all the possible hubs so that the theory comes out fully symmetric. Intri.cate it may be, but messy it is not!

With these understandings, QCD is faithfully encoded in squiggles like Figure 1c, and the force between quarks emerges from squiggles like Figure 1d. We have definite rules to predict how quarks and gluons behave and interact. The calcu.lations involved in describing specific processes, like the organization of quarks and gluons into protons, can be very difficult to carry through, but there is no ambiguity about the outcome. The theory is either right or wrong —there's nowhere to hide.

HOW WE KNOW IT'S RIGHT

Experiment is the ultimate arbiter of scientific truth. There are many experi.ments that test the basic principles of QCD. Most of them require rather sophis.ticated analysis, basically because we don't get to see the underlying simple stuff, the individual quarks and gluons, directly. But there is one kind of experiment that comes very close to doing this, and that is what I'd like to explain to you now.

I'll be discussing what was observed at LEP. But before entering into details, I'd like to review a fundamental point about quantum mechanics, which is neces.sary background for making any sense at all of what happens. According to the principles of quantum mechanics, the result of an individual collision is unpredictable. We can, and do, control the energies and spins of the electrons and positrons precisely, so that precisely the same kind of collision occurs repeatedly; nevertheless, different results emerge. By making many repetitions, we can deter.mine the probabilities for different outcomes. These probabilities encode basic information about the underlying fundamental interactions; according to quantum mechanics, they contain all the meaningful information. When we examine the results of collisions at LEP, we find there are two broad classes of outcomes. Each happens about half the time. In one class, the final state consists of a particle and its antiparticle moving rapidly in opposite directions. These could be an electron and an antielectron (e.e+), a muon and an antimuon (. +), or a tau and an antitau (. +). The little superscripts denote signs of their electric charges, which are all of the same absolute magnitude. These particles, collectively called leptons, are all closely similar in their properties.

“But simply having a computer spit out the answer, after gigantic and totally opaque calculations, does not satisfy our hunger for understanding.”

Leptons do not carry color charges, so their main interactions are with photons, and thus their behavior should be governed by the rules of QED. This is reflected, first of all, in the simplicity of their final states. Once produced, any of these particles could — in the language of Feynman diagrams — attach a photon using a QED hub, or alternatively, in physical terms, radiate a photon. The basic coupling of photons to a unit charge is fairly weak, however. Therefore each attachment is predicted to decrease the probability of the process being described, and so the most usual case is no attachment. In fact, the final state e.e+ , including a photon, does occur, with about 1% of the rate of simply e.e+ (and similarly for the other leptons). By studying the details of these 3-particle events, such as the probability for the photon to be emit.ted in different directions (the “antenna pattern”) and with different energy, we can check all aspects of our hypothesis for the underlying hub. This provides a wonder.fully direct and incisive way to check the soundness of the basic conceptual build.ing block from which we construct QED. We can then go on to address the extremely rare cases (.01%) where two photons get radiated, and so forth. For future reference, let’s call this first class of outcomes “QED events.”
The other broad class of outcomes contains an entirely different class of parti.cles, and is in many ways far more complicated.
In these events the final state typi.cally contains ten or more particles, selected from a menu of pions, rho mesons, protons and antiprotons, and many more. These are all particles that in other circumstances interact strongly with one another, and “It’s such a mess that they are all constructed from quarks and gluons. Here, they make a smorgasbord of Greek and Latin alphabet soup. It’s such a mess physicists have pretty much that physicists have pretty much given up on trying to describe all the possibilities and their

probabilities in detail.given up on trying to describe Fortunately, however, some simple patterns emerge if we change our focus from the individual particles to the overall flow of energy all the possibilities and their and momentum. Most of the time — in about 90% of the cases — the particles emerge probabilities in detail." all moving in either one of two possible directions, opposite to one another. We say there are back-to-back jets. (Here, for once, the scien.tific jargon is both vivid and appropriate.) About 9% of the time, we find flows in three directions; about .9% of the time, four directions; and by then we're left with a very small remainder of complicated events that are hard to analyze this way.

I'll call the second broad class of outcomes "QCD events." Representative 2-jet and 3-jet QCD events, as they are actually observed, are displayed in Figure 2.

Now if you squint a little, you will find that the QED events and the QCD events begin to look quite similar. Indeed, the pattern of energy flow is qualitatively the same in both cases, that is, heavily concentrated in a few narrow jets. There are two main differences. One, relatively trivial, is that multiple jets are more common in QCD than in QED. The other is much more profound. It is that, of course, in the QED events the jets are just single particles, while in the QCD events the jets are sprays of several particles.

In 1973, while I was a graduate student working with David Gross at Prince.ton, I discovered the explanation of these phenomena. We took the attitude that the deep similarities between the observed basic behaviors of leptons (based on QED) and the strongly interacting particles might indicate that the strongly interacting particles are also ultimately described by a simple, rule-based theory, with sticks and hubs. In other words, we squinted.

To bring our simplified picture of the QCD events into harmony with the observations, we relied on a theoretical discovery I'll describe momentarily, which we christened asymptotic freedom. (Please notice that our term is not "cute.") Actually, our discovery of asymptotic freedom preceded these specific experiments, so we were able to predict the results of these experiments before they were performed. As a historical matter, we discovered QCD and asymptotic freedom by trying to come to terms with the MIT-SLAC "scaling" experiments done at the Stanford Linear Collider in the late 1960s, for which Jerome Friedman, Henry Kendall, and Richard Taylor won the Nobel Prize in 1990. Since our analysis of the

“The wave patterns that describe protons, netrons, and their relatives resemble the vibration patterns of musical instruments.”

scaling experiments using QCD was (necessarily) more complicated and indirect, I’ve chosen to focus here on the later, but simpler to understand, experiments involving jets. The basic concept of asymptotic freedom is that the probability for a fast moving quark or gluon to radiate away some of its energy in the form of other quarks and gluons depends on whether this radiation is “hard” or “soft”. Hard radiation is radiation that involves a substantial deflection of the particle doing the radiating, while soft radiation is radiation that does not cause such a deflection. Thus hard radiation changes the flow of energy and momentum, while soft radiation merely distributes it among additional particles, all moving together. Asymptotic freedom says that hard radiation is rare, but soft radiation is common.

This distinction explains why on the one hand there are jets, and on the other hand why the jets are not single particles. A QCD event begins as the materialization of quark and antiquark, similar to how a QED event begins as the materialization of lepton-antilepton. They usually give us two jets, aligned along the original directions of the quark and antiquark, because only hard radiation can change the overall flow of energy and momentum significantly, and asymptotic freedom tells us hard radiation is rare. When a hard radiation does occur, we have an extra jet! But tions. These are what we observe as the energy levels of the atom. When I give the talk on which this article is based, at this point I use Dean Dauger’s marvelous “Atom in a Box” program to show the lovely, almost sensuous patterns.

Musical analogies go back to the prehistory of science. Pythagoras, partly inspired by his discovery that harmonious notes are sounded by strings whose lengths are in simple numerical ratios, proposed that “All things are Number.” Kepler spoke of the music of the spheres, and his longing to find their hidden harmonies sustained him through years of tedious calculations and failed guesses before he identified the true patterns of planetary motions.

Einstein, when he learned of Bohr’s atomic model, called it “the highest form of musicality in the sphere of thought.” Yet Bohr’s model, wonderful as it is, appears to us now as a very watered-down version of the true wave-mechanical atom; and the wave-mechanical proton is more intricate and symmetric by far!

I hope that some artist/nerd will rise to the challenge, and construct a “Proton in a Box” for us to play with and admire.

“Eliminating mass enables us to bring more symmetry into the mathemathical description of Nature.”

The World as Concept, Algorithm, and Number. I will conclude with a few words concerning the broader significance of these developments for our picture of the world.

A major goal of theoretical physics is to describe the world with the greatest possible economy of concepts. For that reason alone, it is an important result that we can largely eliminate mass as an independent property that we are forced to introduce in order to describe matter accurately. But there is more. The equations that describe the behavior of elemen-“Eliminating mass enables us tary particles become fundamentally simpler and more symmetric when the mass of the particles is zero. So elim-to bring more symmetry into inating mass enables us to bring more symmetry into the math. ematical description of Nature. the mathematical description

The understanding of the origin of mass that I’ve sketched for you here is the most perfect realization we have of of Nature.”Pythagoras’ inspiring vision that the world can be built up from concepts, algorithms, and numbers. Mass, a seemingly irreducible property of matter, and a byword for its resistance to change and sluggishness, turns out to reflect a harmonious interplay of symmetry, uncertainty, and energy. Using these concepts, and the algorithms they suggest, pure computation outputs the numer.ical values of the masses of particles we observe.

Still, as I’ve already mentioned, our understanding of the origin of mass is by no means complete. We have achieved a beautiful and profound understanding of the origin of most of the mass of ordinary matter, but not of all of it. The value of the electron mass, in particular, remains deeply mysterious even in our most advanced speculations about unification and string theory. And ordinary matter, we have recently learned, supplies only a small fraction of mass in the Universe as a whole. More beautiful and profound revelations surely await discovery. We continue to search for concepts and theories that will allow us to understand the origin of mass in all its forms, by unveiling more of Nature’s hidden symmetries.

Frank wilczek is considered one of the world’s most eminent theoretical physicists. He is known, among other things, for the discovery of asymptotic freedom, the development of quantum *chromodynamics, the invention of axions, and the discovery and exploitation of new forms of quantum statistics (anyons). When only 21 years old and a graduate student at Princeton University, in work with David Gross he defined the properties of color gluons, which hold atomic nuclei together. Presently his main obsessions are exotic superfluidities on the one hand and dark energy on the other. He suspects the two are connected.*

Professor Wilczek received his B.S. degree from the University of Chicago and his Ph.D. from Princeton University. He taught at Princeton from 1974 to 1981. During the period 1981 to 1988, he was the Chancellor Robert Huttenback Professor of Physics at the University of California at Santa Barbara, and the first permanent member of the National Science Foundation's Institute for Theoretical Physics. In the fall of 2000, he moved from the Institute for Advanced Study, where he was the J.R. Oppenheimer Professor, to the Massachusetts Institute of Technology, where he is the Herman Feshbach Professor of Physics. He has been a Sloan Foundation Fellow (1975 – 77) and a MacArthur Foundation Fellow (1982 – 87). He has received UNESCO's Dirac Medal, the American Physical Society's Sakurai Prize, the Michelson Prize from Case Western University, and the Lorentz Medal of the Netherlands Academy for his contributions to the development of theoretical physics, and the Lilienfeld Prize for his writing.

He is a member of the National Academy of Sciences, the Netherlands Academy of Sciences, and the American Academy of Arts and Sciences. He is a Trustee of the University of Chicago, and an official advisor to CERN and to Daedalus. He contributes regularly to Physics Today and to Nature, explaining topics at the frontiers of physics to wider scientific audiences.

ASYMPTOTIC FREEDOM

FROM PARADOX TO PARADIGM

Nobel Lecture, December 8, 2004

by Frank A. Wilczek
Massachusetts Institute of Technology
(MIT), Cambridge, USA.

1 A PAIR OF PARADOXES

In theoretical physics, paradoxes are good. That's paradoxical, since a paradox appears to be a contradiction, and contradictions imply serious error. But Nature cannot realize contradictions. When our physical theories lead to paradox we must find a way out. Paradoxes focus our attention, and we think harder.

When David Gross and I began the work that led to this Nobel Prize [1, 2, 3, 4], in 1972, we were driven by paradoxes. In resolving the paradoxes we were led to discover a new dynamical principle, asymptotic freedom. This principle in turn has led to an expanded conception of fundamental particles, a new understanding of how matter gets its mass, a new and much clearer picture of the early universe, and new ideas about the unity of Nature's forces. Today I'd like to share with you the story of these ideas.

1.1 **PARADOX 1:** QUARKS ARE BORN FREE, BUT EVER YWHERE THEY ARE IN CHAINS

The first paradox was phenomenological. Near the beginning of the twentieth century, after pioneering experiments by Rutherford, Geiger and Marsden, physicists discovered that most of the mass and all of the positive charge inside an atom is concentrated in a tiny central nucleus. In 1932, Chadwick discovered neutrons, which together with protons could be considered as the ingredients out of which atomic nuclei could be constructed. But the known forces, gravity and electromagnetism, were insufficient to bind protons and neutrons tightly together into objects as small as the observed nuclei. Physicists were confronted with a new force, the most powerful in Nature. It became a major challenge in fundamental physics, to understand this new force.

For many years physicists gathered data to address that challenge, basically by bashing protons and neutrons together and studying what came out. The results that emerged from these studies, however, were complicated and hard to interpret.

What you would expect, if the particles were really fundamental (indestructible), would be the same particles you started with, coming out with just their trajectories changed. Instead, the outcome of the collisions was often many particles. The final state might contain several copies of the originals, or different particles altogether. A plethora of new particles was discovered in this way. Although these particles, generically called hadrons, are unstable, they otherwise behave in ways that broadly resemble the way protons and neutrons behave. So the character of the subject changed. It was no longer natural to think of it as simply as the study of a new force that binds protons and neutrons into atomic nuclei. Rather, a new world of phenomena had come into view. This world contained many unexpected new particles, that could transform into one another in a bewildering variety of ways. Reflecting this change in perspective, there was a change in terminology. Instead of the nuclear force, physicists came to speak of the strong interaction. In the early 1960s, Murray Gell-Mann and George Zweig made a great advance in the theory of the strong interaction, by proposing the concept of quarks. If you imagined that hadrons were not fundamental particles, but rather that they were assembled from a few more basic types, the quarks, patterns clicked into place. The dozens of observed hadrons could be understood, at least roughly, as different ways of putting together just three kinds ("flavors") of quarks. You can have a given set of quarks in different spatial orbits, or with their spins aligned in different ways. The energy of the configuration will depend on these things, and so there will be a number of states with different energies, giving rise to particles with different masses, according to $m = E/c^2$. It is analogous to the way we understand the spectrum of excited states of an atom, as arising from different orbits and spin alignments of electrons. (For electrons in atoms the interaction energies are relatively small, however, and the effect of these energies on the overall mass of the atoms is insignificant.)

The rules for using quarks to model reality seemed quite weird, however. Quarks were supposed to hardly notice one another when they were close together, but if you tried to isolate one, you found that you could not. People looked very hard for individual quarks, but without success. Only bound states of a quark and an antiquark – mesons – or bound states of three quarks – baryons – are observed. This experimental regularity was elevated into The Principle of Confinement. But giving it a dignified name didn't make it less weird.

There were other peculiar things about quarks. They were supposed to have electric charges whose magnitudes are fractions (or) of what appears to be the basic unit, namely the magnitude of charge carried by an electron or proton. All other observed electric charges are known, with great accuracy, to be whole-number multiples of this unit. Also, identical quarks did not appear to obey the normal rules of quantum statistics. These rules would require that, as spin particles, quarks should be fermions, with antisymmetric wave functions. The pattern of observed baryons cannot be understood using antisymmetric wave functions; it requires symmetric wave functions. The atmosphere of weirdness and peculiarity surrounding quarks thickened into paradox when J. Friedman, H. Kendall, R. Taylor and their collaborators at the Stanford Linear

Accelerator (SLAC) used energetic photons to poke into the inside of protons [5]. They discovered that there are indeed entities that look like quarks inside protons. Surprisingly, though, they found that when quarks are hit hard they seem to move (more accurately: to transport energy and momentum) as if they were free particles. Before the experiment, most physicists had expected that whatever caused the strong interaction of quarks would also cause quarks to radiate energy abundantly, and thus rapidly to dissipate their motion, when they got violently accelerated.

At a certain level of sophistication, that association of radiation with forces appears inevitable, and profound. Indeed, the connection between forces and radiation is associated with some of the most glorious episodes in the history of physics. In 1864, Maxwell predicted the existence of electromagnetic radiation – including, but not limited to, ordinary light – as a consequence of his consistent and comprehensive formulation of electric and magnetic forces. Maxwell's new radiation was subsequently generated and detected by Hertz, in 1883 (and over the twentieth century its development has revolutionized the way we manipulate matter and communicate with one another). Much later, in 1935, Yukawa predicted the existence of pions based on his analysis of nuclear forces, and they were subsequently discovered in the late 1940s; the existences of many other hadrons were predicted successfully using a generalization of these ideas. (For experts: I have in mind the many resonances that were first seen in partial wave analyses, and then later in production.) More recently the existence of W and Z bosons, and of color gluons, and their properties, was inferred before their experimental discovery. Those discoveries were, in 1972, still ahead of us, but they serve to confirm, retroactively, that our concerns were worthy ones. Powerful interactions ought to be associated with powerful radiation. When the most powerful interaction in nature, the strong interaction, did not obey this rule, it posed a sharp paradox.

1.2 **PARADOX 2:** SPECIAL RELATIVITY AND QUANTUM MECHANICS BOTH WORK

The second paradox is more conceptual. Quantum mechanics and special relativity are two great theories of twentieth-century physics. Both are very successful. But these two theories are based on entirely different ideas, which are not easy to reconcile. In particular, special relativity puts space and time on the same footing, but quantum mechanics treats them very differently. This leads to a creative tension, whose resolution has led to three previous Nobel Prizes (and ours is another).

The first of these prizes went to P. A. M. Dirac (1933). Imagine a particle moving on average at very nearly the speed of light, but with an uncertainty in position, as required by quantum theory. Evidently it there will be some probability for observing this particle to move a little faster than average, and therefore faster than light, which special relativity won't permit. The only known way to resolve this tension involves introducing the idea of antiparticles. Very roughly speaking, the required uncertainty in position is accommodated by allowing for the possibility that the act of measurement can involve the creation of several particles, each indistinguishable from the original, with different positions. To maintain the balance of conserved quantum numbers, the extra particles must be accompanied by an equal number of antiparticles. (Dirac was led to predict the existence of antiparticles through a sequence of ingenious interpretations and re-interpretations of the elegant relativistic wave equation he invented, rather than by heuristic reasoning of the sort I've presented. The inevitability and generality of his conclusions, and their direct relationship to basic principles of quantum mechanics and special relativity, are only clear in retrospect).

The second and third of these prizes were to R. Feynman, J. Schwinger, and S.-I. Tomonaga (1965) and to G. 't Hooft and M. Veltman (1999) respectively. The main problem that all these authors in one way or another addressed is the problem of ultraviolet divergences. When special relativity is taken into account, quantum theory must allow for fluctuations in energy over brief intervals of time. This is a generalization of the complementarity between momentum and position that is fundamen.tal for ordinary, non-relativistic quantum mechanics. Loosely speaking, ener.gy can be borrowed to make evanescent virtual particles, including particle.antiparticle pairs. Each pair passes away soon after it comes into being, but new pairs are constantly boiling up, to establish an equilibrium distribution. In this way the wave function of (superficially) empty space becomes densely populated with virtual particles, and empty space comes to behave as a dyna.mical medium.

The virtual particles with very high energy create special problems. If you calculate how much the properties of real particles and their interactions are changed by their interaction with virtual particles, you tend to get divergent answers, due to the contributions from virtual particles of very high energy.

This problem is a direct descendant of the problem that triggered the in.troduction of quantum theory in the first place, i.e. the “ultraviolet catastrophe” of black body radiation theory, addressed by Planck. There the problem was that high-energy modes of the electromagnetic field are predicted, classically, to occur as thermal fluctuations, to such an extent that equilibrium at any finite temperature requires that there is an infinite amount of energy in these modes. The difficulty came from the possibility of small-amplitude fluctuations with rapid variations in space and time. The element of discreteness introduced by quantum theory eliminates the possibility of very small-amplitude fluctua.tions, because it imposes a lower bound on their size. The (relatively) large.amplitude fluctuations that remain are predicted to occur very rarely in ther.mal equilibrium, and cause no problem. But quantum fluctuations are much more efficient than are thermal fluctuations at exciting the high-energy modes, in the form of virtual particles, and so those modes come back to haunt us. For example, they give a divergent contribution to the energy of empty space, the so-called zero-point energy.

Renormalization theory was developed to deal with this sort of difficulty. The central observation that is exploited in renormalization theory is that although interactions with high-energy virtual particles appear to produce divergent corrections, they do so in a very structured way. That is, the same corrections appear over and over again in the calculations of many different physical processes. For example in quantum electrodynamics (QED) exactly two independent divergent expressions appear, one of which occurs when we calculate the correction to the mass of the electron, the other of which occurs when we calculate the correction to its charge. To make the calculation mathematically well-defined, we must artificially exclude the highest energy modes, or dampen their interactions, a procedure called applying a cut-off, or regularization. In the end we want to remove the cut-off, but at intermediate stages we need to leave it in, so as to have well-defined (finite) mathematical expressions. If we are willing to take the mass and charge of the electron from experiment, we can identify the formal expressions for these quantities, in.cluding the potentially divergent corrections, with their measured values. Having made this identification, we can remove the cutoff. We thereby obtain well-defined answers, in terms of the measured mass and charge, for everything else of interest in QED.

Feynman, Schwinger, and Tomonoga developed the technique for writing down the corrections due to interactions with any finite number of virtual particles in QED, and showed that renormalization theory worked in the sim.plest cases. (I'm being a little sloppy in my terminology; instead of saying the number of virtual particles, it would be more proper to speak of the number of internal loops in a Feynman graph.) Freeman Dyson supplied a general proof. This was intricate work, that required new mathematical techniques. 't Hooft and Veltman showed that renormalization theory applied to a much wider class of theories, including the sort of spontaneously broken gauge theories that had been used by Glashow, Salam, and Weinberg to construct the (now) standard model of electroweak interactions. Again, this was intricate and highly innovative work.

This brilliant work, however, still did not eliminate all the difficulties. A very profound problem was identified by Landau [6]. Landau argued that virtual particles would tend to accumulate around a real particle as long as there was any uncancelled influence. This is called screening. The only way for this screening process to terminate is for the source plus its cloud of virtual partic.les to cease to be of interest to additional virtual particles. But then, in the end, no uncancelled influence would remain – and no interaction!

Thus all the brilliant work in QED and more general field theories repre.sented, according to Landau, no more than a temporary fix. You could get finite results for the effect of any particular number of virtual particles, but when you tried to sum the whole thing up, to allow for the possibility of an arbitrary number of virtual particles, you would get nonsense – either infinite answers, or no interaction at all.

Landau and his school backed up this intuition with calculations in many different quantum field theories. They showed, in all the cases they calculated, that screening in fact occurred, and that it doomed any straightforward attempt to perform a complete, consistent calculation by adding up the contributions of more and more virtual particles. We can sweep this problem under the rug in QED or in electroweak theory, because the answers includ.ing only a small finite number of virtual particles provide an excellent fit to experiment, and we make a virtue of necessity by stopping there. But for the strong interaction that pragmatic approach seemed highly questionable, because there is no reason to expect that lots of virtual particles won't come into play, when they interact strongly.

Landau thought that he had destroyed quantum field theory as a way of reconciling quantum mechanics and special relativity. Something would have to give. Either quantum mechanics or special relativity might ultimately fail, or else essentially new methods would have to be invented, beyond quantum field theory, to reconcile them. Landau was not displeased with this conclusion, because in practice quantum field theory had not been very helpful in under.standing the strong interaction, even though a lot of effort had been put into it. But neither he, nor anyone else, proposed a useful alternative.

So we had the paradox, that combining quantum mechanics and special relativity seemed to lead inevitably to quantum field theory; but quantum field theory, despite substantial pragmatic success, self-destructed logically due to catastrophic screening.

2 PARADOX LOST: ANTISCREENING, OR ASYMPTOTIC FREEDOM

These paradoxes were resolved by our discovery of asymptotic freedom. We found that some very special quantum field theories actually have anti.screening. We called this property asymptotic freedom, for reasons that will soon be clear. Before describing the specifics of the theories, I'd like to indicate in a rough, general way how the phenomenon of antiscreening allows us to resolve our paradoxes.

Antiscreening turns Landau's problem on its head. In the case of screening, a source of influence – let us call it charge, understanding that it can represent something quite different from electric charge – induces a canceling cloud of virtual particles. From a large charge, at the center, you get a small observable influence far away. Antiscreening, or asymptotic freedom, implies instead that a charge of intrinsically small magnitude catalyzes a cloud of virtual particles that enhances its power. I like to think of it as a thundercloud that grows thicker and thicker as you move away from the source.

Since the virtual particles themselves carry charge, this growth is a self-rein.forcing, runaway process. The situation appears to be out of control. In par.ticular, energy is required to build up the thundercloud, and the required energy threatens to diverge to infinity. If that is the case, then the source could never be produced in the first place. We've discovered a way to avoid Landau's disease – by banishing the patients!

At this point our first paradox, the confinement of quarks, makes a virtue of theoretical necessity. For it suggests that there are in fact sources – specifi.cally, quarks – that cannot exist on their own. Nevertheless, Nature teaches us, these confined particles can play a role as building-blocks. If we have, nearby to a source particle, its antiparticle (for example, quark and anti.quark), then the catastrophic growth of the antiscreening thundercloud is no longer inevitable. For where they overlap, the cloud of the source can be canceled by the anticloud of the antisource. Quarks and antiquarks, bound together, can be accommodated with finite energy, though either in isolation would cause an infinite disturbance.

Because it was closely tied to detailed, quantitative experiments, the sharpest problem we needed to address was the paradoxical failure of quarks to radiate when Friedman, Kendall, and Taylor subjected them to violent acceleration. This too can be understood from the physics of antiscreening. According to this mechanism, the color charge of a quark, viewed up close, is small. It builds up its power to drive the strong interaction by accumulating a growing cloud at larger distances. Since the power of its intrinsic color charge is small, the quark is actually only loosely attached to its cloud. We can jerk it away from its cloud, and it will – for a short while – behave almost as if it had no color charge, and no strong interaction. As the virtual particles in space respond to the altered situation they rebuild a new cloud, moving along with the quark, but this process does not involve significant radiation of energy and momentum. That, according to us, was why you could analyze the most salient aspects of the SLAC experiments – the inclusive cross-sections, which only keep track of overall energy-momentum flow – as if the quarks were free particles, though in fact they are strongly interacting and ultimately confined.

Thus both our paradoxes, nicely dovetailed, get resolved together through antiscreening.

The theories that we found to display asymptotic freedom are called nona.belian gauge theories, or Yang-Mills theories [7]. They form a vast generalization of electrodynamics. They postulate the existence of several different kinds of charge, with complete symmetry among them. So instead of one entity, “charge”, we have several “colors”. Also, instead of one photon, we have a family of color gluons.

The color gluons themselves carry color charges. In this respect the nona.belian theories differ from electrodynamics, where the photon is electrically neutral. Thus gluons in nonabelian theories play a much more active role in the dynamics of these theories than do photons in electrodynamics. Indeed, it is the effect of virtual gluons that is responsible for antiscreening, which does not occur in QED.

It became evident to us very early on that one particular asymptotically free theory was uniquely suited as a candidate to provide the theory of the strong interaction. On phenomenological grounds, we wanted to have the possibility to accommodate baryons, based on three quarks, as well as mesons, based on quark and antiquark. In light of the preceding discussion, this requires that the color charges of three different quarks can cancel, when you add them up. That can oocur if the three colors exhaust all possibilities; so we arrived at the gauge group SU(3), with three colors, and eight gluons. To be fair, several physicists had, with various motivations, suggested the existence of a three.valued internal color label for quarks years before [8]. It did not require a great leap of imagination to see how we could adapt those ideas to our tight requirements. By using elaborate technical machinery of quantum field theory (inclu.ding the renormalization group, operator product expansions, and appropri.ate dispersion relations) we were able to be much more specific and quantita.tive about the implications our theory than my loose pictorial language suggests. In particular, the strong interaction does not simply turn off abrupt. ly, and there is a non-zero probability that quarks will radiate when poked. It is only asymptotically, as energies involved go to infinity, that the probability for radiation vanishes. We could calculate in great detail the observable effects of the radiation at finite energy, and make experimental predictions based on these calculations.

At the time, and for several years later, the data was not accurate enough to test these particular predictions, but by the end of the 1970s they began to look good, and by now they're beautiful.

Our discovery of asymptotic freedom, and its essentially unique realization in quantum field theory, led us to a new attitude towards the problem of the strong interaction. In place of the broad research programs and fragmentary insights that had characterized earlier work, we now had a single, specific candidate theory – a theory that could be tested, and perhaps falsified, but which could not be fudged. Even now, when I re-read our declaration [3]

Finally let us recall that the proposed theories appear to be uniquely singled out by nature, if one takes both the SLAC results and the renormalization-group approach to quantum field theory at face value. I re-live the mixture of exhilaration and anxiety that I felt at the time.

3 A FOURSOME OF PARADIGMS

Our resolution of the paradoxes that drove us had ramifications in unantici.pated directions, and extending far beyond their initial scope.

3.**1 PARADIGM 1:** THE HARD REALITY OF QUARKS AND GLUONS

Because, in order to fit the facts, you had to ascribe several bizarre properties to quarks – paradoxical dynamics, peculiar charge, and anomalous statistics – their “reality” was, in 1972, still very much in question. This despite the fact that they were helpful in organizing the hadrons, and even though Friedman, Kendall, and Taylor had “observed” them! The experimental facts wouldn’t go away, of course, but their ultimate significance remained doubtful. Were quarks basic particles, with simple properties, that could be used to in formu.lating a profound theory – or just a curious intermediate device, that would need to be replaced by deeper conceptions? Now we know how the story played out, and it requires an act of imagination to conceive how it might have been different. But Nature is imaginative, as are theoretical physicists, and so it’s not impossible to fantasize alternative

FIGURE 1: A photograph from the L3 collaboration, showing three jets emerging from electron.positron annihilation at high energy [9]. These jets are the materialization of a quark, antiquark, and gluon. histories. For example, the quasiparticles of the fractional quantum Hall effect, which are not basic but rather emerge as collective excitations involving ordinary electrons, also cannot exist in isolation, and they have fractional charge and anomalous statistics! Related things happen in the Skyrme model, where nucleons emerge as collective excitations of pions. One might have fantasized that quarks would follow a similar script, emerging somehow as collective excitations of hadrons or of strings.

Together with the new attitude toward the strong interaction problem, that I just mentioned, came a new attitude toward quarks and gluons. These words were no longer just names attached to empirical patterns, or to notio.nal building blocks within rough phenomenological models. Quarks and (es.pecially) gluons had become ideally simple entities, whose properties are fully defined by mathematically precise algorithms.

You can even see them! Here's a picture, which I'll now explain. Asymptotic freedom is a great boon for experimental physics, because it leads to the beautiful phenomenon of jets. As I remarked before, an important part of the atmosphere of mystery surrounding quarks arose from the fact that they could not be isolated. But if we change our focus, to follow flows of energy and momentum rather than individual hadrons, then quarks and gluons come into view, as I'll now explain.

There is a contrast between two different kinds of radiation, which expresses the essence of asymptotic freedom. Hard radiation, capable of significantly re-directing the flow of energy and momentum, is rare. But soft radiation, that produces additional particles moving in the same direction, without deflecting the overall flow, is common. Indeed, soft radiation is associated.

FIGURE 2: These Feynman graphs are schematic representations of the fundamental processes in electron-positron annihilation, as they take place in space and time. They show the origin of two jet and three-jet events with the build-up of the clouds I discussed before, as it occurs in time. Let's consider what it means for experiments, say to be concrete the sort of experi.ment done at the Large Electron Positron collider (LEP) at CERN during the 1990s, and contemplated for the International Linear Collider (ILC) in the future. At these facilities, one studies what emerges from the annihilation of electrons and positrons that collide at high energies. By well-understood processes that belong to QED or electroweak theory, the annihilation proceeds through a virtual photon or Z boson into a quark and an antiquark. Conservation and energy and momentum dictate that the quark and antiquark will be mov.ing at high speed in opposite directions. If there is no hard radiation, then the effect of soft radiation will be to convert the quark into a spray of hadrons moving in a common direction: a jet. Similarly, the antiquark becomes a jet moving in the opposite direction. The

observed result is then a 2-jet event. Occasionally (about 10% of the time, at LEP) there will be hard radiation, with the quark (or antiquark) emitting a gluon in a significantly new direction. From that point on the same logic applies, and we have a 3-jet event, like the one shown in Figure 1. The theory of the underlying space-time process is depicted in Figure 2. And roughly 1% of the time 4 jets will occur, and so forth. The relative probability of different numbers of jets, how it varies with the overall energy, the relative frequency of different angles at which the jets emerge and the total energy in each – all these detailed aspects of the "antenna pattern" can be predicted quantitatively. These predictions reflect the basic couplings among quarks and gluons, which define QCD, quite directly.

The predictions agree well with very comprehensive experimental meas.urements. So we can conclude with confidence that QCD is right, and that what you are seeing, in Figure 1, is a quark, an antiquark, and a gluon – although, since the predictions are statistical, we can't say for sure which is which!

FIGURE 3: Many quite different experiments, performed at different energies, have been success.fully analyzed using QCD. Each fits a large quantity of data to a single parameter, the strong coupling s. By comparing the values they report, we obtain direct confirmation that the coup.ling evolves as predicted [10].

By exploiting the idea that hard radiation processes, reflecting fundamental quark and gluon interactions, control the overall flow of energy and momen.tum in high-energy processes, one can analyze and predict the behavior of many different kinds of experiments. In most of these applications, including the original one to deep inelastic scattering, the analysis necessary to separate out hard and soft radiation is much more involved and harder to visualize than in the case of electron-positron annihilation. A lot of ingenuity has gone, and continues to go, into this subject, known as perturbative QCD. The results have been quite successful and gratifying. Figure 3 shows one aspect of the success. Many different kinds of experiments, performed at many different energies, have been successfully described by QCD predictions, each in terms of the one relevant parameter of the theory, the overall coupling strength. Not only must each experiment, which may involve hundreds of independent measurements, be fit consistently, but one can then check whether the values of the coupling change with the energy scale in the way we predicted. As you can see, it does.

A remarkable tribute to the success of the theory, which I've been amused to watch evolve, is that a lot of the same activity that used to be called testing QCD is now called calculating backgrounds.

As a result of all this success, a new paradigm has emerged for the opera.tional meaning of the concept of a fundamental particle. Physicists designing and interpreting high-energy experiments now routinely describe their results in terms of producing and detecting quarks and gluons: what they mean, of course, is the corresponding jets.

3.2 PARADIGM 2: MASS COMES FORM ENERGY

My friend and mentor Sam Treiman liked to relate his experience of how, during World War II, the U.S. Army responded to the challenge of training a large number of radio engineers starting with very different levels of prepara.tion, ranging down to near zero. They designed a crash course for it, which Sam took. In the training manual, the first chapter was devoted to Ohm's three laws. Ohm's first law is $V = IR$. Ohm's second law is $I = V/R$. I'll leave it to you to reconstruct Ohm's third law.

Similarly, as a companion to Einstein's famous equation $E = mc\ 2$ we have his second law, $m = E/c\ 2$. All this isn't quite as silly as it may seem, because different forms of the same equation can suggest very different things. The usual way of writing the equation, $E = mc\ 2$, suggests the possibility of obtaining large amounts of ener.gy by converting small amounts of mass. It brings to mind the possibilities of nuclear reactors, or bombs. Stated as $m = E/c\ 2$, Einstein's law suggests the possibility of explaining mass in terms of energy. That is a good thing to do, because in modern physics energy is a more basic concept than mass. Actually, Einstein's original paper does not contain the equation $E = mc\ 2$, but rather $m = E/c\ 2$. In fact, the title is a question: "Does the Inertia of a Body Depend Upon its Energy Content?" From the beginning, Einstein was thinking about the origin of mass, not about making bombs.

Modern QCD answers Einstein's question with a resounding "Yes!" Indeed, the mass of ordinary matter derives almost entirely from energy – the energy of massless gluons and nearly massless quarks, which are the ingredients from which protons, neutrons, and atomic nuclei are made.

The runaway build-up of antiscreening clouds, which I described before, cannot continue indefinitely. The resulting color fields would carry infinite energy, which is not available. The color charge that threatens to induce this runaway must be cancelled. The color charge of a quark can be cancelled either with an antiquark of the opposite color (making a meson), or with two quarks of the complementary colors (making a baryon). In either case, perfect cancellation would occur only if the particles doing the canceling were located right on top of the original quark – then there would be no uncanceled source of color charge anywhere in space, and hence no color field. Quantum mechanics does not permit this perfect cancellation, however. The quarks and antiquarks are described by wave functions, and spatial gradients in these wave function cost energy, and so there is a high price to pay for localizing the wave function within a small region of space. Thus, in seeking to minimize the energy, there are two conflicting considerations: to minimize the field energy, you want to cancel the sources accurately; but to minimize the wave.

FIGURE 4: Comparison of observed hadron masses to the energy spectrum predicted by QCD, upon direct numerical integration of the equations, exploiting immense computer power [11]. The small remaining discrepancies are consistent with what is expected given the approximations that were necessary to make the calculation practical function localization energy, you want to keep the sources fuzzy. The stable configurations will be based on different ways of compromising between those two considerations. In each such configuration, there will be both field energy and localization energy. This gives rise to mass, according to m = E/c 2 , even if the gluons and quarks started out without any non-zero mass of their own. So the different stable compromises will be associated with particles that we can observe, with different masses; and metastable compromises will be associated with observable particles that have finite lifetimes. To determine the stable compromises concretely, and so to predict the masses of mesons and baryons, is hard work. It

requires difficult calculations that continue to push the frontiers of massively parallel processing. I find it quite ironical that if we want to compute the mass of a proton, we need to deploy something like 1030 protons and neutrons, doing trillions of multipli.cations per second, working for months, to do what one proton does in 10–24 seconds, namely figure out its mass. Maybe it qualifies as a paradox. At the least, it suggests that there may be much more efficient ways to calculate than the ones we're using.

In any case, the results that emerge from these calculations are very gratifying. They are displayed in Figure 4. The observed masses of prominent mesons and baryons are reproduced quite well, stating from an extremely tight and rigid theory. Now is the time to notice also that one of the data points in Figure 3, the one labeled "Lattice", is of a quite different character from the others. It is based not on the perturbative physics of hard radiation, but rather on the comparison of a direct integration of the full equations of QCD with experiment, using the techniques of lattice gauge theory.

The success of these calculations represents the ultimate triumph over our two paradoxes:

The calculated spectrum does not contain anything with the charges or other quantum numbers of quarks; nor of course does it contain massless gluons. The observed particles do not map in a straightforward way to the primary fields from which they ultimately arise. Lattice discretization of the quantum field theory provides a cutoff procedure that is independent of any expansion in the number of virtual particle loops. The renormalization procedure must be, and is, carried out without reference to perturbation theory, as one takes the lattice spacing to zero. Asymptotic freedom is crucial for this, as I discussed – it saves us from Landau's catastrophe.

By fitting some fine details of the pattern of masses, one can get an estimate of what the quark masses are, and how much their masses are contributing to the mass of the proton and neutron. It turns out that what I call QCD Lite – the version in which you put the u and d quark masses to zero, and ignore the other quarks entirely – provides a remarkably good approximation to reality. Since QCD Lite is a theory whose basic building-blocks have zero mass, this result quantifies and makes precise the idea that most of the mass of ordina.ry matter – 90 % or more – arises from pure energy, via m = E/c 2 .

The calculations make beautiful images, if we work to put them in eyefriendly form. Derek Leinweber has made some striking animations of QCD fields as they fluctuate in empty space. Figure 5 is a snapshot from one of his animations. Figure 6 from Greg Kilcup, displays the (average) color fields, over and above the fluctuations, that are associated with a very simple hadron, the pion, moving through space-time. Insertion of a quark-antiquark pair, which we subsequently remove, produces this disturbance in the fields. These pictures make it clear and tangible that the quantum vacuum is a dynamic medium, whose properties and responses largely determine the behavior of matter. In quantum mechanics, energies are associated with frequencies, according to the Planck relation E = h. The masses of hadrons, then, are uniquely associated to tones emitted by the dynamic medium of space when it is disturbed in various ways, according to E = mc 2/h (1) We thereby discover, in the reality of masses, an algorithmic, precise Music of the Void. It is a modern embodiment of the ancients' elusive, mystical "Music of the Spheres".

3.3 PARADIGM 3: THE EARLY UNIVERSE WAS SIMPLE

In 1972 the early universe seemed hopelessly opaque. In conditions of ultra-high temperatures, as occurred close to the Big Bang singularity, one would have lots of hadrons and antihadrons, each one an extended entity that inter.

FIGURE 5: A snapshot of spontaneous quantum fluctuations in the gluon fields [12]. For experts: what is shown is the topological charge density in a typical contribution to the functional inte.gral, with high frequency modes filtered out.

FIGURE 6: The calculated net distribution of field energy caused by injecting and removing a quark-antiquark pair [13]. By calculating the energy in these fields, and the energy in analo.gous fields produced by other disturbances, we predict the masses of hadrons. In a profound sense, these fields are the hadrons.
acts strongly and in complicated ways with its neighbors.

They'd start to over.lap with one another, and thereby produce a theoretically intractable mess.

But asymptotic freedom renders ultra-high temperatures friendly to theorists. It says that if we switch from a description based on hadrons to a description based on quark and gluon variables, and focus on quantities like total energy, that are not sensitive to soft radiation, then the treatment of the strong inter.action, which was the great difficulty, becomes simple. We can calculate to a first approximate by pretending that the quarks, antiquarks and gluons behave as free particles, then add in the effects of rare hard interactions. This makes it quite practical to formulate a precise description of the properties of ultra-high temperature matter that are relevant to cosmology.

We can even, over an extremely limited volume of space and time, repro.duce Big Bang conditions in terrestrial laboratories. When heavy ions are caused to collide at high energy, they produce a fireball that briefly attains temperatures as high as 200 MeV. "Simple" may not be the word that occurs to you in describing the explosive outcome of this event, as displayed in Figure 7, but in fact detailed study does permit us to reconstruct aspects of the initial fireball, and to check that it was a plasma of quarks and gluons.

3.4 PARADIGM 4: SYMMETRY RULES

Over the course of the twentieth century, symmetry has been immensely fruitful as a source of insight into Nature's basic operating principles. QCD, in particular, is constructed as the unique embodiment of a huge symmetry group, local SU(3) color gauge symmetry (working together with special relativity, in the context of quantum field theory). As we try to discover new laws, that improve on what we know, it seems good strategy to continue to use symmetry as our guide. This strategy has led physicists to

FIGURE 7: A picture of particle tracks emerging from the collision of two gold ions at high energy. The resulting fireball and its subsequent expansion recreate, on a small scale and briefly, physical conditions that last occurred during the Big Bang [14].

3.4.1 UNIFIED FIELD THEORIES

several compelling suggestions, which I'm sure you'll be hearing more about in future years! QCD plays an important role in all of them – either directly, as their inspiration, or as an essential tool in devising strategies for experimental exploration.

I will discuss one of these suggestions schematically, and mention three others telegraphically.

Both QCD and the standard electroweak standard model are founded on gauge symmetries. This combination of theories gives a wonderfully econo.mical and powerful account of an astonishing range of phenomena. Just be-cause it is so concrete and so successful, this rendering of Nature can and should be closely scrutinized for its aesthetic flaws and possibilities. Indeed, the structure of the gauge system gives powerful suggestions for its further fruitful development. Its product structure SU(3)SU(2) U(1), the reduci.bility of the fermion representation (that is, the fact that the symmetry does not make connections linking all the fermions), and the peculiar values of the quantum number hypercharge assigned to the known particles all suggest the desirability of a larger symmetry. The devil is in the details, and it is not at all automatic that the superficial.ly complex and messy observed pattern of matter will fit neatly into a simple mathematical structure. But, to a remarkable extent, it does.

FIGURE 8: A schematic representation of the symmetry structure of the standard model. There are three independent symmetry trans.formations, under which the known fermions fall into five independent units (or fifteen, after threefold family repetition). The color gauge group SU(3) of QCD acts horizontally, the weak interaction gauge group SU(2) acts vertically, and the hypercharge U(1) acts with the relative strengths indicated by the subscripts. Right.handed neutrinos do not participate in any of these symmetries.

FIGURE 9: The hypothetical enlarged symmetry SO(10) [15] accommodates all the symmetries of the standard model, and

more, into a unified mathematical structure. The fermions, inclu. ding a right-handed neutrino that plays an im.portant role in understanding observed neutri.no phenomena, now form an irreducible unit (neglecting family repetition). The allowed color charges, both strong and weak, form a perfect match to what is observed. The phenomenologi.cally required hypercharges, which appear so peculiar in the standard model, are now the.oretically determined by the color and weak charges, according to the formula displayed.

Most of what we know about the strong, electromagnetic, and weak inter.actions is summarized (rather schematically!) in Figure 8. QCD connects particles horizontally in groups of 3 (SU(3)), the weak interaction connects particles vertically in groups of 2 (SU(2)) in the horizontal direction and hypercharge (U(1)) senses the little subscript numbers. Neither the different interactions, nor the different particles, are unified. There are three different interaction symmetries, and five disconnected sets of particles (actually fifteen sets, taking into account the threefold repetition of families).

We can do much better by having more symmetry, implemented by addi.tional gluons that also change strong into weak colors. Then everything clicks into place quite beautifully, as displayed in Figure 9. There seems to be a problem, however. The different interactions, as ob.served, do not have the same overall strength, as would be required by the ex.

FIGURE 10: We can test the hypothesis that the disparate coupling strengths of the different gauge interactions derive a common value at short distances, by doing calculations to take into account the effect of virtual particle clouds [16]. These are the same sort of calculations that go into Figure 3, but extrapolated to much higher energies, or equivalently shorter distances. Top panel: using known virtual particles. Bottom panel: including also the virtual particles required by low.energy supersymmetry [17].

tended symmetry. Fortunately, asymptotic freedom informs us that the observed interaction strengths at a large distance can be different from the basic strengths of the seed couplings viewed at short distance. To see if the basic theory might have the full symmetry, we have to look inside the clouds of virtual particles, and to track the evolution of the couplings. We can do this, using the same sort of calculations that underlie Figure 3, extended to include the electroweak interactions, and extrapolated to much shorter distances (or equivalently, larger energy scales). It is convenient to display inverse couplings and work on a logarithmic scale, for then the evolution is (approximately) linear. When we do the calculation using only the virtual particles for which we have convincing evidence, we find that the couplings do approach each other in a promising way, though ultimately they don't quite meet. This is shown in the top panel of Figure 10.

Interpreting things optimistically, we might surmise from this near-success that the general idea of unification is on the right track, as is our continued reliance on quantum field theory to calculate the evolution of couplings. After all, it is hardly shocking that extrapolation of the equations for evolution of the couplings beyond their observational foundation by many orders of magnitude is missing some quantitatively significant ingredient. In a moment I'll mention an attractive hypothesis for what's missing.

A very general consequence of this line of thought is that an enormously large energy scale, of order 1015 GeV or more, emerges naturally as the scale of unification. This is a profound and welcome result. It is profound, because the large energy scale – which is far beyond any energy we can access directly – emerges from careful consideration of experimental realities at energies more than ten orders of magnitude smaller! The underlying logic that gives us such leverage is a synergy of unification and asymptotic freedom, as follows. If evolution of couplings is to be responsible for their observed gross inequality then, since this evolution is only logarithmic in energy, it must act over a very wide range.

The emergence of a large mass scale for unification is welcome, first, because many effects we might expect to be associated with unification are observed to be highly suppressed. Symmetries that unify SU(3) SU(2) U(1) will almost inevitably involve wide possibilities for transformation among quarks, leptons, and their antiparticles. These extended possibilities of transformation, mediated by the corresponding gauge bosons, undermine conservation laws including lepton and baryon number conservation. Violation of lepton number is closely associated with neutrino oscillations. Violation of baryon number is closely associated with proton instability. In recent years neutrino oscillations have been observed; they correspond to miniscule neutrino masses, indicating a very feeble violation of lepton number. Proton instability has not yet been obser.ved, despite heroic efforts to do so. In order to keep these processes sufficiently small, so as to be consistent with observation, a high scale for unification, which suppresses the occurrence of the transformative gauge bosons as virtual particles, is most welcome. In fact, the unification scale we infer from the evolution of couplings is broadly consistent with the observed value of neutrino masses, and that encourages further vigorous pursuit of the quest to observe proton decay. The emergence of a large mass scale for unification is welcome, secondly, because it opens up possibilities for making quantitative connections to the remaining fundamental interaction in Nature: gravity. It is notorious that gra.vity is absurdly feebler than the other interactions, when they are compared acting between fundamental particles at accessible energies. The gravitatio.nal force between proton and electron, at any macroscopic distance, is about Gmemp / 10−40 of the electric force. On the face of it, this fact poses a severe challenge to the idea that these forces are different manifestations of a common source – and an even more severe challenge to the idea that gravity, because of its deep connection to space-time dynamics, is the primary force.

By extending our consideration of the evolution of couplings to include gravity, we can begin to meet these challenges.

Whereas the evolution of gauge theory couplings with energy is a subtle quantum mechanical effect, the gravitational coupling evolves even classically, and much more rapidly. For gravity responds directly to energy-momentum, and so it appears stronger when viewed with high.energy probes. In moving from the small energies where we ordinarily measure to unification energy scales, the ratio GE 2/ ascends to values that are no longer absurdly small.

If gravity is the primary force, and special relativity and quantum mecha.nics frame the discussion, then Planck's system of physical units, based on Newton's constant G, the speed of light c, and Planck's quantum of action h, is privileged. Dimensional analysis then suggests that the value of naturally defined quantities, measured in these units, should be of order unity. But when we measure the proton mass in Planck units, we discover.

On this hypothesis, it makes no sense to ask “Why is gravity so feeble?”. Gravity, as the primary force, just is what it is. The

right question is the one we confront here: “Why is the proton so light?”. Given our new, profound understanding of the origin of the proton’s mass, which I’ve sketched for you today, we can formulate a tentative answer. The proton’s mass is set by the scale at which the strong coupling, evolved down from its primary value at the Planck energy, comes to be of order unity. It is then that it becomes worthwhile to cancel off the growing color fields of quarks, absorb. ing the cost of quantum localization energy. In this way, we find, quantita.tively, that the tiny value of the proton mass in Planck units arises from the fact that the basic unit of color coupling strength, g, is of order
at the Planck scale! Thus dimensional reasoning is no longer mocked. The apparent feebleness of gravity results from our partiality toward the perspective supplied by matter made from protons and neutrons.

3.4.2 SUPERSYMMETRY

As I mentioned a moment ago, the approach of couplings to a unified value is suggested, but not accurately realized, if we infer their evolution by including the effect of known virtual particles. There is one particular proposal to expand the world of virtual particles, which is well motivated on several inde.pendent grounds. It is known as low-energy supersymmetry [18].
As the name suggests, supersymmetry involves expanding the symmetry of the basic equations of physics. This proposed expansion of symmetry goes in a different direction from the enlargement of gauge symmetry. Supersymmetry makes transformations between particles having the same color charges and different spins, whereas expanded gauge symmetry changes the color charges while leaving spin untouched. Supersymmetry expands the space-time symmetry of special relativity.
In order to implement low-energy supersymmetry, we must postulate the existence of a whole new world of heavy particles, none of which has yet been observed directly. There is, however, a most intriguing indirect hint that this idea may be on the right track: If we include the particles needed for low-energy supersymmetry, in their virtual form, in the calculation of how couplings evolve with energy, then accurate unification is achieved! This is shown in the

bottom panel of Figure 10. By ascending a tower of speculation, involving now both extended gauge symmetry and extended space-time symmetry, we seem to break though the clouds, into clarity and breathtaking vision. Is it an illusion, or reality? This question creates a most exciting situation for the Large Hadron Collider (LHC), due to begin operating at CERN in 2007, for this great accelerator will achieve the energies necessary to access the new world of of heavy particles, if it exists. How the story will play out, only time will tell. But in any case I think it is fair to say that the pursuit of unified field theories, which in past (and many present) incarnations has been vague and not fruitful of testable consequences, has in the circle of ideas I've been describing here attained entirely new levels of concreteness and fecundity.

3.4.3 AXIONS [19]

As I have emphasized repeatedly, QCD is in a profound and literal sense con.structed as the embodiment of symmetry. There is an almost perfect match between the observed properties of quarks and gluons and the most general properties allowed by color gauge symmetry, in the framework of special rela.tivity and quantum mechanics. The exception is that the established symme.tries of QCD fail to forbid one sort of behavior that is not observed to occur. The established symmetries permit a sort of interaction among gluons – the so-called term – that violates the invariance of the equations of QCD under a change in the direction of time. Experiments provide extremely severe limits on the strength of this interaction, much more severe than might be expected to arise accidentally.

By postulating a new symmetry, we can explain the absence of the undesired interaction. The required symmetry is called Peccei-Quinn symmetry after the physicists who first proposed it. If it is present, this symmetry has remarkable consequences. It leads us to predict the existence of new very light, very weakly interacting particles, axions. (I named them after a laundry detergent, since they clean up a problem with an axial current.) In principle axions might be observed in a variety of ways, though none is easy. They have interesting implications for cosmology, and they are a leading candidate to provide cosmological dark matter.

3.4.4 IN SEARCH OF SYMMETRY LOST [20]

It has been almost four decades since our current, wonderfully successful theory of the electroweak interaction was formulated. Central to that theory is the concept of spontaneously broken gauge symmetry. According to this concept, the fundamental equations of physics have more symmetry than the actual physical world does. Although its specific use in electroweak theory involves exotic hypothetical substances and some sophisticated mathematics, the underlying theme of broken symmetry is quite old. It goes back at least to the dawn of modern physics, when Newton postulated that the basic laws of mechanics exhibit full symmetry in three dimensions of space despite the fact that everyday experience clearly distinguishes ‘up and down’ from ‘sideways’ directions in our local environment. Newton, of course, traced that asymmetry to the influence of Earth’s gravity. In the framework of electroweak theory, modern physicists similarly postulate that the physical world is described by a solution wherein all space, throughout the currently observed Universe, is permeated by one or more (quantum) fields that spoil the full symmetry of the primary equations.

Fortunately this hypothesis, which might at first hearing sound quite extra.vagant, has testable implications. The symmetry-breaking fields, when suitably excited, must bring forth characteristic particles: their quanta. Using the most economical implementation of the required symmetry breaking, one predicts the existence of a remarkable new particle, the so-called Higgs particle. More ambitious speculations suggest that there should be not just a single Higgs particle, but rather a complex of related particles. Low-energy super.symmetry, for example, requires at least five “Higgs particles”.

Elucidation of the Higgs complex will be another major task for the LHC. In planning this endeavor, QCD and asymptotic freedom play a vital support.ing role. The strong interaction will be responsible for most of what occurs in collisions at the LHC. To discern the new effects, which will be manifest only in a small proportion of the events, we must understand the dominant backgrounds very well. Also, the production and decay of the Higgs particles themselves usually involves quarks and gluons. To anticipate their signatures, and eventually to interpret the observations, we must use our understanding of how protons – the projectiles at LHC – are assembled from quarks and gluons, and how quarks and gluons show themselves as jets.

5 POSTCRIPT: REFLECTIONS

Evidently asymptotic freedom, besides resolving the paradoxes that originally concerned us, provides a conceptual foundation for several major insights into Nature's fundamental workings, and a versatile instrument for further investi.gation.

The greatest lesson, however, is a moral and philosophical one. It is truly awesome to discover, by example, that we humans can come to comprehend Nature's deepest principles, even when they are hidden in remote and alien realms. Our minds were not created for this task, nor were appropriate tools ready at hand. Understanding was achieved through a vast international effort involving thousands of people working hard for decades, competing in the small but cooperating in the large, abiding by rules of openness and honesty. Using these methods – which do not come to us effortlessly, but require nurture and vigilance – we can accomplish wonders. That was the conclusion of the lecture as I gave it. I'd like to add, in this written version, a few personal reflections.

5.1 THANKS

Before concluding I'd like to distribute thanks. First I'd like to thank my parents, who cared for my human needs and encouraged my curiosity from the beginning. They were children of immi.grants from Poland and Italy, and grew up in difficult circumstances during the Great Depression, but managed to emerge as generous souls with an inspiring admiration for science and learning. I'd like to thank the people of New York, for supporting a public school system that served me extremely well. I also got a superb undergraduate education, at the University of Chicago. In this connection I'd especially like to mention the inspiring influ.ence of Peter Freund, whose tremendous enthusiasm and clarity in teaching a course on group theory in physics was a major influence in nudging me from pure mathematics toward physics. Next I'd like to thank the people around Princeton who contributed in crucial ways to the circumstances that made my development and major work in the 1970s possible. On the personal side, this includes especially my wife Betsy Devine. I don't think it's any coincidence that the beginning of my scientific maturity, and a special surge of energy, happened at the same time as I was falling in love with her. Also Robert Shrock and Bill Caswell, my fellow graduate students, from whom I learned a lot, and who made our extremely intense life-style seem natural and even fun. On the scientific side, I must of course thank David Gross above all. He swept me up in his drive to know and to calculate, and through both his generous guidance and his personal ex.ample started and inspired my whole career in physics. The environment for theoretical physics in Princeton in the 1970s was superb. There was an atmos.phere of passion for understanding, intellectual toughness, and inner confi.dence whose creation was a great achievement. Murph Goldberger, Sam Treiman, and Curt Callan especially deserve enormous credit for this. Also Sidney Coleman, who was visiting Princeton at the time, was very actively interested in our work. Such interest from a physicist I regarded as uniquely brilliant was inspiring in itself; Sidney also asked many challenging specific questions that helped us come to grips with our results as they developed. Ken Wilson had visited and lectured a little earlier, and his renormalization group ideas were reverberating in our heads.

Fundamental understanding of the strong interaction was the outcome of decades of research involving thousands of talented people. I'd like to thank my fellow physicists more generally. My theoretical efforts have been inspired by, and of course informed by, the ingenious persistence of my experimental colleagues. Thanks, and congratulations, to all. Beyond that generic thanks I'd like to mention specifically a trio of physicists whose work was particularly important in leading to ours, and who have not (yet?) received a Nobel Prize for it. These are Yoichiro Nambu, Stephen Adler, and James Bjorken. Those heroes advanced the cause of trying to understand hadronic physics by taking the concepts of quantum field theory seriously, and embodying them in spe.cific mechanistic models, when doing so was difficult and unfashionable. I'd like to thank Murray Gell-Mann and Gerard 't Hooft for not quite inventing everything, and so leaving us something to do. And finally I'd like to thank Mother Nature for her extraordinarily good taste, which gave us such a beau.tiful and powerful theory to discover.

This work is supported in part by funds provided by the U.S. Department of Energy (D.O.E.) under cooperative research agreement. DE-FC02.94ER40818.

5.2 A NOTE TO HISTORIANS

I have not, here, given an extensive account of my personal experiences in discovery. In general, I don't believe that such accounts, composed well after the fact, are reliable as history. I urge historians of science instead to focus on the contemporary documents; and especially the original papers, which by definition accurately reflect the understanding that the authors had at the time, as they could best articulate it. From this literature, it is I think not diffi.cult to identify where the watershed changes in attitude I mentioned earlier occurred, and where the outstanding paradoxes of strong interaction physics and quantum field theory were resolved into modern paradigms for our understanding of Nature.

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Space Log

OCTOBER 22ND, 1998

$$H = \frac{2\hbar^{2}}{Md^{2}} \left[\left(-i \frac{\partial}{\partial q_{1}} - \sqrt{N}\alpha \right)^{2} + \sum_{j-2}^{N} \left(- \frac{\partial}{\partial q_{j}^{2}} + \eta^{2} \omega_{j}^{2} q_{j}^{2} \right) \right]$$

We decided to undertake a journey. I was with two friends. One of them had taken a trip with me before the other was new to the process. We were in Colorado and the time was 10:30 PM.

We decided to go on to visit the planet Venus. We went through the process of visualization and proceeded to our destination. All went well with the transport and as I probed my friends mentally, I saw that they were both fine.

I then saw myself arriving in a large spaceport full of activity and lights. I felt that I had to register our arrival. This formality took about a minute and I asked that if possible, my comrades and I could meet personal guides to that dimension. I felt that I was granted clearance and that my request was to be approved.

I proceeded to the inner planes of the planet, where all activities are taking place. I could see that the planet was completely filled with space of various shapes and colors. It came to me that the big north - south volume connecting the poles through the center of the sphere was used as the central administration of the planet.

From my position I could perceive many areas, all of different colors and different shapes. I could see the whole inner planet from where I was. My attention went to one of the largest space of deep dark blue color. The whole picture was very beautiful but I could not penetrate any ofthe areas I was looking at. May be I did not try as I was comfortable watching the whole picture from my position. I remained there for a few minutes, watching those colorful spaces and I began to see activities happening between the various areas. I could not figure out what exactly what was happening although I was feeling more and more the level of energy that was exchanged between the various spaces.

A guide then greeted me, something I had mentally requested at the time of arrival. She proceeded to a lift going from my present location on the inner planes of the planet leading directly to a platform above the clouds and the upper atmosphere. I followed her. I knew that my guide was a woman, she had a very attractive energy and I felt that she was taller then I but I could not see her face or even her physical appearance.

From that space platform we entered a small ship which was waiting there and flew off.

That ship was small but fast and maneuverable. We had a large view screen in front of us and two smaller screens on each side. In a just few second she had taken us back into the Earth atmosphere and as we were going down, I could see the vision of the land below with great accuracy and acuteness. She attempted to show me a point somewhere on a southern coast of a peninsula of the eastern Canadian coast.

The ship was of very comfortable

and I could see through the large view screen, the part of the Earth she was pointing out to me coming closer. The definition of view screen was very clear and having impressive zooming ability. She did not communicate the significance of that point but I felt that she was showing it to me for a good reason, which did eludes me at the time. I now suspect why she pointed my attention there and I am sure that I will sooner or later be able to investigate my series about that particular vortex.

Then the ship shifted and swiftly moved out of the Earth and the next thing I saw was the planet Saturn a few seconds later. We took a wide turn above the rings and then we were flying through space, I did felt the acceleration of the ship but very little gravity pressure.

I next saw through the central window two bright lights approaching. I realized that we were on the border of the space of the Alpha Centauri system. The ships approaching were border patrols ships or so it felt. We kept moving until they could almost reached us, then she turned our ship away and said to me telepathically in English□ □the place you like□. She somehow knew that I have always loved my visits on Alpha Centauri, and I felt her smile as we pulled away and returning to the space of our own solar system before those ships could reach us.

The return trip only took a few seconds and then we landed back on the platform, to find myself back in the spaceport where we first arrived I thank her for that wonderful voyage, sent blessings and wished her well. I was back at my point of arrival and so I felt it was the time to gather my group and return home. Two minutes later called back my friends to return, then we all back in our physical bodies in Colorado. I asked for a report on the experience they had and they both told me they had a good time. The first one said that she had an interesting experience but was shy to talk about it. My other friend was greeted on Venus and spent time with a guide with a very long neck, a joyful guide who took her in a very playful dimension of lights and sounds. Has she described him, I could perceive him and I could see that his skin was of a bright violet hue color. I could see his face and physical appearance as well. As a result of this, she was later inspired to create a series of paintings representing dancing figures who were flying through space in warm and pleasing colors. As for me this trip was wonderful and a unique experience. I am hoping to return sometime and may be to meet again that person who was so kind to show me around our solar system.

"The ships approaching were border patrols ships or so it felt."

TIME-TRAVEL SURVIVAL QUIZ

DEVELOPED BY: LORD OF FOOLS - THE QUIZ IS DEVELOPED ON: 2004-10-01 - 7357 TAKEN.
TIME-LIMIT:< <10'

According to theory, time travel is possible. But once we've got the necessary travelling part out of the way, would you survive the cultural shock, language barriers and various other dangers of another world?

YOU KNEW YOU SHOULDN'T HAVE TOUCHED THAT RUSTY PIECE OF METAL! OH WELL... AT LEAST YOU HAVEN'T GONE BACK TO THE STONE AGE. YOU LOOK AROUND AT YOUR SURROUNDINGS. INSTEAD OF THAT "YOU ARE HERE" SIGN, THERE IS A DELIGHTFUL PICTURE OF MEN CUTTING OFF EACH OTHERS' HEADS. YOU:

A. Wander the halls looking for something to eat.

B. Cry.

C. Look around for someone else.

D. Sigh to yourself and moan "Why me?".

E. Investigate the artwork and try to decipher from. the materials used exactly what time period you're in.

OKAY, THERE'S NO ONE AROUND. SO WHAT DO YOU DO? YOU

A. Gnaw your fist.

B. Wonder where the hell everybody is.

C. Wait a little, twiddling your thumbs.

D. Try to work out which century it is from the stonework.

E. Nibble some rocks to see if they're edible.

NOW THAT YOU'RE ABSOLUTELY, POSITIVELY SURE THAT NO ONE'S AROUND, YOU:

A. Try to work out which century it is from the foliage in the window. *snigger* Nerd.

B. Listen.

C. Prance around.

D. Go outside and see if there's anybody out there.

E. There aren't. So you come back inside
Sit down and grumble about how much your head hurts.

SUDDENLY YOU HEAR SOMETHING. YOU:

A. Follow the noise.

B. While following, try to work out which century it is from the sounds.

C. Run towards the sound screaming, with your arms flailing about.

D. Walk down the hall swearing.

E. Approach with caution.

INSIDE THE ROOM WHERE THE NOISE CAME FROM STANDS A WOMAN. SHE'S EXTREMELY WELL DRESSED AND LOOKS AT YOU IMPERIOUSLY. YOU:

A. Punch the woman in the nose.

B. Kiss the woman's foot. It tastes like shoe.

C. Immediately start explaining yourself... she has an uncanny resemblance to your great aunt.

D. Say 'my, what lovely hair you have'.

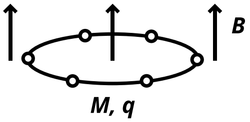
E. Having finally worked out the century, you start gabbling in something you hope is close to the language she speaks.

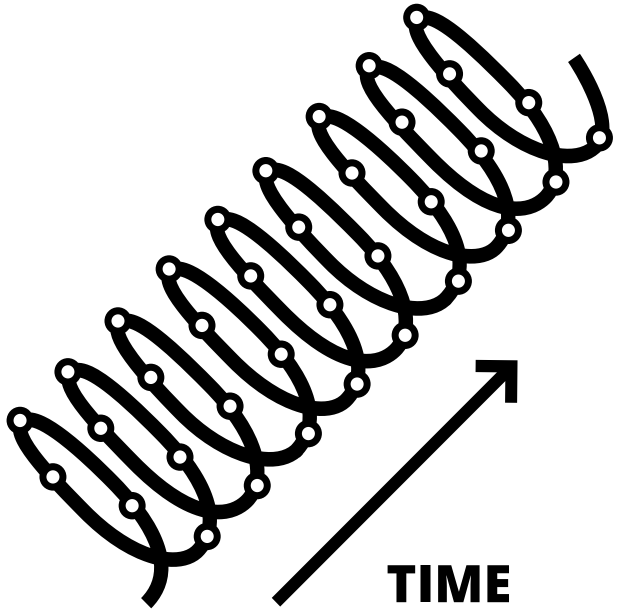
WELL, WHATEVER YOU WERE GOING TO DO, YOU WERE SCREWED FROM THE BEGINNING. SHE WAS THE QUEEN! GUARDS RUN OUT AND DRAG YOU TO A DISGUSTING CELL WITH RATS AND MILDEW AND NO LIGHTS. A MISERABLE LOOKING, GREY HAIRED OLD MAN EYEBALLS YOU FROM THE CORNER. YOU.

A. You look around and wonder if you could catch plague or rabies from the rats in the cell. Punch the man in the nose, and then drink some of the slimy water dripping from a pipe in the ceiling.

B. Start screaming at the guards and weeping for forgiveness.

C. You go up to the man and ask what he's in for. he answers in the gibberish the queen spoke.




TIME

D. Walk over to the man and kiss his foot. He looks at you strangely. You gag-- the foot tasted like dry rot.

THE GUARDS OPEN THE DOOR AGAIN AND PUT A BOWL OF FOOD INTO THE CELL. IT DOESN'T LOOK VERY NICE. YOU:

A. You ignore the man, eating all the food and then looking around guiltily.

B. Complain to the guards and demand more respect.
You have a nibble of the food. It's stale and quite gross, but probably won't kill you.

C. Sorry, but anyone who chose this option last time is now officially dead. The slimy water was poisoned.

D. You kiss the guard's foot (stop doing that!) and he kicks you in the mouth. You knock the food over, and it lands in slimy water.

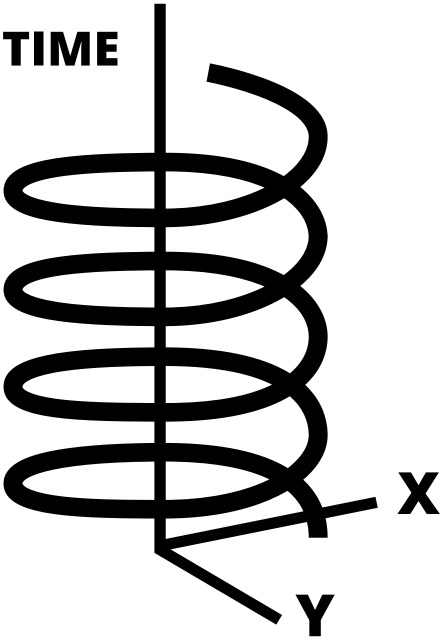
WELL, CHUM, IT LOOKS LIKE YOU'RE HERE FOR THE NIGHT. THE OLD MAN PATS YOU ON THE HEAD. YOU RESIST ALL URGES TO PURR. HE'S QUITE NICE, REALLY. YOU:

A. The man offers you some slime covered
B. R.I.P.

C. You throw up in his lap.

D. Try to make conversation.

E. Open your heart to him and tell him how you've never felt true love... until now...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AS THE NIGHT PROGRESSES, THE GUARD TOWER, VISIBLE THROUGH A GRATE IN THE CEILING, BECOMES QUITE ROWDY. SUDDENLY A RIVER OF BLOOD GUSHES THROUGH THE GRATE. YOU:

A. R.I.P.

B. You sleep.

C. You continue your conversation after a shuddering session. The old man is impressed you know what year it is- he's lost track after being in prison so long.

D. You think it's bath time and hurry under the grate. Splendid! Now you're covered in blood.

E. Have bread stuffed in your mouth and don't notice.

MORNING COMES, AND YOU HAVE A SUDDEN THOUGHT THAT SOMETHING BAD IS GOING TO HAPPEN. GUARDS BURST IN. YOU:

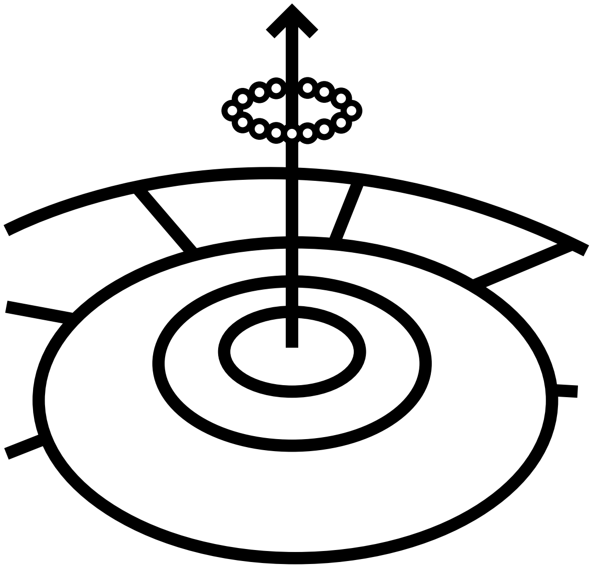
A. Point to the blood on your shirt and swear a lot.

B. R.I.P.

C. Complain that you hardly slept a wink because of the rats.

D. Apologize and explain yourself.

E. Point to the old man and say 'he did it'.



TIME-TRAVEL QUIZ

DEVELOPED BY: LORD OF FOOLS - THE QUIZ IS DEVELOPED ON: 2004-10-01 - 7357 TAKEN.

NO TIME LIMIT

The idea of traveling to the future or past has intrigued people for centuries. Research in physics has shown that this concept may not be as impossible as it once seemed.

TIME TRAVEL (TRAVELING TO THE PAST OR FUTURE) HAS BEEN A POPULAR THEME IN FILM AND FICTION. ALBERT EINSTEIN OFFERED A GROUNDBREAKING THEORY THAT GIVES SOME SCIENTIFIC POSSIBILITY TO ACTUAL TIME TRAVEL. WHAT THEORY IS THIS?

A. Special Relativity Theory

B. Time Travel Theory

C. Wave Particle Duality Theory

D. Big Bang Theory

MANY SCIENTISTS BELIEVE THAT TIME TRAVEL TO THE FUTURE COULD BE ACHIEVED. WHAT IS ONE WAY IN WHICH A PERSON COULD HYPOTHETICALLY TRAVEL TO THE FUTURE?

A. None of these

B. Travel slower than the speed of light

C. Travel at a speed close to the speed of light

D. Make use of very weak gravity

THERE ARE VARIOUS SPACE PHENOMENA, IN THEORY, THAT ASTRONOMERS COULD USE TO TRAVEL BACK AND FORTH IN TIME. BLACK HOLES ARE ONE OPTION. WHICH OF THE FOLLOWING IS TRUE ABOUT BLACK HOLES?

A. No object can escape their gravitational pull.

B. There is no real evidence that black holes exist.

C. A black hole's gravity does not bend light.

D. The sun is likely to become a black hole.

COSMIC STRINGS HAVE BEEN SINGLED OUT BY SCIENTISTS AS POSSIBLE ENABLERS OF TIME TRAVEL. WHAT IS THE PROBLEM WITH COSMIC STRINGS?

A. Quantum mechanics do not allow for cosmic strings.

B. They have no effect on time or space.

C. They have not actually been found.

D. They have a two-dimensional singularity.

WORMHOLES ARE THE MOST POPULAR "TIME MACHINE" OPTION FOR ASTROPHYSICISTS.

A. True

B. False

TRAVELING TO THE PAST POSES MORE PROBLEMS THAN TRAVELING TO THE FUTURE. MANY COMPLEX OBSTACLES COULD ARISE IN PAST TIME TRAVEL, LEADING PHYSICISTS TO BELIEVE THAT IT IS IMPOSSIBLE. ONE OF THE MAJOR OBJECTIONS TO THE POSSIBILITY OF TIME TRAVEL IS THE "GRANDFATHER PARADOX". WHAT DOES THIS PARADOX STATE?

A. If you went back in time, you might meet your grandfather and learn secrets about your past.

B. If you went back in time and killed your grandfather, then you could not exist, so you could not have killed your grandfather, etc.

C. There is no "Grandfather Paradox".

D. If you traveled to the past, you might run into yourself, but how can there be two of you?

THE "TWINS PARADOX" IS ANOTHER EXAMPLE USED BY PHYSICISTS TO DENY HYPOTHETICAL TIME TRAVEL.

A. True

B. False

OTHER SCIENTISTS CLAIM THAT IF PAST TIME TRAVEL WERE POSSIBLE, PEOPLE FROM THE FUTURE WOULD HAVE VISITED US BY NOW. ASTRONOMER CARL SAGAN REFUTED THIS LOGIC WITH ALL OF THE FOLLOWING POINTS EXCEPT:

A. Perhaps time travelers just haven't reached our time yet.

B. Time travelers are likely exploring other planets.

C. Maybe past time travel is only possible up to the time that time travel was invented.

D. Time travelers are possibly among us, but have disguised themselves.

WHAT SOLUTION DO TIME TRAVEL PROPONENTS OFFER TO THOSE WHO NEGATE ITS POSSIBILITY?

A. Parallel universes

B. Predestination

C. Chronology protection

D. Infinite loop of time

WHAT IS A MAJOR PHYSICAL OBSTACLE TO THE POTENTIAL OF TIME TRAVEL?

A. We cannot create a gravitational field strong enough to make an enclosed, circular vacuum.

B. We do not have a strong enough power source that we are able to control.

C. We are unable to accurately manipulate negative energy density.

EJEMPLOS DE DOCUMENTOS IMPRESOS

MONOGRAFIAS

APELLIDO(S), Nombre. Título del libro. Mención de responsabilidad secundaria (traductor; prologuista; ilustrador; coordinador; etc.)*. Nº de edición. Lugar de edición: editorial, año de edición. Nº de páginas*. Serie*. Notas*. ISBN

Ejemplos:

BOBBIO, Norberto. Autobiografía. Papuzzi, Alberto (ed. lit.); Peces-Barba, Gregorio (prol.); Benitez, Esther (trad.). Madrid: Taurus, 1988. 299 p. ISBN: 84-306-0267-4

El Lazarillo de Tormes. Marañón, Gregorio (prol.). 10a ed. Madrid: Espasa Calpe, 1958. 143 p. Colección Austral; 156.

PARTES DE MONOGRAFÍAS

APELLIDO(S), Nombre. Título de la parte. En: Responsabilidad de la obra completa. Título de la obra. Edición. Lugar de edición: editorial, año de edición. Situación de la parte en la obra.

Ejemplos:

SNAVELY, B.B. Continuous-Wave Dye lasers I. En: SCHÄFER, F.P. (ed). Dye lasers. Berlin: Springer, 1990. p. 91-120.

TEROL ESTEBAN, Alberto. El nuevo modelo de financiación autonómica : una aproximación desde el punto de vista del empresario-contribuyente. Dins: XX Aniversario del Círculo de Empresarios, 20 temas para el futuro. Madrid : Círculo de Empresarios, 1997. p. 85-92

PUBLICACIONES EN SERIE

Título de la publicación en cursiva. Responsabilidad. Edición. Identificación del fascículo. Lugar de edición: editorial, fecha del primer volumen-fecha del último volumen. Serie*. Notas*. ISSN

Ejemplos:

Boletín económico. Banco de España. 1998, nº 1. Madrid: Banco de España, Servicio de Publicaciones, 1979- .ISSN: 0210-3737

IEEE Transactions on computers. IEEE Computer Society. 1998, vol 47. Los Alamitos (Ca): IEEE Computer Society, 1988. ISSN 0018-9340.

ARTÍCULOS DE PUBLICACIONES EN SERIE

APELLIDO(S), Nombre. Título del artículo. Responsabilidad secundaria. Título de la publicación seriada. Edición. Localización en el documento fuente: año, número, páginas.

Ejemplos:

LLOSA, Josep, et al. Modulo scheduling with reduced register pressure. IEEE Transactions on computers,1998, vol 47, núm. 6, p. 625-638.

ALVAREZ, Begoña; BALLINA, F. Javier de la; VÁZQUEZ, Rodolfo. La reacción del consumidor ante las promociones. MK Marketing + Ventas, núm- 143, (Enero 2000), p. 33-37.

LEGISLACIÓN

País. Título. Publicación, fecha de publicación, número, páginas.

Ejemplo:

España. Ley orgánica 10/1995, de 23 de noviembre, del Código penal. Boletín Oficial del Estado, 24 de noviembre de 1995, núm. 281, p. 33987.

PATENTES

MENCIÓN DE RESPONSABILIDAD PRINCIPAL. Denominación del elemento patentado. Responsabilidad subordinada. Notas*. Identificador del documento (país u oficina que lo registra). Clase de documento de patente. Número. Año-mes-día de publicación del documento.

NORMAS

ENTIDAD RESPONSABLE DE LA NORMA. Título. Nº ó código de la norma. Edición. Lugar de publicación: editorial, año de publicación.

Ejemplo:

AENOR. Gestión de la I+D+I. UNE 166000 EX, UNE 166001 EX, UNE 166002 EX. Madrid: AENOR, 2002.

CONGRESOS

APELLIDO(S), Nombre. Título. Responsabilidades secundarias*. Nº de edición. Lugar: editorial, año de publicación. Nª de páginas o volúmenes*. ISBN

Ejemplo:

Actas del I Congreso de Historia de la Lengua Española en América y España: noviembre de 1994 - febrero de 1995. M. Teresa Echenique, Milagros Aleza y M. José Martínez (eds.).València : Universitat, Departamento de Filología Española, 1995. 564 p. ISBN: 8480022698.

PONENCIAS DE CONGRESOS

Se citan como parte de una monografía.

APELLIDO(S), Nombre. “Título de la parte”. En: APELLIDO(S), Nombre. Título de la obra completa. Responsabilidades secundarias*. Nº de edición. Lugar: editorial, año de publicación. Serie*. ISBN

Ejemplo:

CEREZO GALÁN, Pedro. “La antropología del espíritu en Juan de la Cruz”. En: Actas del Congreso Internacional Sanjuanista, (Ávila 23-28 de septiembre de 1991), v. III. [S.l.]: [s.n.], 1991. P. 128-154

TESIS NO PUBLICADAS

APELLIDO(S), Nombre. “Título de la tesis”. Dirección. Clase de tesis. [Tipo de documento]. Institución académica en la que se presenta, lugar, año.

Ejemplo:

LASCURAIN SÁNCHEZ, María Luisa. “Análisis de la actividad científica y del consumo de información de los psicólogos españoles del ámbito universitario durante el período 1986-1995”. Director: Elias Sanz Casado. Tesis doctoral. Universidad Carlos III de Madrid, Departamento de Biblioteconomía y Documentación, 2001.

INFORMES

Informes publicados: APELLIDO(S), Nombre. Título del informe. Lugar de publicación: editorial, año. Serie, nº de la serie. (Disponibilidad)

Ejemplo:

1999 Informe del Mercado de Trabajo. [Guadalajara]: Dirección Provincial del Instituto Nacional de Empleo de Guadalajara, 2000. 155 p.

Informes inéditos:

APELLIDO(S), Nombre. “Título del informe”. Informe inédito. Organismo que lo produce, año.

Ejemplo:

GUIRADO ROMERO, Nuria. Proyecto de conservación y recuperación de una especie amenazada, Testudo graeca, a partir de las poblaciones relictas del sureste español. Informe inédito. Almeria: [s.n.], 1988. 115 p. Informe técnico Dirección General de Medio Ambiente

EJEMPLOS DE DOCUMENTOS AUDIOVISUALES

Grabaciones: APELLIDO(S), Nombre. Título. [Designación específica del tipo de documento]. Lugar: editorial, año.

Ejemplo:

WAGNER, Richard. El drama musical wagneriano. [Grabación sonora]. Barcelona: CYC, 1998.

BARDEM, Juan Antonio. Calle Mayor. [Vídeo]. Madrid : Paramount Pictures : El Mundo , [2002]. 1 disco compacto.

Progamas de radio y televisión: Nombre del programa. Responsabilidad. Entidad emisora, fecha de emisión.

Ejemplo:

Jorge Luis Borges. Director y presentador: Joaquín Soler Serrano. RTVE, 1980. Videoteca de la memoria literaria ; 1

Materiales gráficos:

APELLIDO(S), Nombre. Título. [Designación específica del tipo de documento]. Lugar: editorial, año.

Ejemplo:

BALLESTEROS, Ernesto. Arquitectura contemporánea. [Material gráfico proyectable]. 2a ed. Madrid : Hiares , [1980]. 32 diapositivas. Historia del Arte Español; 57.

EJEMPLOS DE DOCUMENTOS ELECTRÓNICOS

TEXTOS ELECTRÓNICOS, BASES DE DATOS Y PROGRAMAS INFORMÁTICOS

Responsable principal. Título [tipo de soporte]. Responsables secundarios*. Edición. Lugar de publicación: editor, fecha de publicación, fecha de actualización o revisión, [fecha de consulta]**. Descripción física*. (Colección)*. Notas*. Disponibilidad y acceso** . Número normalizado*

Ejemplos (en norma ISO 690-2):

CARROLL, Lewis. Alice’s Adventures in Wonderland [en línea]. Texinfo ed. 2.1. [Dortmund, Alemania]: WindSpiel, November 1994 [ref. de 10 de febrero de 1995]. Disponible en Web: <http://www.germany.eu.net/books/carroll/alice.html>. Igualmente disponible en versiones PostScrip y ASCII en Internet: <ftp://ftp.Germany.EU.net/pub/books/carroll/>

U.S. ISBN Agency. The Digital World and the Ongoing Development of ISBN [en línea]. New Providence, N.J.: RR Bowker, s.d. [ref. de 16 de agosto 2002]. Disponible en Web: http://www.isbn.org/standards/home/isbn/digitalworld.asp>.

Otros:

Museo Nacional Centro de Arte Reina Sofía. Catálogo [en línea]: de la biblioteca. <http://museoreinasofia.mcu.es/biblio/default.htm> [Consulta: 21 de abril de 1999]

PARTES DE TEXTOS ELECTRÓNICOS, BASES DE DATOS Y PROGRAMAS INFORMÁTICOS

Responsable principal (del documento principal). Título [tipo de soporte]. Responsable(s) secundario(s) (del documento principal*). Edición. Lugar de publicación: editor, fecha de publicación, fecha de actualización o revisión [fecha de consulta]**. "Designación del capítulo o parte, Título de la parte", numeración y/o localización de la parte dentro del documento principal*. Notas*. Disponibilidad y acceso**. Número normalizado*

Ejemplos (en norma ISO 690-2):

CARROLL, Lewis. Alice's Adventures in Wonderland [en línea]. Texinfo. ed. 2.2. [Dortmund, Alemania]: WindSpiel, November 1994 [ref. de 30 marzo 1995]. Chapter VII. A Mad Tea-Party. Disponible en World Wide Web: <http://www.germany.eu.net/books/carroll/alice_10.html#SEC13>.

CONTRIBUCIONES EN TEXTOS ELECTRÓNICOS, BASES DE DATOS Y PROGRAMAS INFORMÁTICOS

Son aquéllas partes de documentos que tienen un contenido unitario e independiente de las otras partes del documento que las contiene.

Responsable principal (de la contribución). "Título" [tipo de soporte]. En: Responsable principal (del documento principal). Título. Edición. Lugar de publicación: editor, fecha de publicación, fecha de actualización o revisión [fecha de consulta]**. Numeración y/o localización de la contribución dentro del documento fuente. Notas*. Disponibilidad y acceso**. Número normalizado*

Ejemplos (en norma ISO 690-2):

Political and Religious Leaders Support Palestinian Sovereignty Over Jerusalem. IN Eye on the Negotiations [en línea].

Palestine Liberation Organization, Negotiations Affairs Department, 29 August 2000 [ref. de 15 agosto 2002]. Disponible en Web: <http://www.nad-plo.org/eye/pol-jerus.html>.

Belle de Jour. Magill's Survey of Cinema [en línea]. Pasadena (Calif.): Salem Press, 1985- [ref. de 1994-08-04]. Accession no. 0050053. Disponible en DIALOG Information Services, Palo Alto. (Calif.).

MCCONNELL, WH. Constitutional History. The Canadian Encyclopedia [CD-ROM]. Macintosh version 1.1. Toronto: McClelland & Stewart, c1993. ISBN 0-7710-1932-7.

PUBLICACIONES ELECTRÓNICAS SERIADAS COMPLETAS

Responsable principal. Título [tipo de soporte]. Edición. Designación de los números (fecha y/o número)*. Lugar de publicación: editor, fecha de publicación [fecha de consulta]**. Descripción física*. (Colección)*. Notas*. Disponibilidad y acceso**. Número normalizado

Ejemplos (en norma ISO 690-2):

Journal of Technology Education [en línea]. Blacksburg (Virginie): Virginia Polytechnic Institute and State University, 1989- [ref. de 15 marzo 1995]. Semestral. Disponible en Internet: <gopher://borg.lib.vt.edu:70/1/jte>. ISSN 1045-1064.

Profile Canada [CD-ROM]. Toronto: Micromedia, 1993- . The Canadian Connection. Acompañado por: User's guide. Configuracion necesaria: IBM PC ó compatible; lector CD-ROM MPC Standard; DOS 3.30 ó más; 490 kB RAM; MS-DOS Extensiones 2.1 ó más. Trimestral.

ARTÍCULOS Y CONTRIBUCIONES EN PUBLICACIONES ELECTRÓNICAS SERIADAS

Responsable principal (del artículo). "Título (del artículo)". Título (de la publicación principal) [tipo de soporte]. Edición. Designación del número de la parte. Fecha de actualización o revisión [fecha de consulta]**. Localización de la parte dentro del documento principal. Notas*. Disponibilidad y acceso**. Número normalizado.

Ejemplos (en norma ISO 690-2):

STONE, Nan. The Globalization of Europe. Harvard Business Review [en línea]. May-June 1989 [ref. de 3 septembre 1990]. Disponible en BRS Information Technologies, McLean (Virginie).

PRICE-WILKIN, John. Using the World-Wide Web to Deliver Complex Electronic Documents: Implications for Libraries. The Public-Access Computer Systems Review [en línea]. 1994, vol. 5, no. 3 [ref. de 1994-07-28], pp. 5-21. Disponible sur Internet: <gopher://info.lib.uh.edu:70/00/articles/e-journals/uhlibrary/pacsreview/v5/n3/pricewil.5n3>.ISSN 1048-6542

Otros:

CUERDA, José Luis. "Para abrir los ojos" [en línea]. El País Digital. 9 mayo 1997 nº 371. http://www.elpais.es/p/19970509/cultura/tesis.htm/uno [consulta: 9 mayo 1997]

BOLETINES DE NOTICIAS, LISTAS DE DISCUSIÓN

Título [tipo de soporte]. Responsable(s) secundario(s). Lugar de publicación: editor, fecha de publicación [Fecha de consulta]**. Notas*. Disponibilidad y acceso**

Ejemplo (en norma ISO 690-2):

PACS-L (Public Access Computer Systems Forum) [en línea]. Houston (Tex.): University of Houston Libraries, Junio 1989- [ref. de 17 mayo 1995]. Disponible en Internet: <listserv@uhupvm1.uh.edu>.

E-BOOKS

Según el manual de estilo de la MLA, se haría la referencia bibliográfica como en el caso de un libro impreso, añadiendo al final el tipo de fichero si se conoce. Si no tenemos identificado el tipo de fichero, se añadiría el tipo genérico 'Digital file'.

Ejemplo (estilo MLA):

Rowley, Hazel. Franklin and Eleanor: An Extraordinary Marriage. New York: Farrar, 2010. Kindle file.

TWEETS

Siguiendo el manual de estilo de la MLA, los elementos de la referencia bibliográfica serían:

Apellido, nombre del autor. "Texto del tweet". Fecha, hora del mensaje. Medio de publicación (Tweet).

Ejemplo (estilo MLA):

Athar, Sohaib. "Helicopter hovering above Abbottabad at 1AM (is a rare event)." 1 May 2011, 3:58 p.m. Tweet.

MENSAJES ELECTRÓNICOS

Distribuídos por boletines o listas: Responsable principal del mensaje. "Título del mensaje" [tipo de soporte]. En: Título (del boletín o lista). Numeración y/o localización del mensaje [Fecha de consulta]**. Notas*. Disponibilidad y acceso**

Ejemplo (en norma ISO 690-2):

PARKER, Elliott. "Re: Citing Electronic Journals". En: PACS-L (Public Access Computer Systems Forum) [en línea]. Houston (Tex.) : University of Houston Libraries, 24 November 1989; 13:29:35 CST [citado 1 enero 1995;16:15 EST]. Disponible en Internet: <telnet://brsuser@a.cni.org>.

Mensajes electrónicos personales: Responsable principal del mensaje. "Título del mensaje" [tipo de soporte]. Fecha del mensaje. Nota con el tipo de mensaje

Ejemplo (en norma ISO 690-2):

Thacker, Jane. "MPEG-21 project stream on digital item identification" [en línea]. Mensaje en: <iso.tc46.sc9@nlc-bnc.ca>. 3 octubre 2000; 13:33 EST [ref. de 6 octubre 2000; 13:10 EST]. Message-ID: <002f01c02d60$051a64a0$22a2580c@vaio>. Comunicación personal.

PRESENTACIÓN Y ORDENACIÓN DE LISTAS DE REFERENCIAS BIBLIOGRÁFICAS

Existen dos tipos de presentación:

Las referencias que van al final de la obra se ordenan generalmente según el orden alfabético del primer elemento (autor o título).

Las citaciones bibliográficas se ordenan siguiendo una sucesión numérica que corresponde al orden de citas en el texto.

En caso de haber varios documentos de un mismo autor, se reemplaza el primer elemento de la segunda referencia y siguientes por una raya.

Ejemplo:

Graham, Sheila. College of one. New York: Viking, 1967. The real F. Scott Fitzgerald Thirty-five years later. NewYork: Grosset &Dunlap, 1976.

Acceso a RefWorks: Gestor bibliográfico. EndNote Web: gestor de referencias bibliográficas

CITAS

Una citación es una forma de referencia breve colocada entre paréntesis dentro de un texto o añadida a un texto como nota a pie de página, al final de un capítulo, o al final de la obra completa. La citación permite identificar la publicación de la que se extrae la idea parafraseada.

Ejemplo: (Umberto Eco, 1993, p.240-245)

La norma ISO-690 define en su capítulo 9 las relaciones entre las referencias y las citaciones bibliográficas, y los diferentes métodos de citas.

Para citar direcciones electrónicas y páginas web puede consultar: Recomendaciones para direcciones electrónicas de Isidro F. Aguillo (pdf)

BIBLIOGRAFÍA

NORMAS

INTERNATIONAL STANDARIZATION ORGANIZATION. Documentation Références bibliographiques- contenu, forme et structure. Norme international ISO 690:1987 (F). 2a ed. Genève: ISO, 1987, 11 p.

INTERNATIONAL STANDARIZATION ORGANIZATION. Information Références bibliographiques. Partie 2: Documents électroniques, documents ou parties de documents. Norme international ISO 690-2: 1997 (F).Genève: ISO, 1997, 18 p.

AENOR: Documentación. Referencias bibliograficas. contenido, formas y estructura. UNE 50 104 94. Madrid: AENOR, 1994.

AENOR. Documentación : recopilación de normas UNE / AENOR. 2ª ed. Madrid: AENOR, 1997.

Consulte la lista de ediciones de las ISBD (International Standard Bibliographic

Description) para los distintos tipos de documentos en nuestro catálogo. Consulte la lista de ediciones de las AACR (Anglo-American cataloguing rules) en nuestro catálogo.

LIBROS DE ESTILO DE OTROS ESTÁNDARES DE CITAS

AMERICAN PSYCOLOGICAL ASSOCIATION. ApaStyle.org. Style tips [en línea]. APA, s.d. <http://www.apastyle.org/styletips.html>. [Consulta: 9 septiembre 2002]

The Chicago manual of style. 14th ed. Chicago; London: University of Chicago Press,1993. ISBN: 0-226-10389-7

Algunos ejemplos prácticos sobre “APA Citation Style”:

Manual de estilo APA. Luis Carro

Página de Cornell University Library

Página de “Online Writing Lab”

THE MODERN LANGUAGE ASSOCIATION OF AMERICA. MLA Style Manual and Guide to Scholarly Publishing. Gibaldi, Joseph (ed. lit.). 2nd ed. 1998. 343 p. ISBN: 0-87352-699-6

THE MODERN LANGUAGE ASSOCIATION OF AMERICA. MLA Handbook for Writers of Research Papers. Gibaldi, Joseph (ed. lit.). 5th ed. 1999. 332 p. ISBN: 0-87352-975-8

HARNACK, Andrew; KLEPPINGER, Eugene. Online! A reference guide to use internet sources [en línea]. Bedford/St. Martin’s, actualización 2001 [Consulta 9 septiembre 2002]. Chapters 5-8. Citation styles. <http://www.bedfordstmartins.com/online/citex.html>

CONCORDIA UNIVERSITY LIBRARIES. Citation & Style Guides [en línea]. Last updated on July 18, 2002. <http://juno.concordia.ca/services/citations.html> [Consulta: 9 septiembre 2002]

Internet citation guides. Citing Electronic Sources in Research Papers and Bibliographies [en línea]. Susan Barribeau (comp.); Jessica Baumgart (act.) Wisconsin: University of Wisconsin-Madison, Memorial Library, updated: March 7, 2001. <http://www.library.wisc.edu/libraries/Memorial/citing.htm> [Consulta: 9 septiembre 2002]

ESTIVILL, Assumpció; URBANO, Cristóbal. Cómo citar recursos electrónicos [en línea]. Versión 1.0. [Barcelona]: Universitat de Barcelona. Facultat de Biblioteconomía y Documentació, 30 mayo 1997. <http://www.ub.es/biblio/citae-e.htm> [Consulta: 9 septiembre 2002]

- See more at: http://www.uc3m.es/portal/page/portal/biblioteca/aprende_usar/como_citar_bibliografia#sthash.tAttPLH8.dpuf

...Travellers
GUIDE

ONE

KHRONOS
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