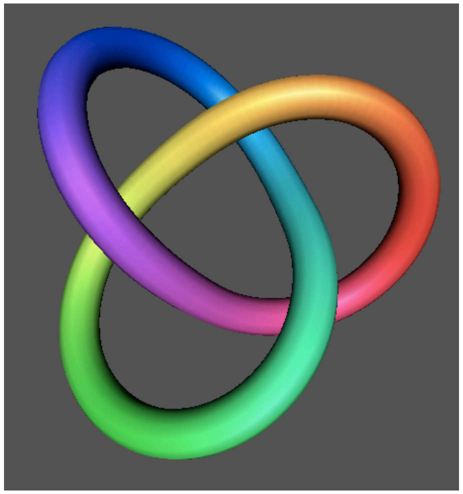

Physical Knots and Particle Topology

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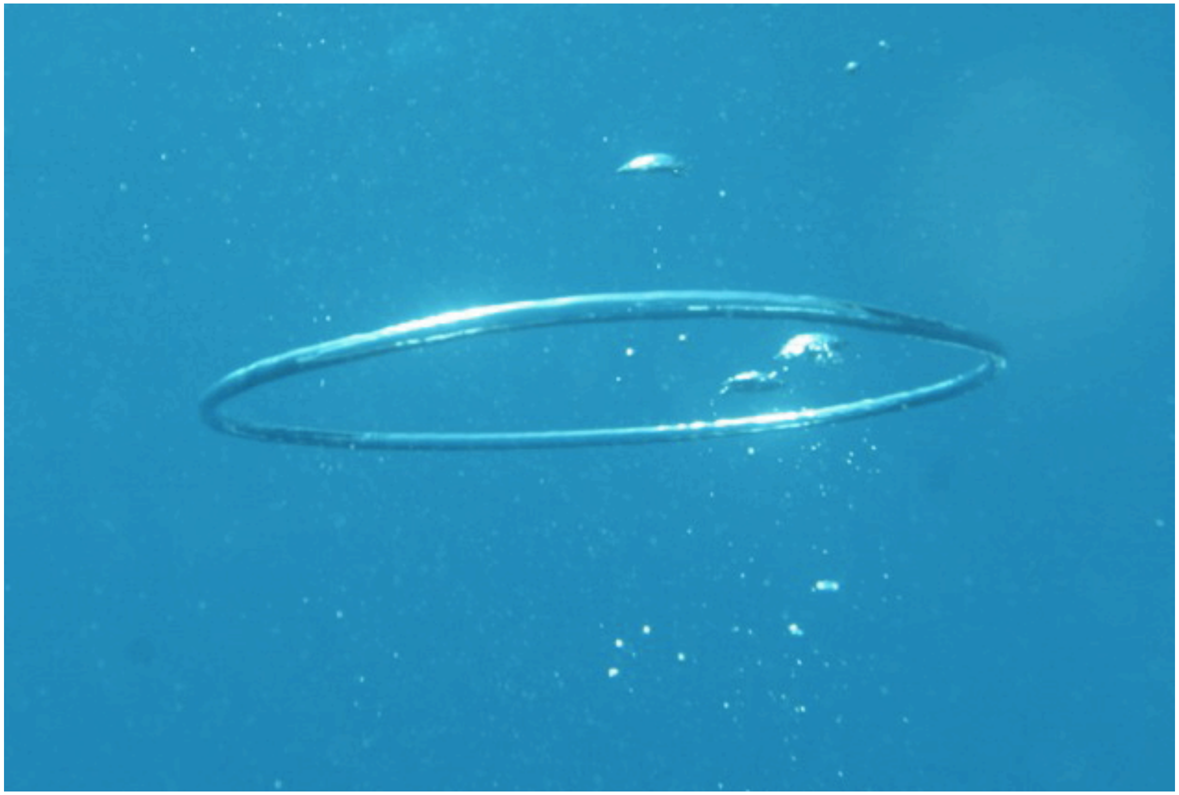
<kauffman@uic.edu>

(including joint work with
Sam Lomonaco,
Sundance Bilson-Thompson,
Jonathon Hackett)

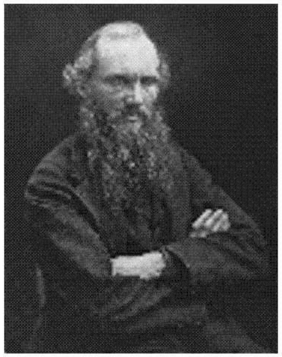
19-th Century
Sir William Thompson (Lord Kelvin)
Theory of (Knotted) Vortex Atoms



Lord Kelvin's Vortex Atoms

Idea of knotted strings as fundamental constituents of matter is old

Lord Kelvin and the
1867 string revolution:



atoms are knotted tubes of aether

- topological stability of knots = stability of matter
- variety of knots = variety of chemical elements

For decades considered as *the* theory of fundamental Matter

Maxwell: *Kelvin's theory satisfies more of the conditions than any atom hitherto considered*

Leadbetter - Besant Atom -- Inspired by Lord Kelvin's Vortex Theory of Atoms

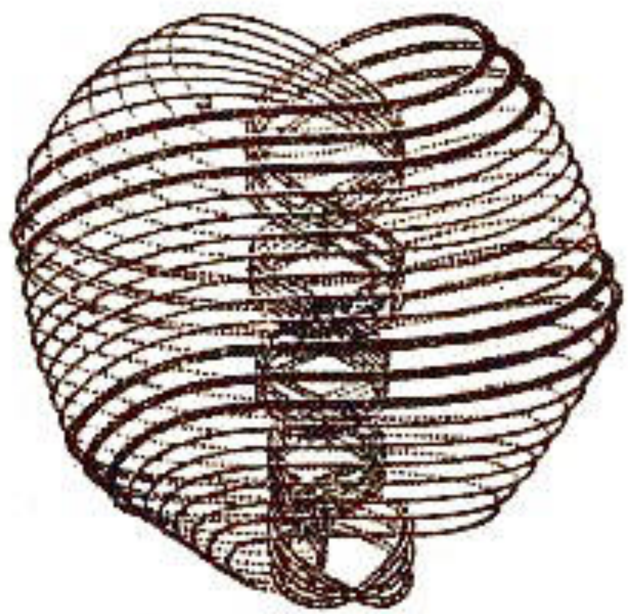
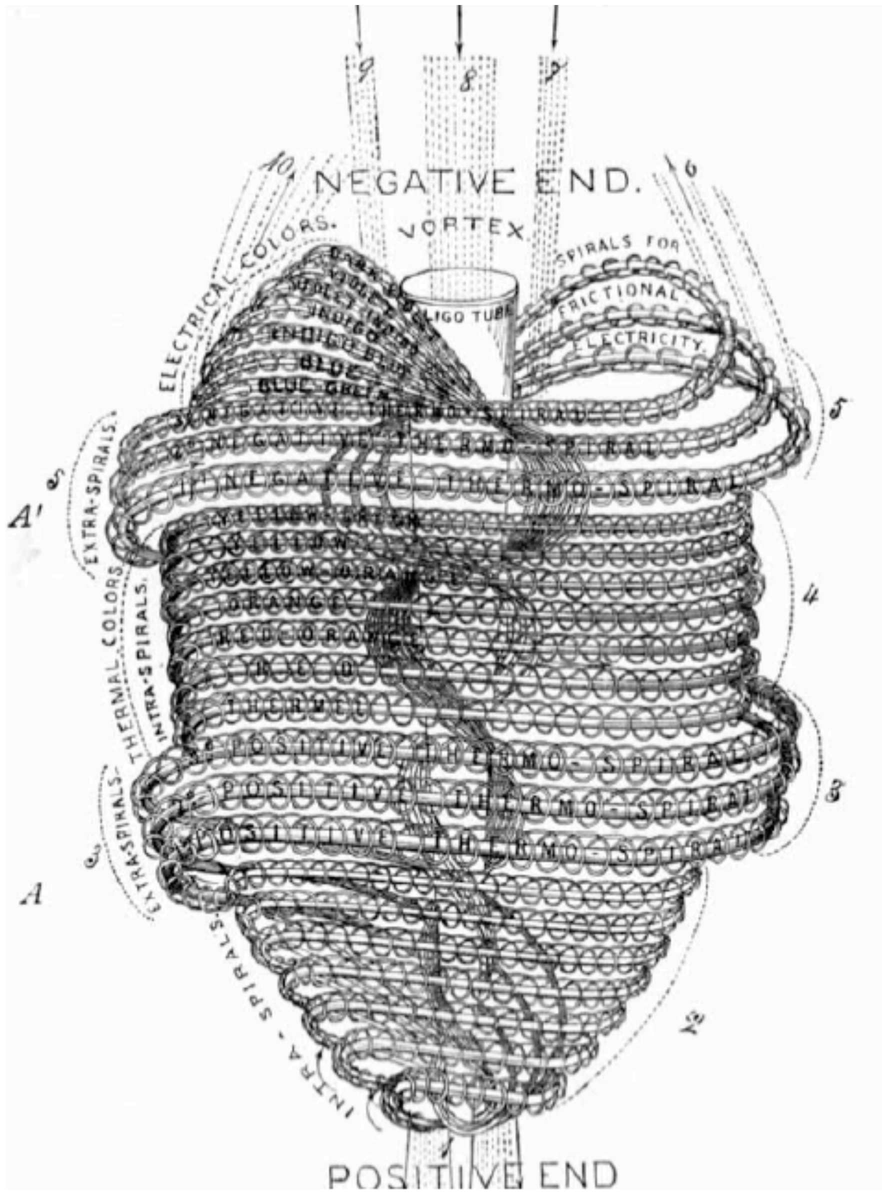
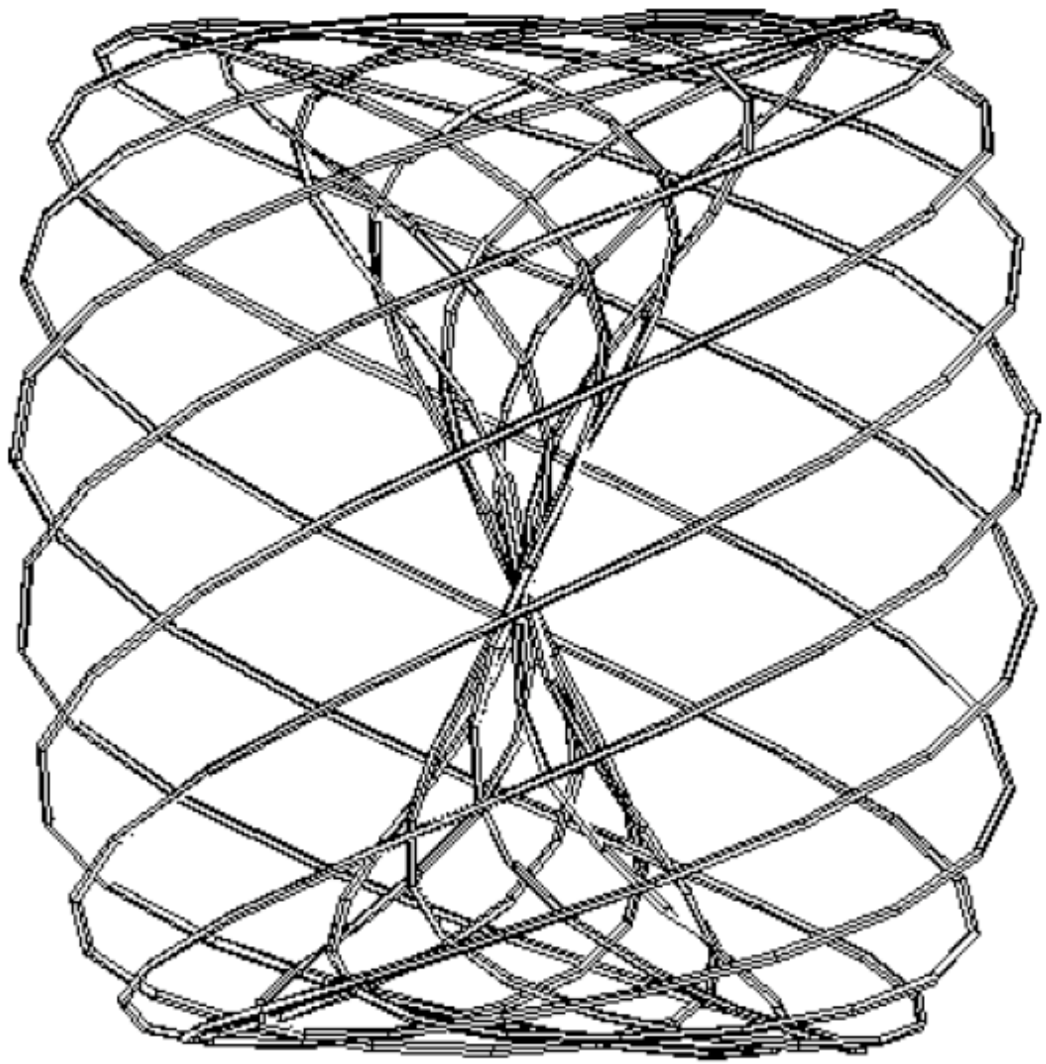


DIAGRAM 20—**An Ultimate Physical Atom.** The atom represented is male or positive. It is a heart-shaped structure, seemingly composed of ten sets of spirally-arranged "wires," of which three sets are thicker than the others. Under observation an atom is seen to be extremely active, three movements being chiefly noticeable: First, it spins rapidly on its axis; second, it moves rapidly round a small orbit; third, it is all the while expanding and contracting, pulsating like a beating heart. All the so-called chemical elements, and hence all compounds of every sort derived from these elements, are made of geometrically-arranged groups of these ultimate atoms.

Babbitt’s Earlier Version





X = COS(8*T)

FIBONACCI FOURIER KNOT

Y= COS(13*T+.5)

Z= .5*COS(21*T + .5) + .5*SIN(13*T + .5)

Creation and Dynamics of Knotted Vortices

Dustin Kleckner[1] & William T. M. Irvine[1]

[1]*James Franck Institute, Department of Physics, The University of Chicago, Chicago, Illi*

60637, USA

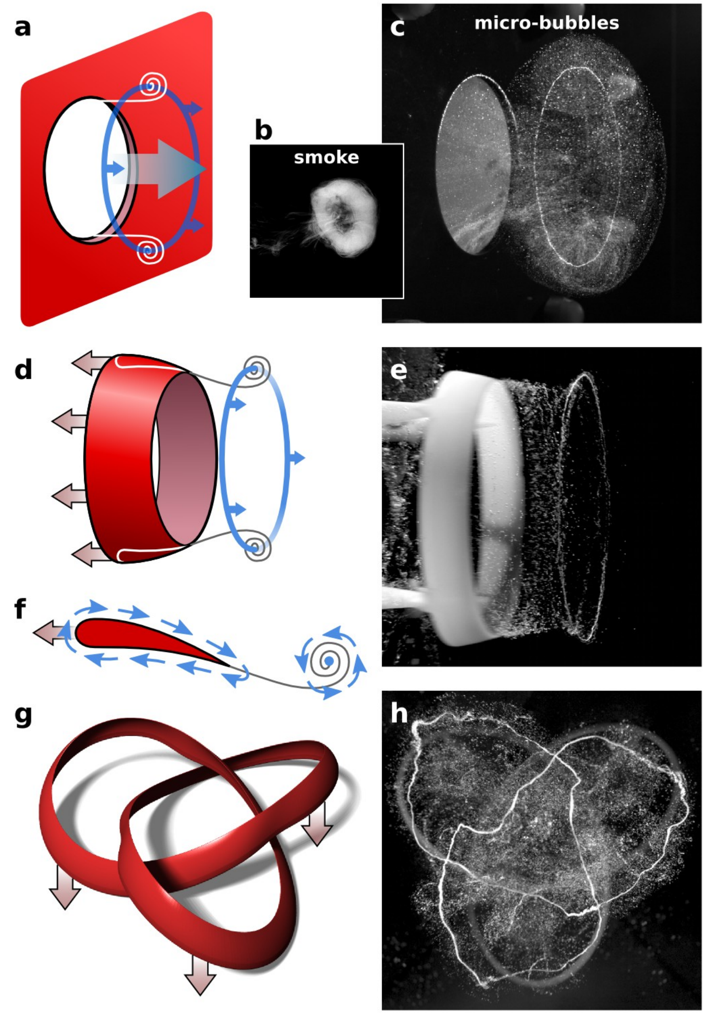
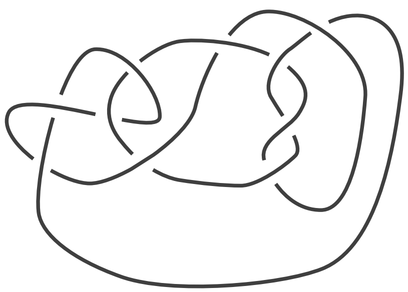
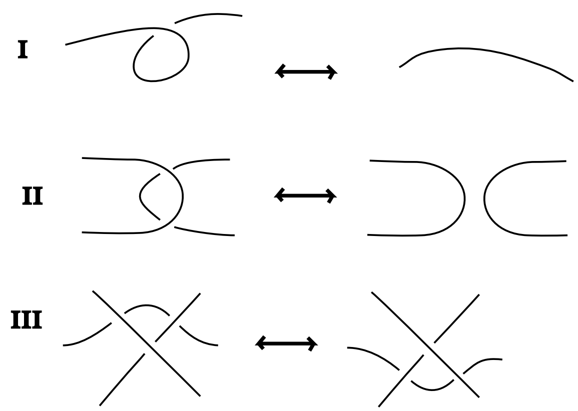
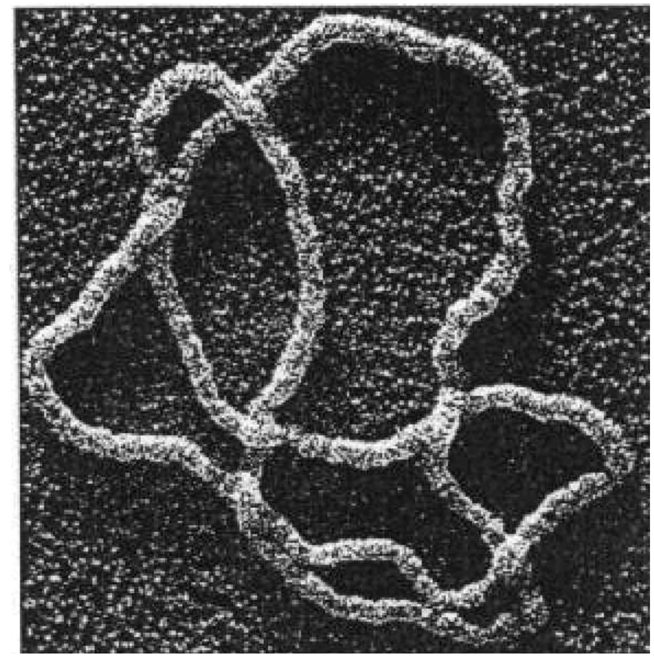


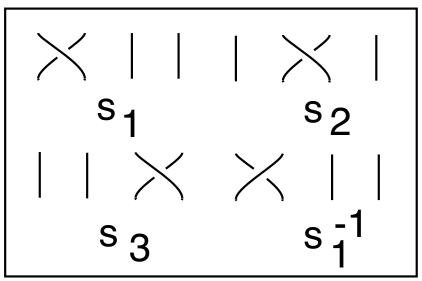
FIG. 1. The creation of vortices with designed shape and topology. **a,** The conventional method for generating a vortex ring, in which a burst of fluid is forced through an orifice. **b,** A vortex ring in air visualized with smoke. **c,** A vortex ring in water traced by a line of ultra-fine gas bubbles, which show finer core details than smoke or dye. **d-e,** A vortex ring can alternatively be generated as the starting vortex of a suddenly accelerated, specially designed wing. For a wing with the trailing edge angled inward, the starting vortex moves in the *opposite* of the direction of wing motion **f,** The starting vortex is a result of conservation of circulation – the bound circulation around a wing is balanced by the counter-rotating starting vortex. **g,** A rendering of a wing tied into a knot, used to generate a knotted vortex, shown in **h**.

Knots and Links

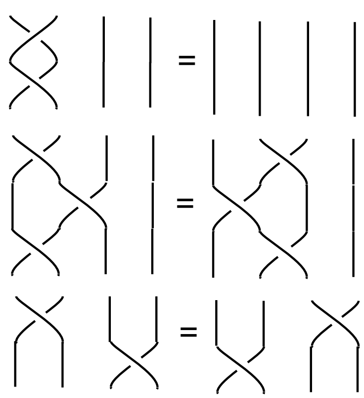








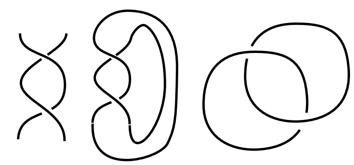
Braid Generators



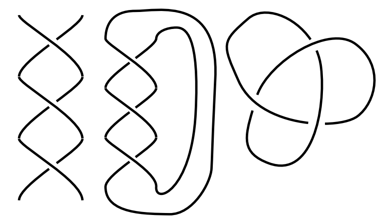
$s_1^{-1} s_1 = 1$

$s_1 s_2 s_1 = s_2 s_1 s_2$

$s_1 s_3 = s_3 s_1$



Hopf Link



Trefoil Knot

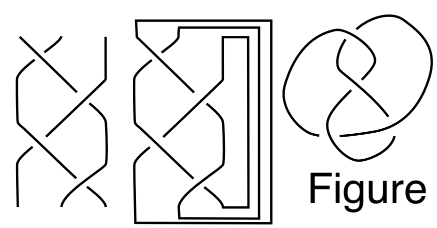
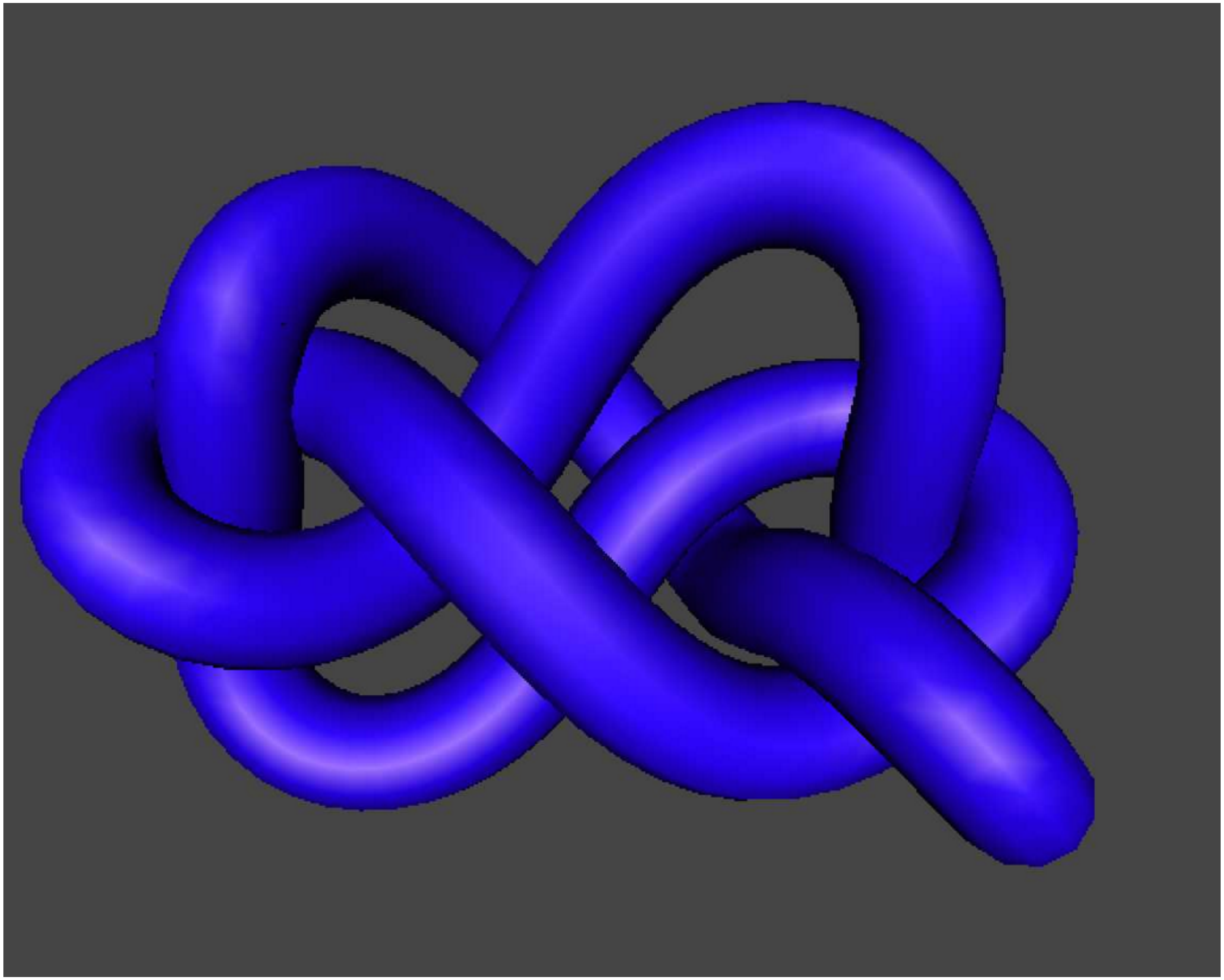
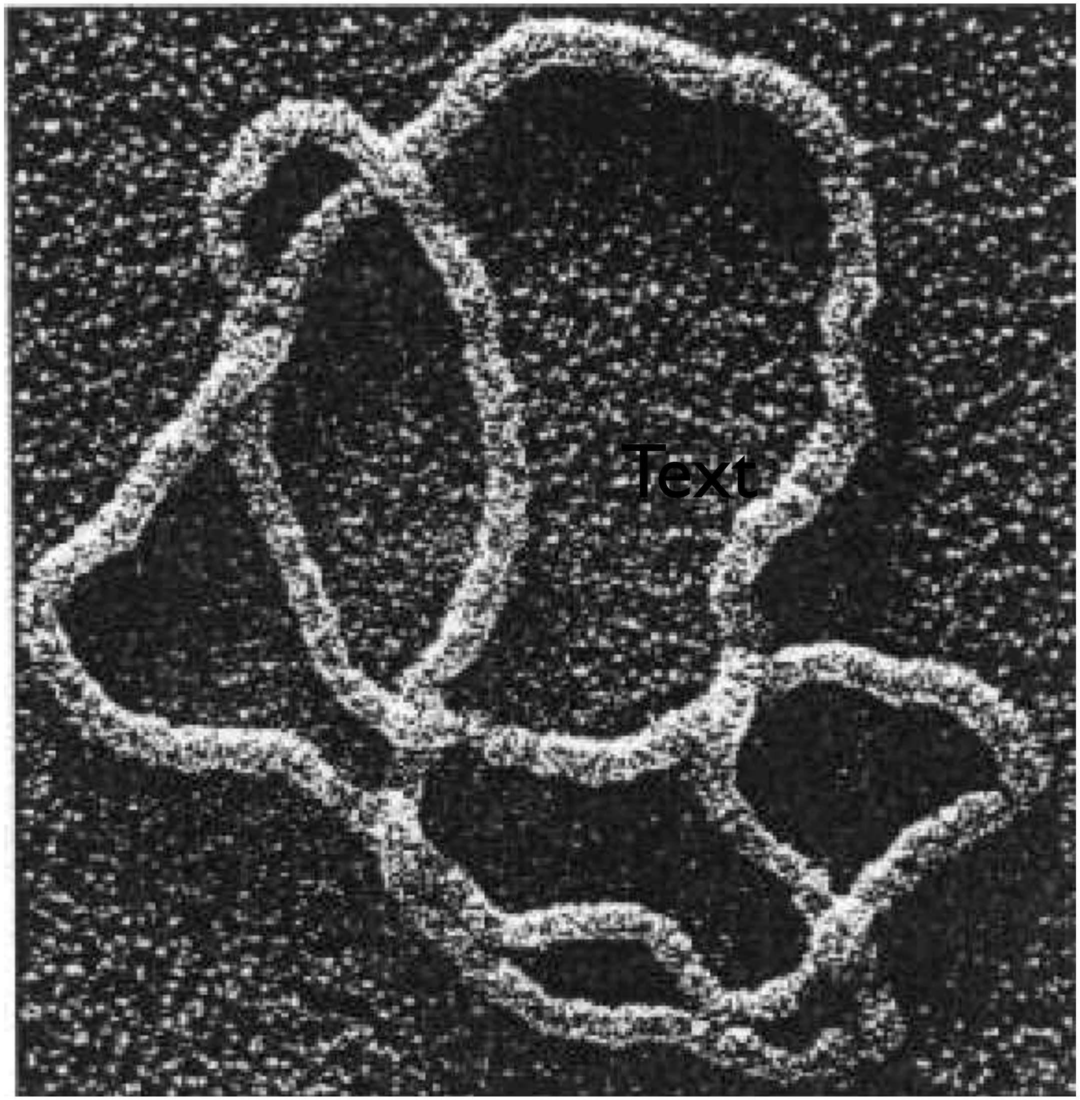


Figure Eight Knot



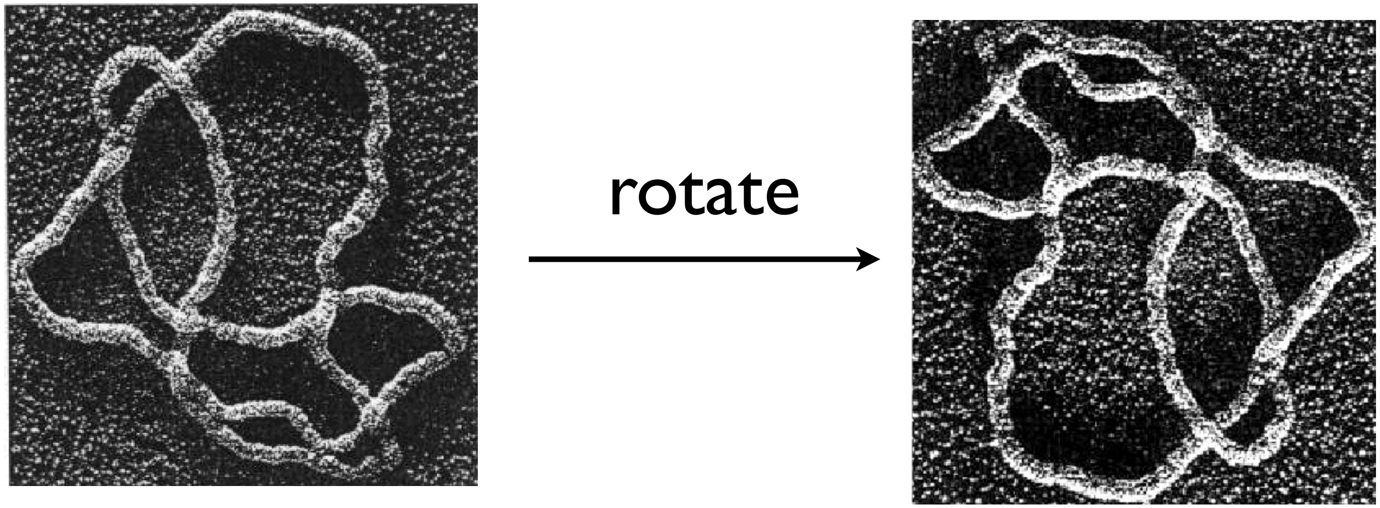
Is it Knotted? (See Rob Scharein's Program: KnotPlot)

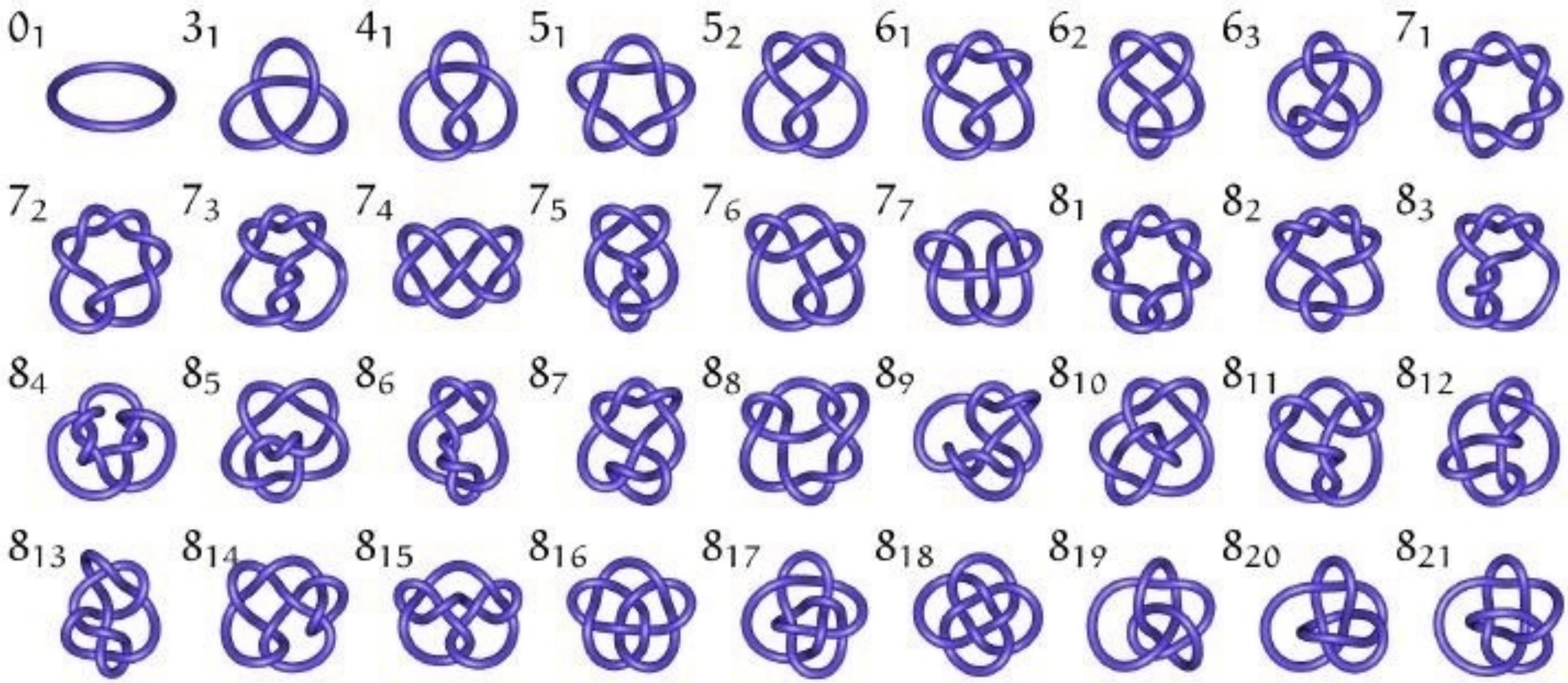
Knotted DNA - Electron Micrograph, Protein Coated DNA Molecule



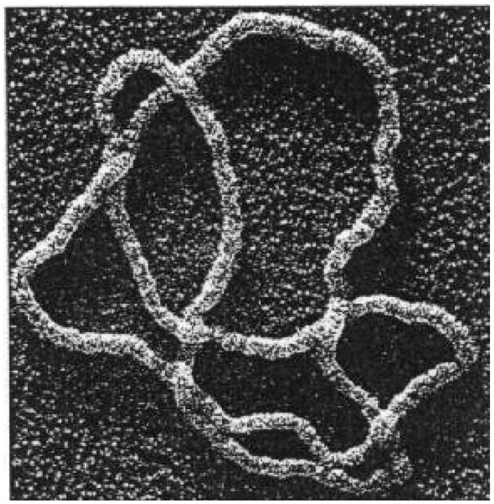
Work of Cozzarelli, Stasiak and Spengler.

Spengler SJ, Stasiak A, Cozzarelli NR. The stereostructure of knots and catenanes produced by phage lambda integrative recombination: implications for mechanism and DNA structure. *Cell*. 1985 Aug; **42**(1):325–334.


rotate


0_1 3_1 4_1 5_1 5_2 6_1 6_2 6_3 7_1
7_2 7_3 7_4 7_5 7_6 7_7 8_1 8_2 8_3
8_4 8_5 8_6 8_7 8_8 8_9 8_{10} 8_{11} 8_{12}
8_{13} 8_{14} 8_{15} 8_{16} 8_{17} 8_{18} 8_{19} 8_{20} 8_{21}

DNA Knotting and Recombination



Tangle Model for DNA Recombination: C. Ernst and D.W. Sumners.

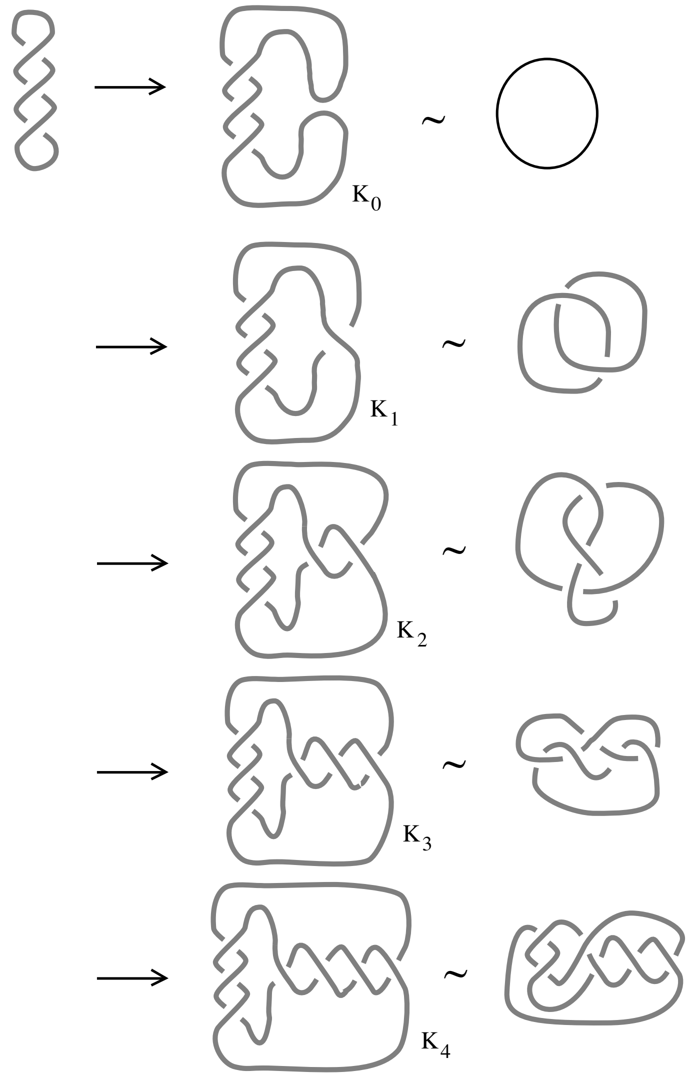


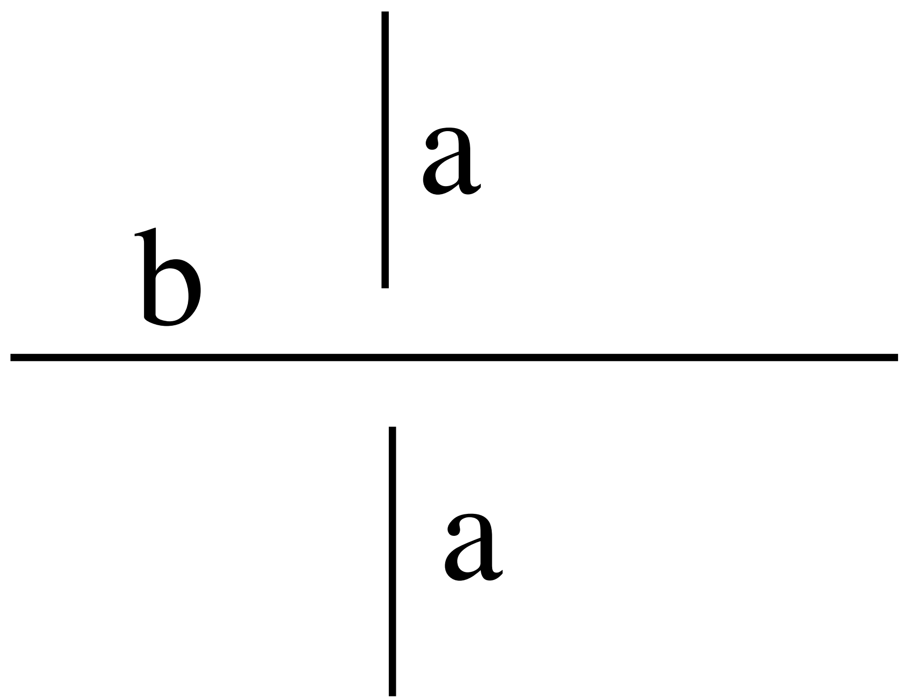
Figure 28 - Processive Recombination with $S = [-1/3]$.

Patterned Integrity

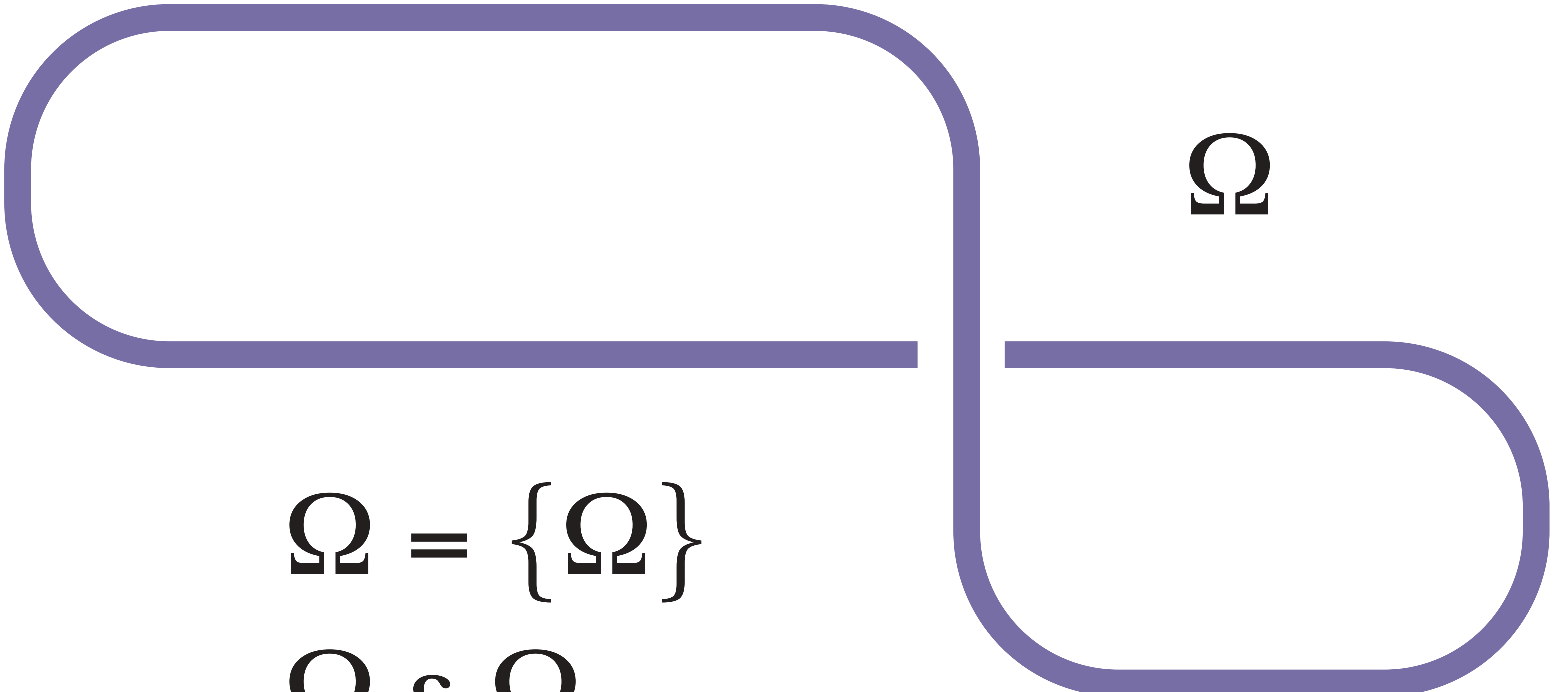
The knot is information independent
of the substrate that carries it.

Knot Sets

Knot Sets

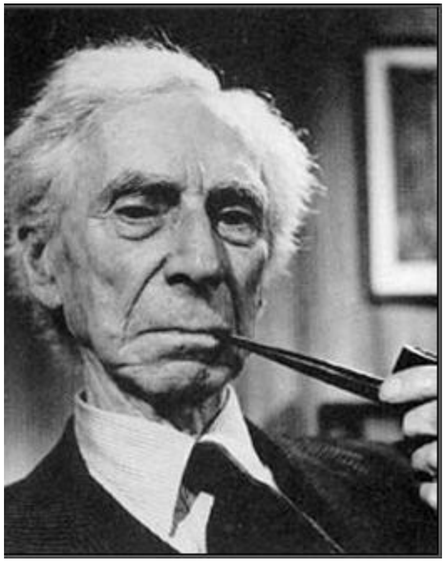


$\boxed{a\ \varepsilon\ b}$



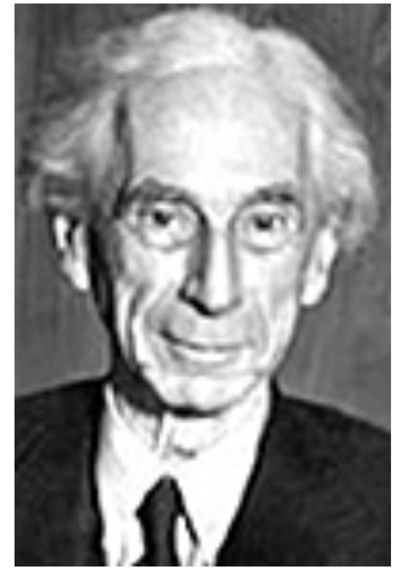
$$\Omega = \{\Omega\}$$

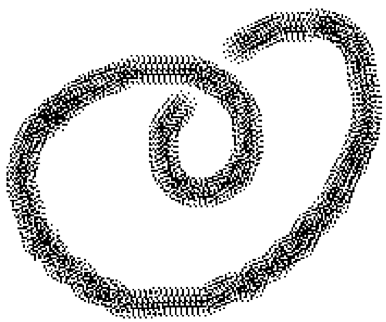
$$\Omega \ \varepsilon \ \Omega$$



$$\boxed{\begin{aligned} Rx &= {\sim}xx \\ RR &= {\sim}RR \end{aligned}}$$

Russell Paradox (K)not.



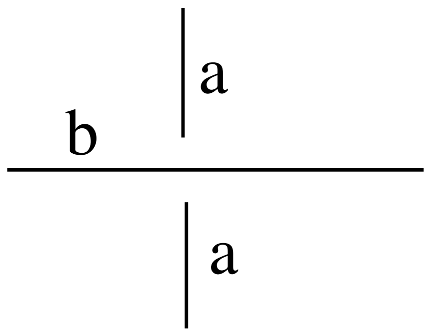


A
belongs to A.

$\Longleftrightarrow$

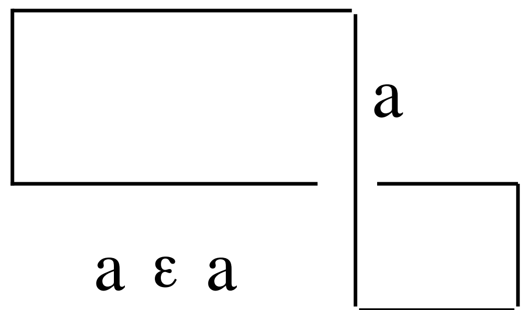
A does not
belong to A.

Knot Sets



$\boxed{a \,\varepsilon\, b}$

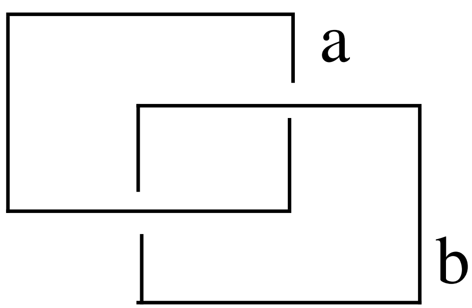
Crossing as Relationship



$a \;\varepsilon\; a$

$a = \{a\}$

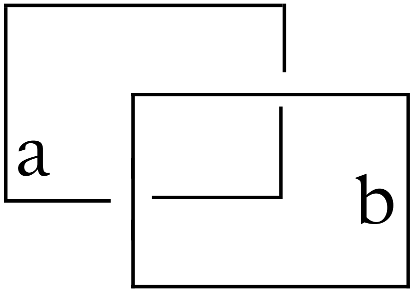
Self-Membership



Mutuality

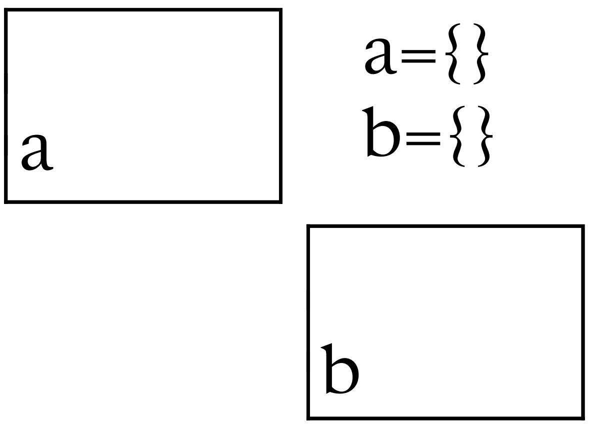
$a=\{b\}$

$b=\{a\}$



$a = \{\}$
$b = \{a,a\}$

topological equivalence

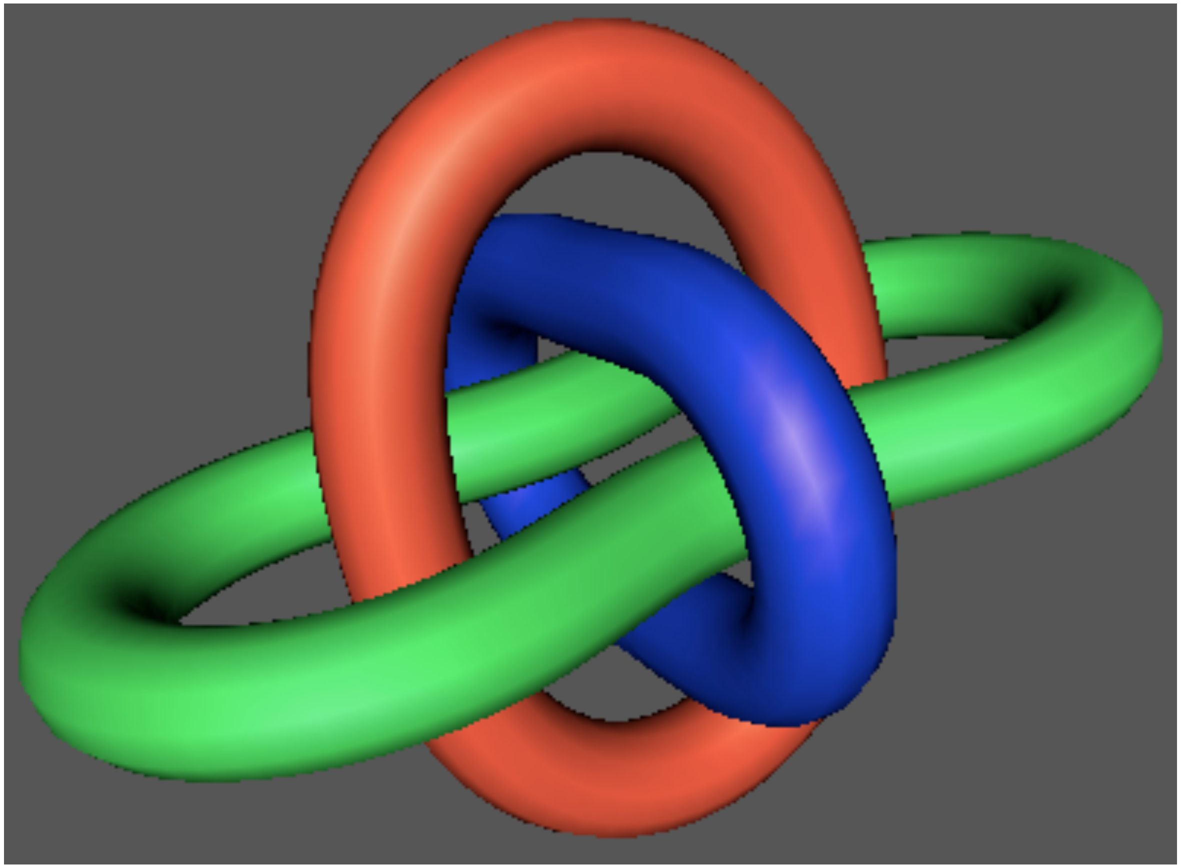


$a=\{\}$
$b=\{\}$

Knot Sets are "Fermionic". Identical elements cancel in pairs.

(There is no problem with invariance under third Reidemeister move.)

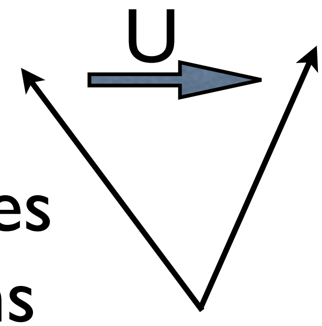
Borromean Rings



Green surrounds Red.
Red surrounds Blue.
Blue surrounds Green.

Quantum Mechanics in a Nutshell

0. A state of a physical system corresponds to a unit vector $|S\rangle$ in a complex vector space.

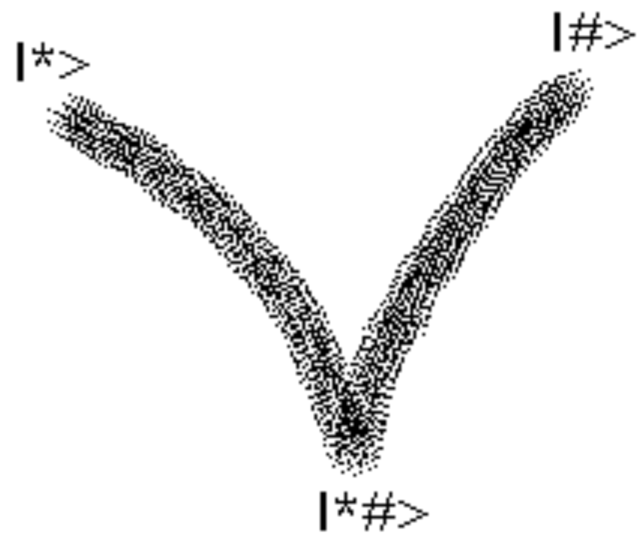


1. (measurement free) Physical processes are modeled by unitary transformations applied to the state vector: $|S\rangle \text{ -----> } U|S\rangle$

2. If $|S\rangle = z1|e1\rangle + z2|e2\rangle + \ldots + zn|en\rangle$ in a measurement basis $\{|e1\rangle,|e2\rangle,\ldots,|en\rangle\}$, then measurement of $|S\rangle$ yields $|ei\rangle$ with probability $|zi|$^2.

An Entangled State

The EPR State



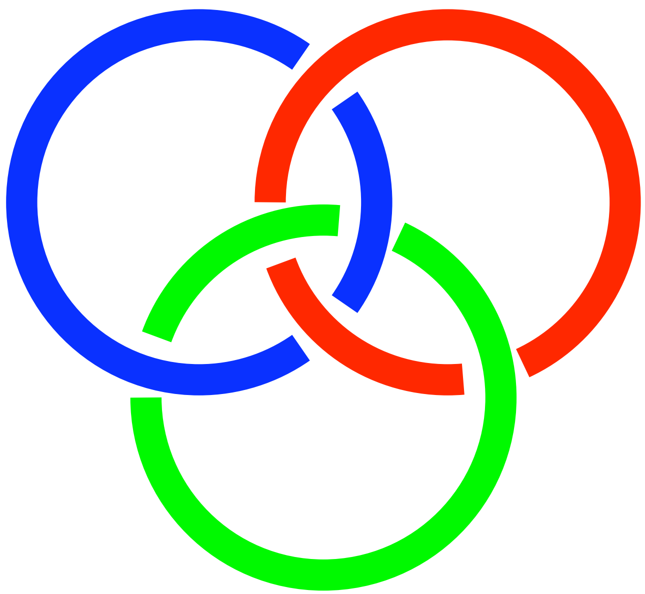
$|*\#\rangle = (|01\rangle + |10\rangle)/\mathrm{Sqrt}(2)$

Quantum Entanglement and Topological Entanglement

An example of Aravind [1] makes the possibility of such a connection even more tantalizing. Aravind compares the Borromean rings (see figure 2) and the GHZ state

$$|\psi\rangle = (|\beta_1\rangle|\beta_2\rangle|\beta_3\rangle - |\alpha_1\rangle|\alpha_2\rangle|\alpha_3\rangle)/\sqrt{2}.$$

(|000> - |111>)/Sqrt(2)



Is the Aravind analogy only superficial?!

Compare

|000>+|111>

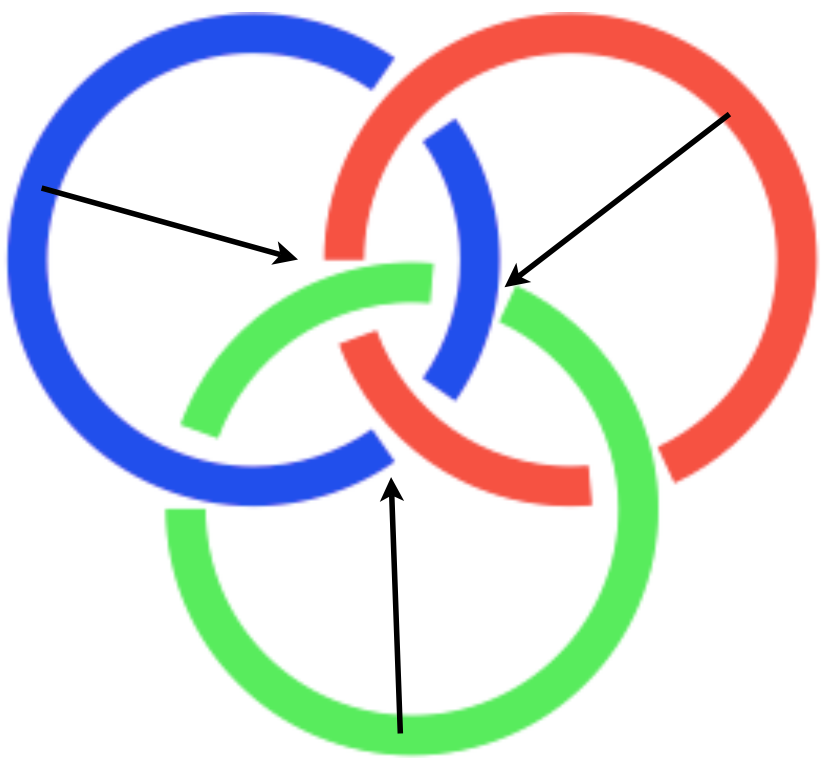
and

|100>+|010>+|001>.

In the second case, observation in a given tensor factor yields an entangled state with 50-50 probability.

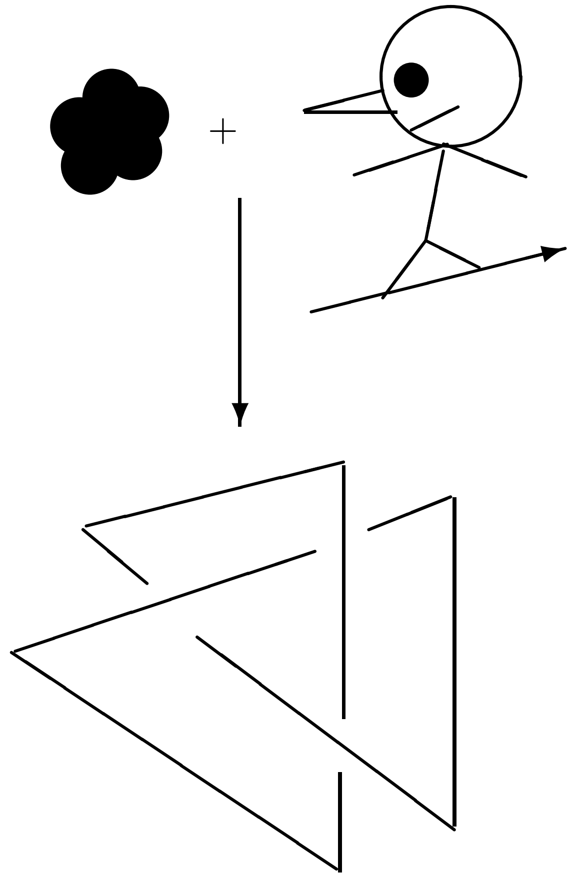
In this way, we can make a case for quantum knots.

You can imagine a topological state that is a superposition of multiple link types.



Quantum Knots

WHAT IS A QUANTUM KNOT?



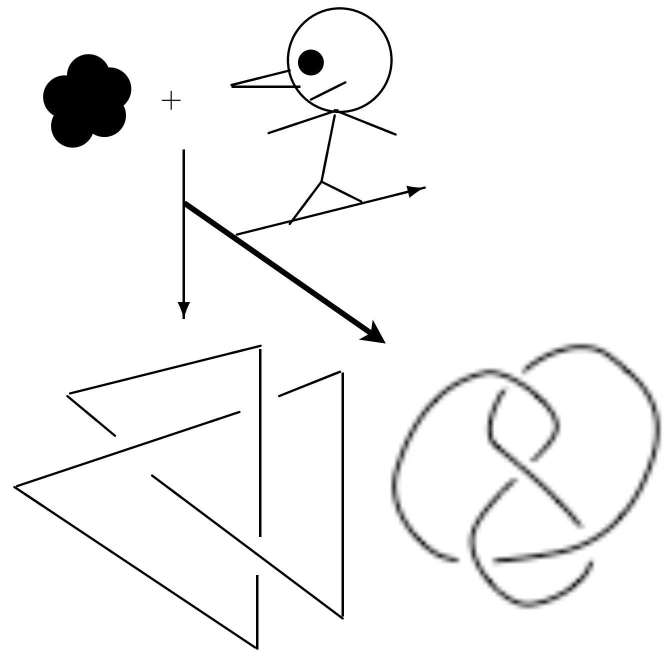
Observing a Quantum Knot

We need Quantum Knots!

a|K> + b|K’>

K: probability |a|^2

K’:probability |b|^2



K K’

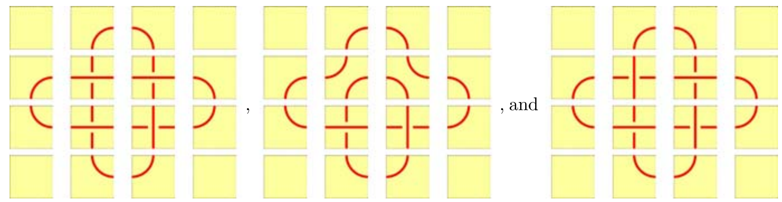
Observing a Quantum Knot

Definition. A *quantum knot* is a linear superposition of classical knots.

(or a linear superposition of representatives for knot types.)

Quantum knots and mosaics

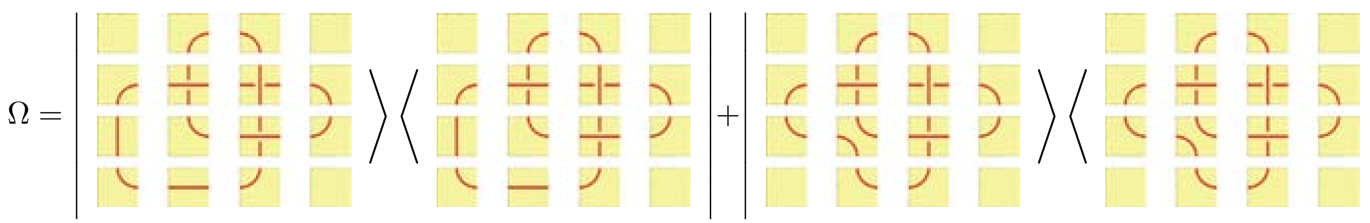
with
Sam
Lomonaco



Each of these knot mosaics is a string made up of the following 11 symbols

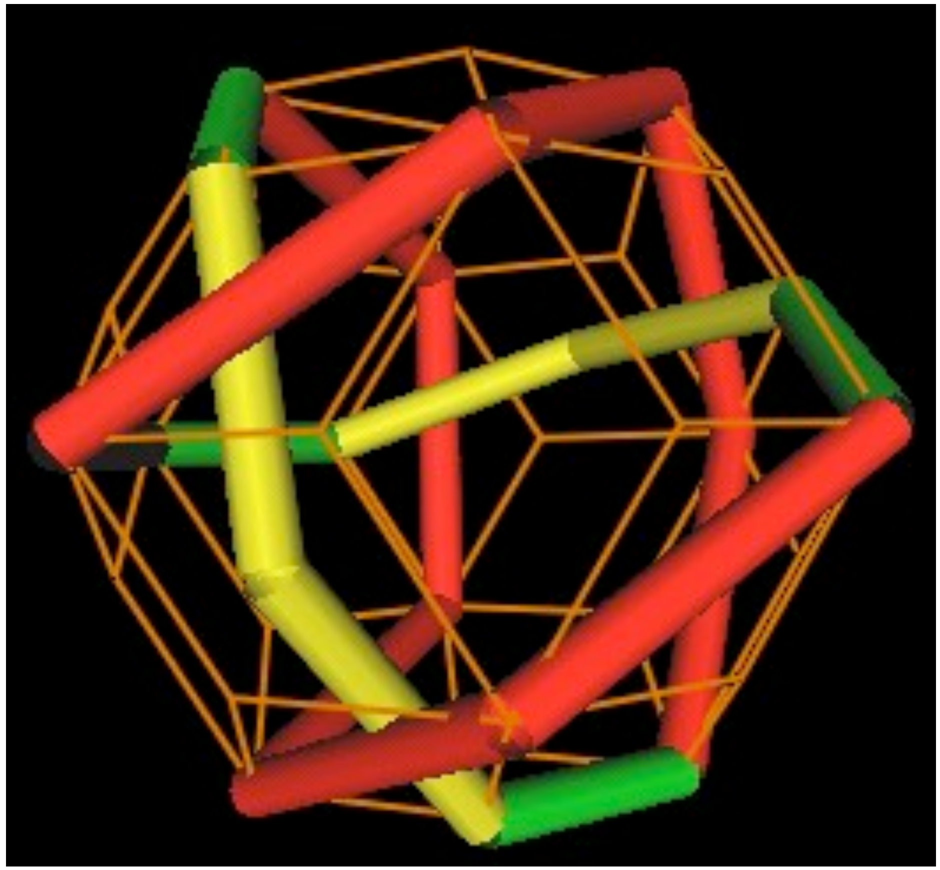
called *mosaic tiles*.

Each mosaic is a tensor product of elementary tiles.



This observable is a quantum knot invariant for 4x4 tile space. Knots have characteristic invariants in nxn tile space.

Knot Woven on the Surface
of a Rhombic Triacontahedron



Courtesy of Robert Gray and
Lynnclaire Dennis

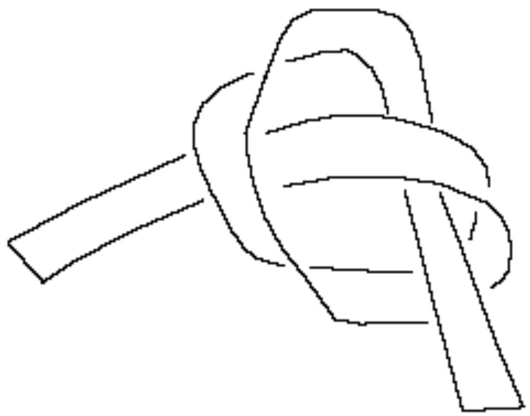


Figure 26 - Tying a Ribbon into a Trefoil Knot

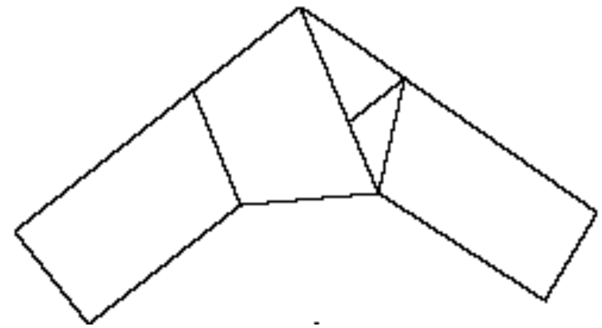
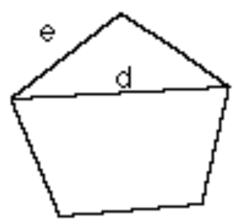


Figure 27 - Tightening the Ribbon Trefoil Knot to Form a Pentagon



$$f = d/e$$

$$d/e = (d+e)/d = 1 + 1/(d/e)$$

$$f = 1 + 1/f$$

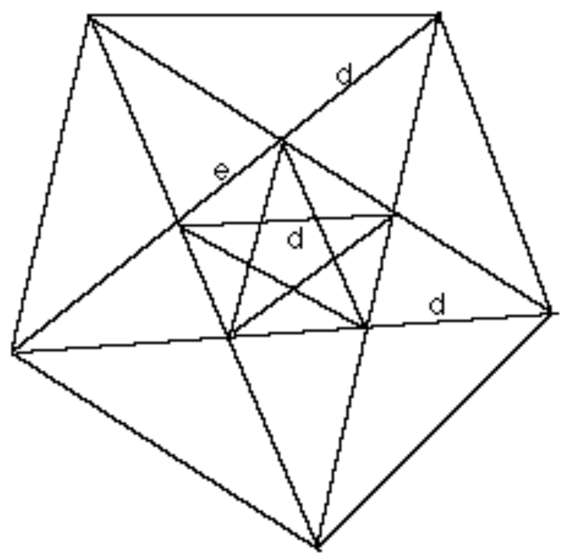
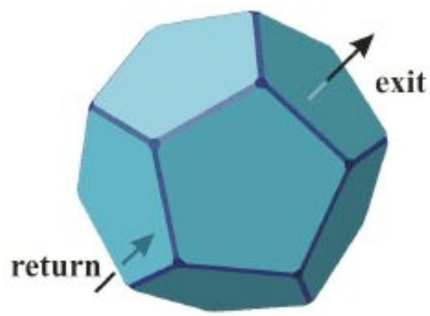
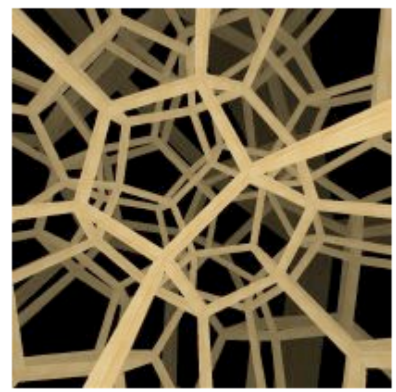


Figure 32 - The Internal Geometry of the Pentagon Gives Rise to the Golden Ratio

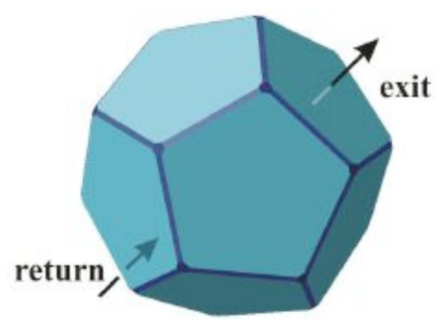
Is the Geometric Universe a Poincare Dodecahedral Space?

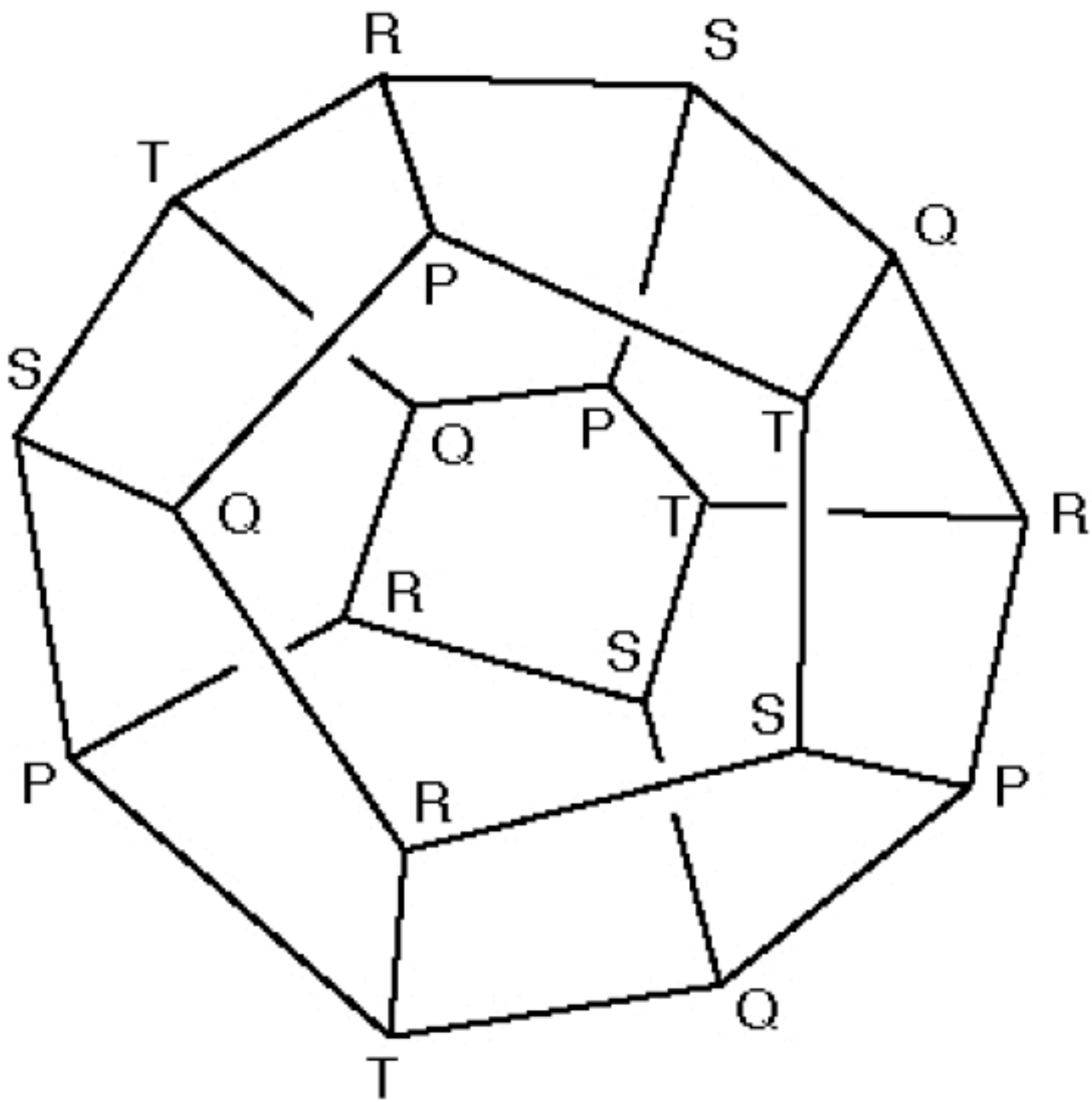




A franco-american team of cosmologists [1] led by J.-P. Luminet, of the Laboratoire Univers et Théories (LUTH) at the Paris Observatory, has proposed an explanation for a surprising detail observed in the Cosmic Microwave Background (CMB) recently mapped by the NASA satellite WMAP. According to the team, who published their study in the 9 October 2003 issue of Nature, an intriguing discrepancy in the temperature fluctuations in the afterglow of the big bang can be explained by a very specific global shape of space (a "topology"). The universe could be wrapped around, a little bit like a "soccer ball", the volume of which would represent only 80% of the observable universe! (figure 1) According to the leading cosmologist George Ellis, from Cape Town University (South Africa), who comments on this work in the "News & Views" section of the same issue: "If confirmed, it is a major discovery about the nature of the universe".

The Poincare Dodecahedral space is
obtained by identifying opposite
sides of a dodedahedron with
a twist.
The resulting space, if you were inside it,
would be something like the next slide.
Whenever you crossed a pentagonal face,
you would find yourself back in
the Dodecahedron.




R
S
T
Q
P
S
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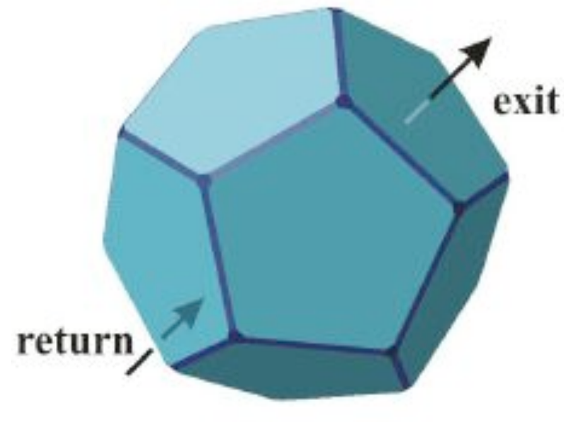
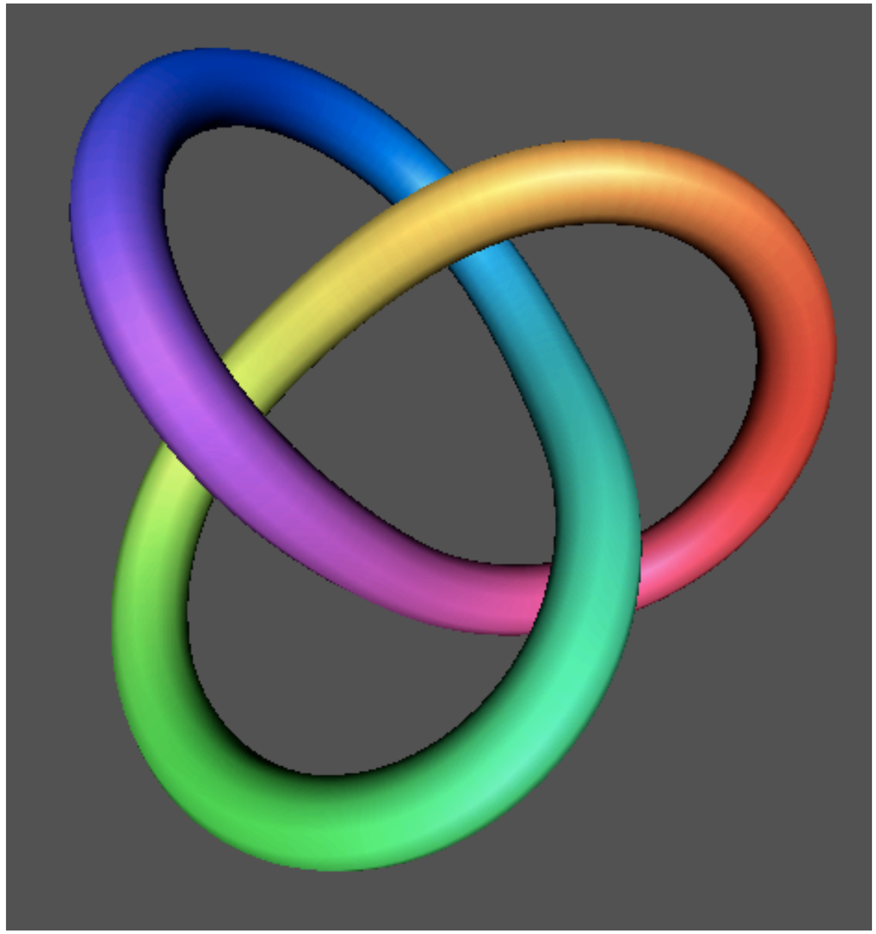
What Does This Have
to do with Knot Theory?



The dodecahedral Space M has
Axes of Symmetry:
five-fold, three-fold and two-fold.

The dodecahedral space M is the
5-fold cyclic branched covering
of the three-sphere, branched along the
trefoil knot.

M = Variety(x^2 + y^3 + z^5)
Intersected with S^5 in C^3.



So perhaps the trefoil knot is the key to the universe.

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Flux Quantization and Particle Physics

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(Received 27 September 1971; revised manuscript received 27 December 1971)

Quantized flux has provided an interesting model for muons and for electrons: One closed flux loop of the form of a magnetic dipole field line is assumed to adopt alternative forms which are superposed with complex probability amplitudes to define the magnetic field of a source lepton. The spinning of that loop with an angular velocity equal to the *Zitterbewegung* frequency $2mc^2/\hbar$ implies an electric Coulomb field, (negative) positive, depending on (anti) parallelism of magnetic moment and spin. The model implies CP invariance. A quark may be represented by a quantized flux loop if interlinked with another loop in the case of a meson, with two other loops in the case of a baryon. Because of the link, their spinning is very different from that of a single loop (lepton). The concept of a single quark does not exist accordingly, and it is seen that a baryon with a symmetric spin-isospin function in the SU(2) $\times$ SU(3) quark representation might not violate the Pauli principle because the wave function representing the relative position of linked loops may be chosen antisymmetric. Weak interactions may be understood to occur when the flux loops involved in the interaction have to cross over themselves or over each other. Strangeness is readily interpreted in terms of the trefoil character of a λ quark: Strangeness-violating interactions imply crossing of flux lines and are thus weak and parity-nonconserving. $\Delta S = \Delta Q$ is favored in such interactions. Intrinsic symmetries may be interpreted in terms of topology of linked loops. Sections I and II give a short résumé of the 1971 paper.

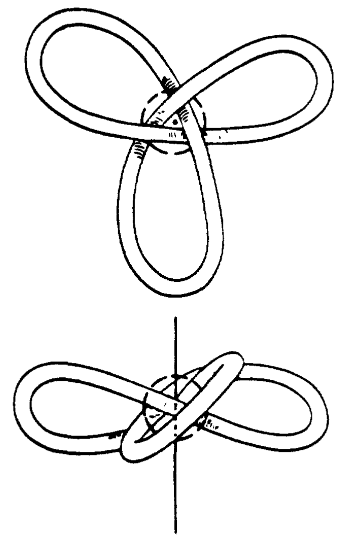


FIG. 2. A trefoil representing a neutrino loop which, like a coasting three-bladed propeller, moves in a helical spinning motion in the direction of the spin axis. In this and in subsequent figures, flux loops are drawn as double lines merely to better visualize the form of the loops. The loops are singular lines, the alternative forms of which define fibration of space. The question of orientation of the magnetic flux is still open; a neutrino might even be a superposition, not only of different loopforms, but also of both signatures of magnetic flux orientation. The difference between electron and muon neutrino is discussed in Sec. IV and in Appendix II of Ref. 1; the distinction is in regard to phase-related versus random-phased probability amplitudes superposition of the contributions of loopform bundles. A *single* loop of this form never represents anything else but a neutrino.

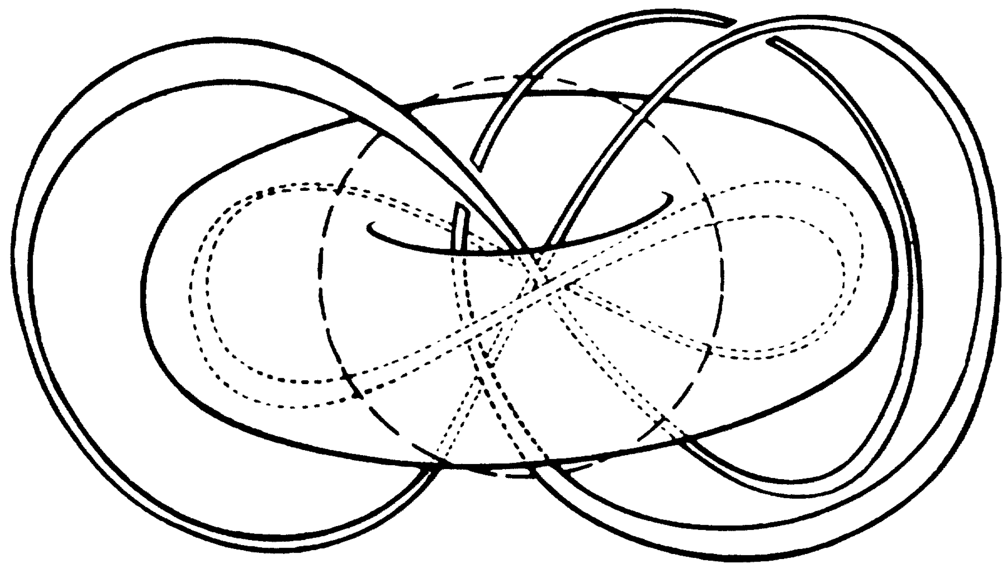


FIG. 4. Spinning-top model. λ and $\overline{\mathfrak{N}}$ quark interlinked, contributing to a meson. To illustrate the topological (knot-theoretical) relationships of the two loops, space is here subdivided by a toroidal surface [dashed lines in Fig. 4(a) which show a doughnut cut in half]. The λ is located entirely outside this doughnut shaped surface, the $\overline{\mathfrak{N}}$ entirely inside. This surface is dividing the fibrated space of λ loopforms from that of $\overline{\mathfrak{N}}$ loopforms; this toroidal interface may arbitrarily shrink or extend itself. Both loops pass through the spherical core region which is indicated by the dashed circle; the two loops may spin independently in a rolling-spinning motion about both the circular and the straight axes.

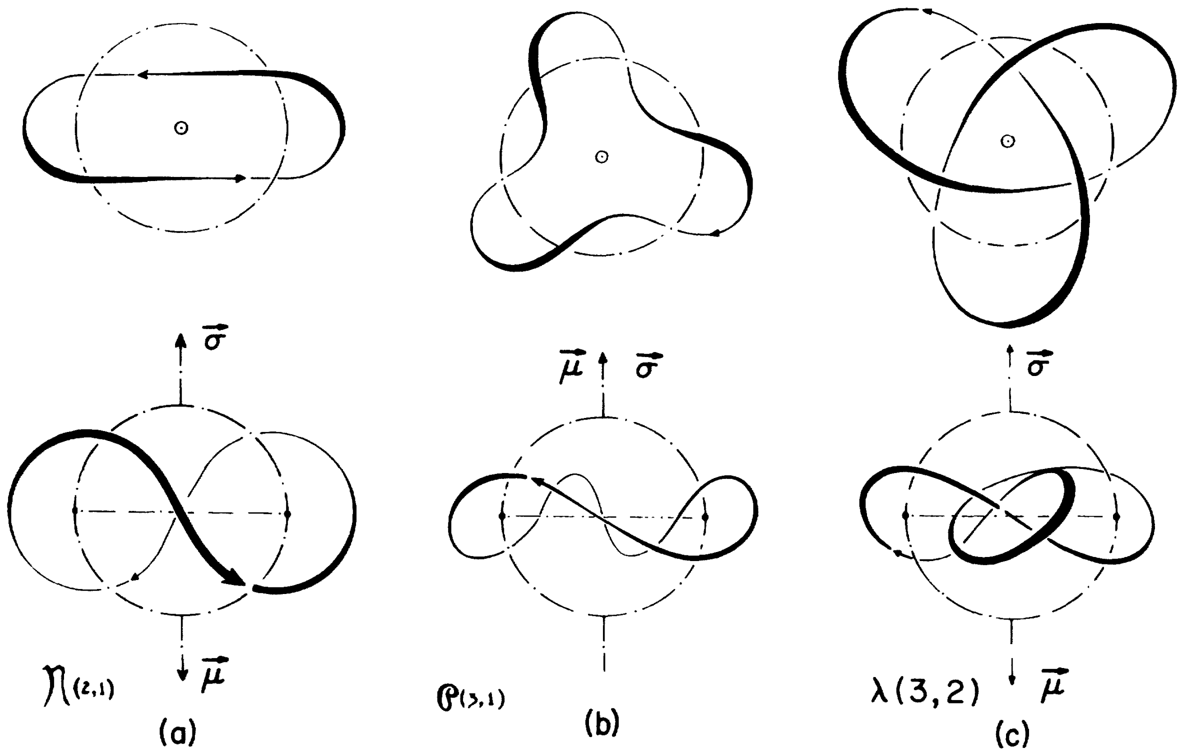
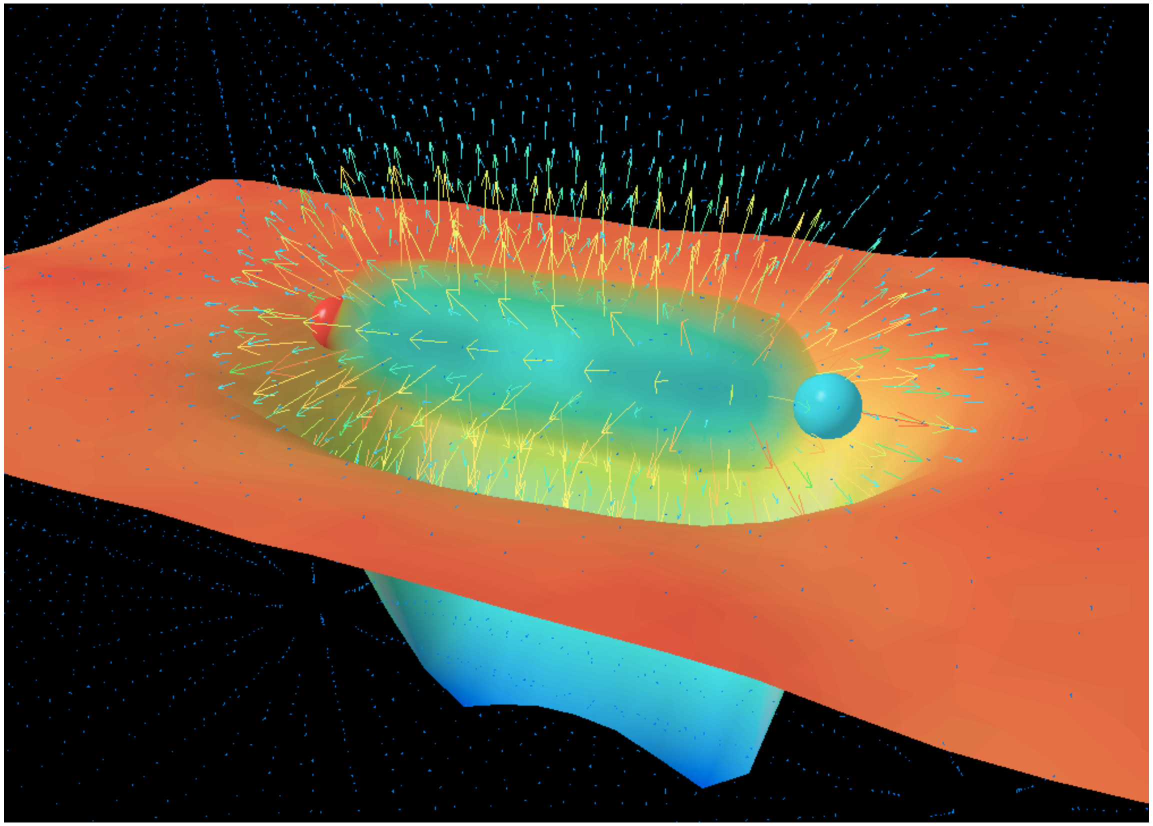
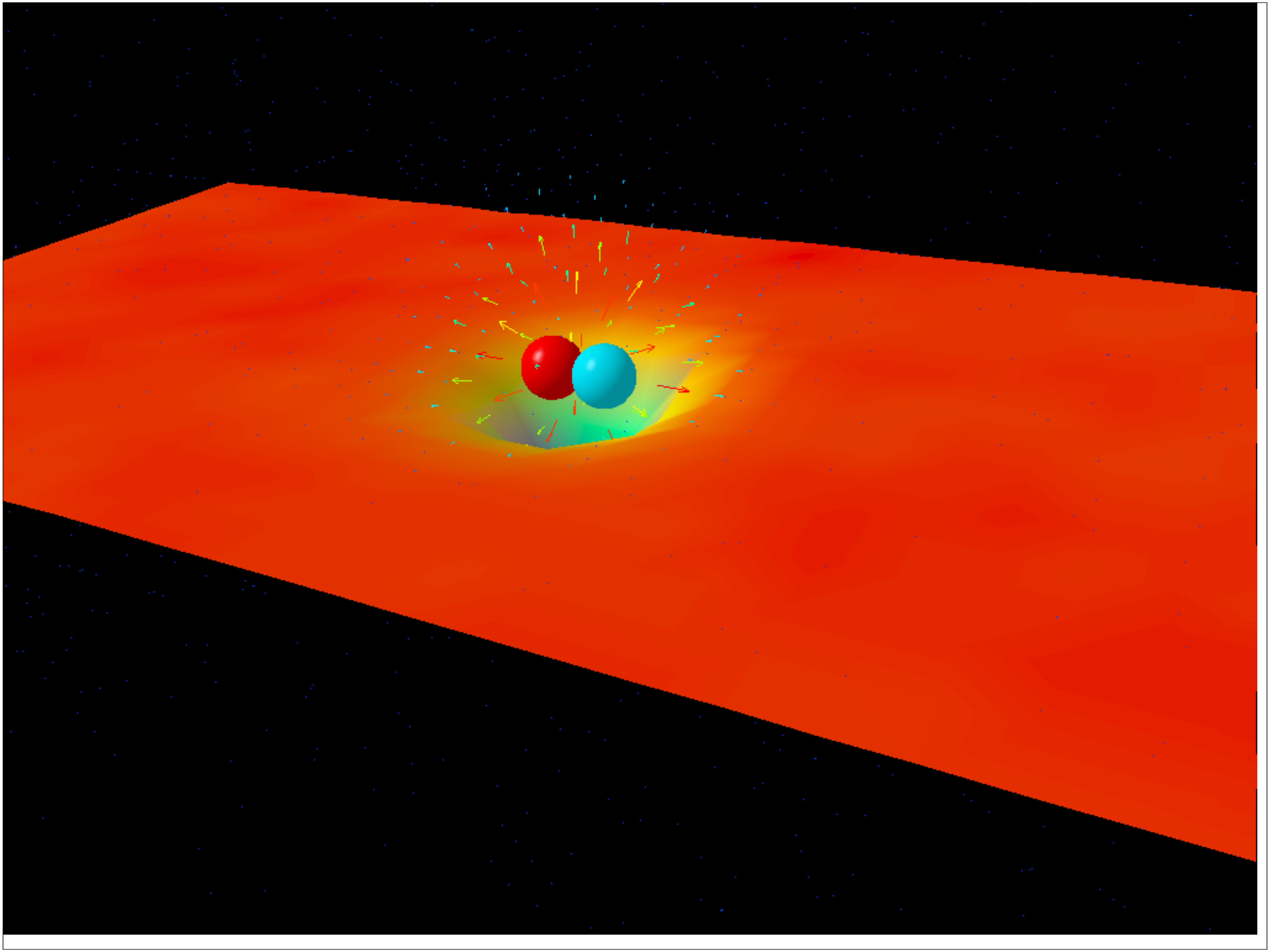


FIG. 3. Forms of quarks in the spinning-top model. These loops represent quarks only if interlinked with other loops as shown in Figs. 4 and 5. The difference of winding numbers about the two dash-dot-dash axes, i.e., $2-1=1(\mathfrak{N})$, $3-1=2(\mathcal{P})$, $3-2=1(\lambda)$, multiplied with the signature of spin with respect to magnetic moment, is proportional to the equivalent electric charge of the respective quarks. Quarks are assumed to be left-handed, antiquarks to be right-handed. Winding numbers have obviously a simple group-theoretical interpretation.

MODERN TIMES
Quarks and Gluons - Gluon Flux

http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/index.html





Are Glueballs Knotted Closed Strings?

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Box 803, S-75 108 Uppsala, Sweden

May 29, 2006

Abstract

Glueballs have a natural interpretation as closed strings in Yang-Mills theory. Their stability requires that the string carries a nontrivial twist, or then it is knotted. Since a twist can be either left-handed or right-handed, this implies that the glueball spectrum must be degenerate. This degeneracy becomes consistent with experimental observations, when we identify the $\eta_L(1410)$ component of the $\eta(1440)$ pseudoscalar as a 0^{-+} glueball, degenerate in mass with the widely accepted 0^{++} glueball $f_0(1500)$. In addition of qualitative similarities, we find that these two states also share quantitative similarity in terms of equal production ratios, which we view as further evidence that their structures must be very similar. We explain how our string picture of glueballs can be obtained from Yang-Mills theory, by employing a decomposed gauge field. We also consider various experimental consequences of our proposal, including the interactions between glueballs and quarks and the possibility to employ glueballs as probes for extra dimensions: The coupling of strong interactions to higher dimensions seems to imply that absolute color confinement becomes lost.

Universal energy spectrum of tight knots and links in physics*

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We argue that a systems of tightly knotted, linked, or braided flux tubes will have a universal mass-energy spectrum, since the length of fixed radius flux tubes depend only on the topology of the configuration. We motivate the discussion with plasma physics examples, then concentrate on the model of glueballs as knotted QCD flux tubes. Other applications will also be discussed.

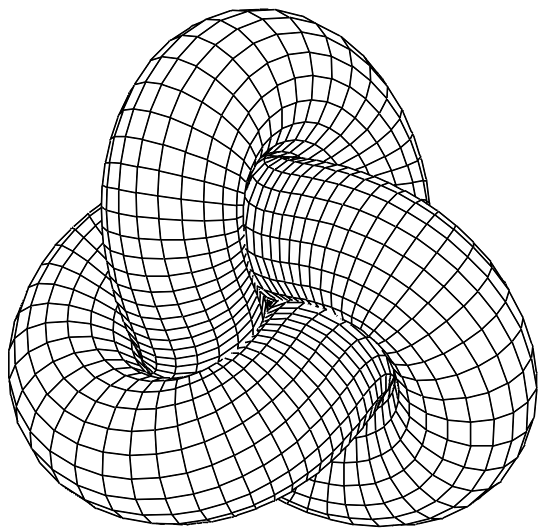
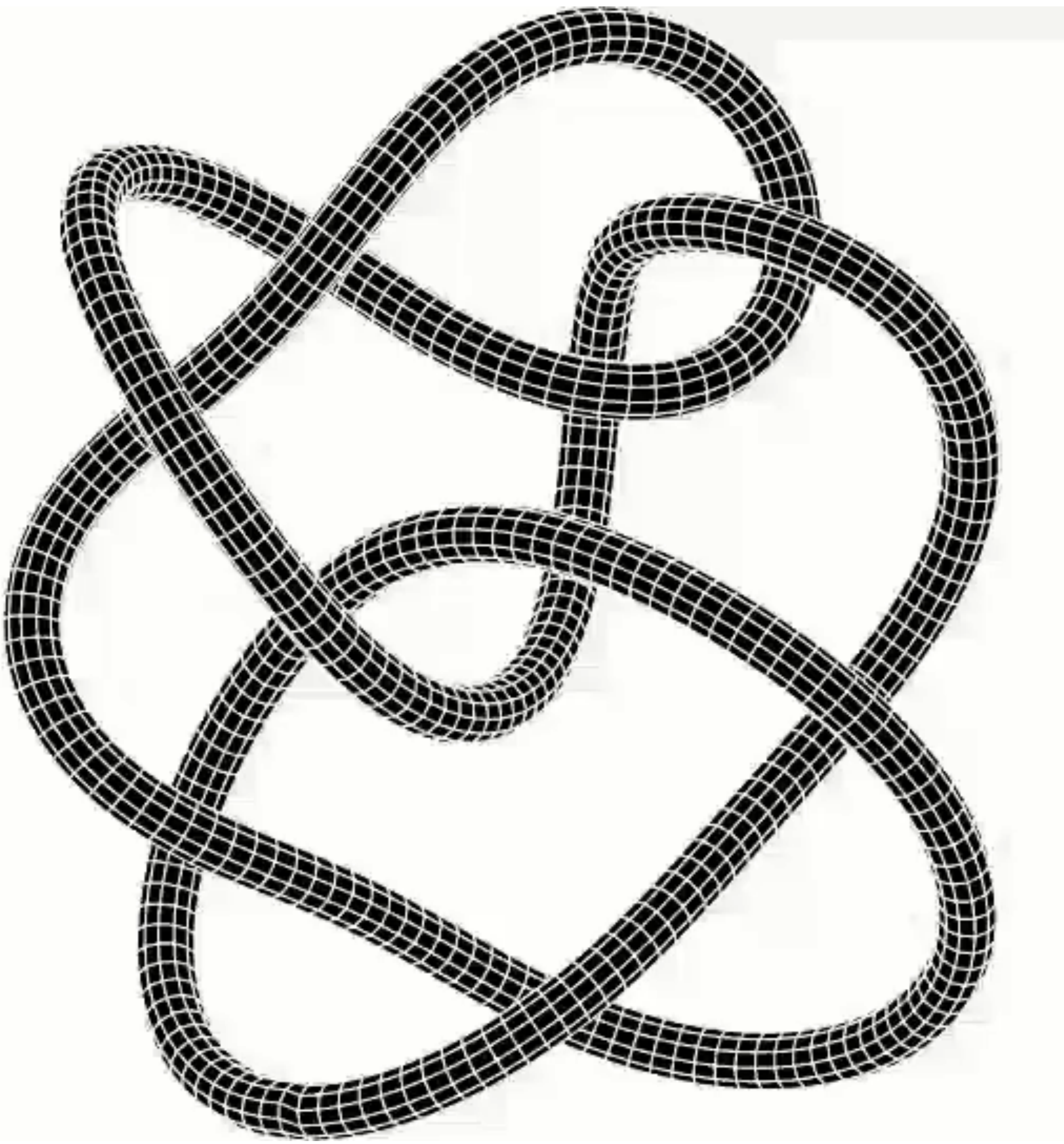


Figure 2: The second shortest solitonic flux configuration is the trefoil knot 3_1 corresponding to the second lightest glueball candidate $f_0(980)$.

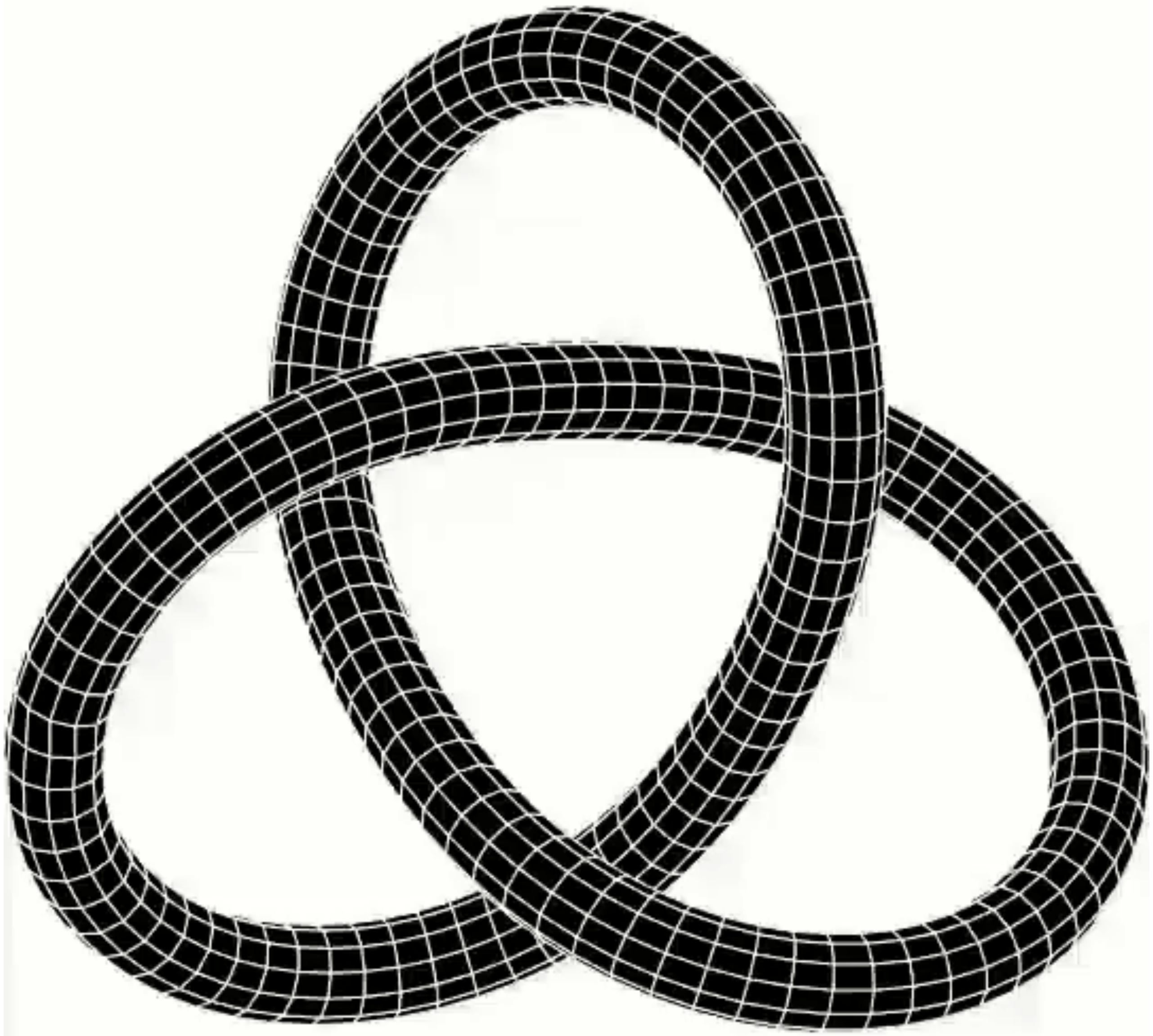
The next demonstration is
made by Jason Cantarella,
using his program “ridgerunner”.

http://www.math.uga.edu/~cantarel/

In the next frame we show
a Cantarella film,
contracting the knot 9_{42}.
This is the first chiral knot
that is undetected from its mirror
image by the Jones polynomial.



And here is the contraction of the trefoil knot.



Mobius Strip Particles

A Visualizable Representation of the Elementary Particles

J.S. Avrin*

Abstract

Rudimentary knots are invoked to generate a representation of the elementary particles, a model that endows the particles with visualizable structure. The model correlates with the basic tenets, taxonomy, and interactions of the Standard Model, but goes beyond it in a number of important ways, the most significant being that all particles (hadrons and leptons, fermions and bosons) and interactions share a common topology. Among other consequences of the modeling are the topological basis for isospin invariance and its connection to electric charge, the necessary identity of electron and proton charge magnitudes, and the existence of precisely three generations on the particle family tree. The salient feature of the model is that the elementary particles are viewed not as discrete, point-like objects in a vacuum but rather as sustainable, membrane-like distortions embodying curvature and torsion in and of an otherwise featureless continuum and that their manifest physical attributes correlate with the distortion. There are additional connections to the theories of fiber bundles, superstrings and instantons and, historically, to the work of Kelvin in the mid-nineteenth century and Cartan in the 1920s among others.

(published in Journal of Knot Theory and Its Ramifications)

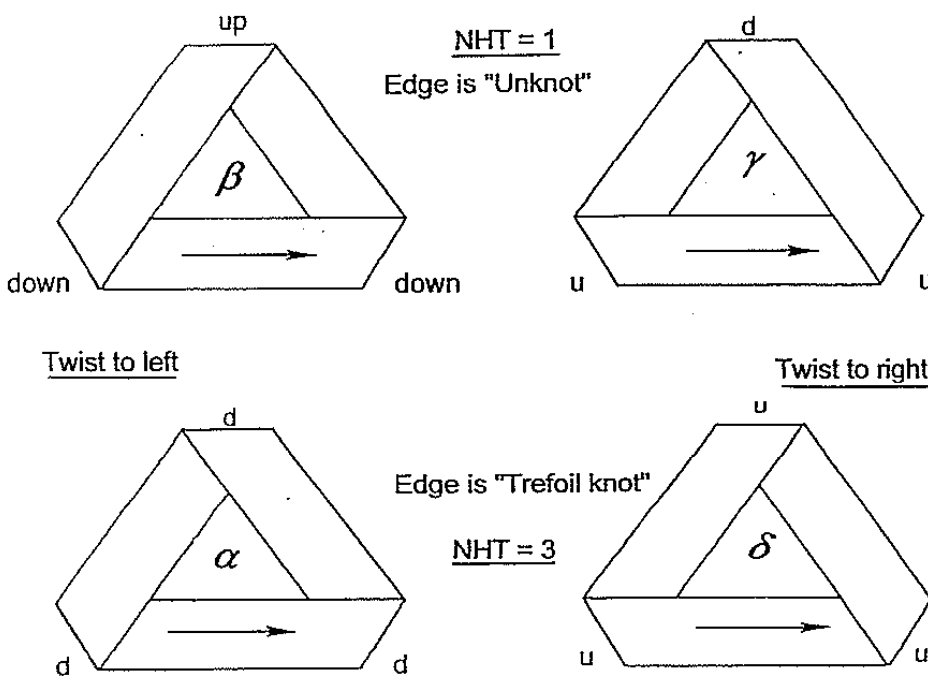


Figure 3a: Basic Set; Spin 1/2 Fermion Diagrams

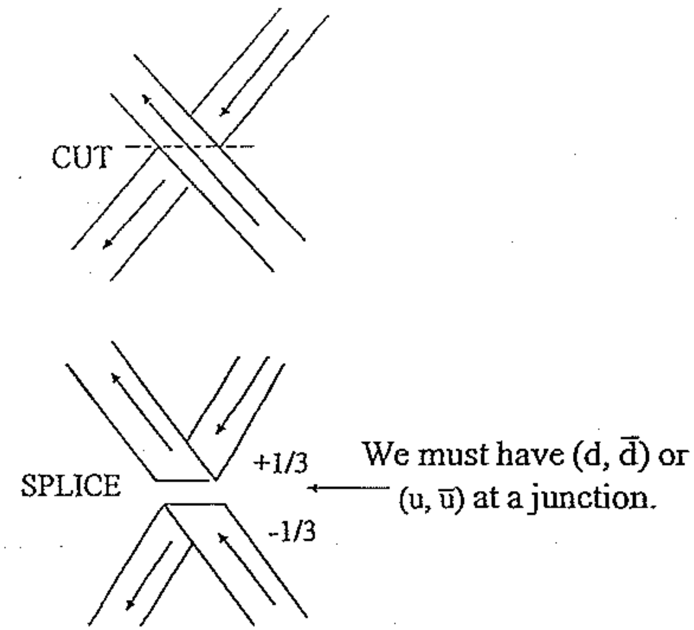


Figure 6: Fission (Cut and Splice)

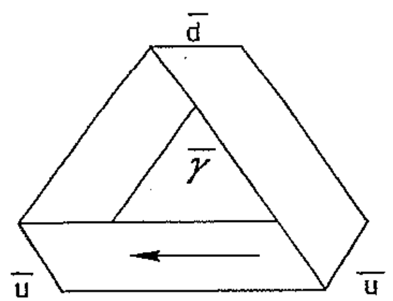
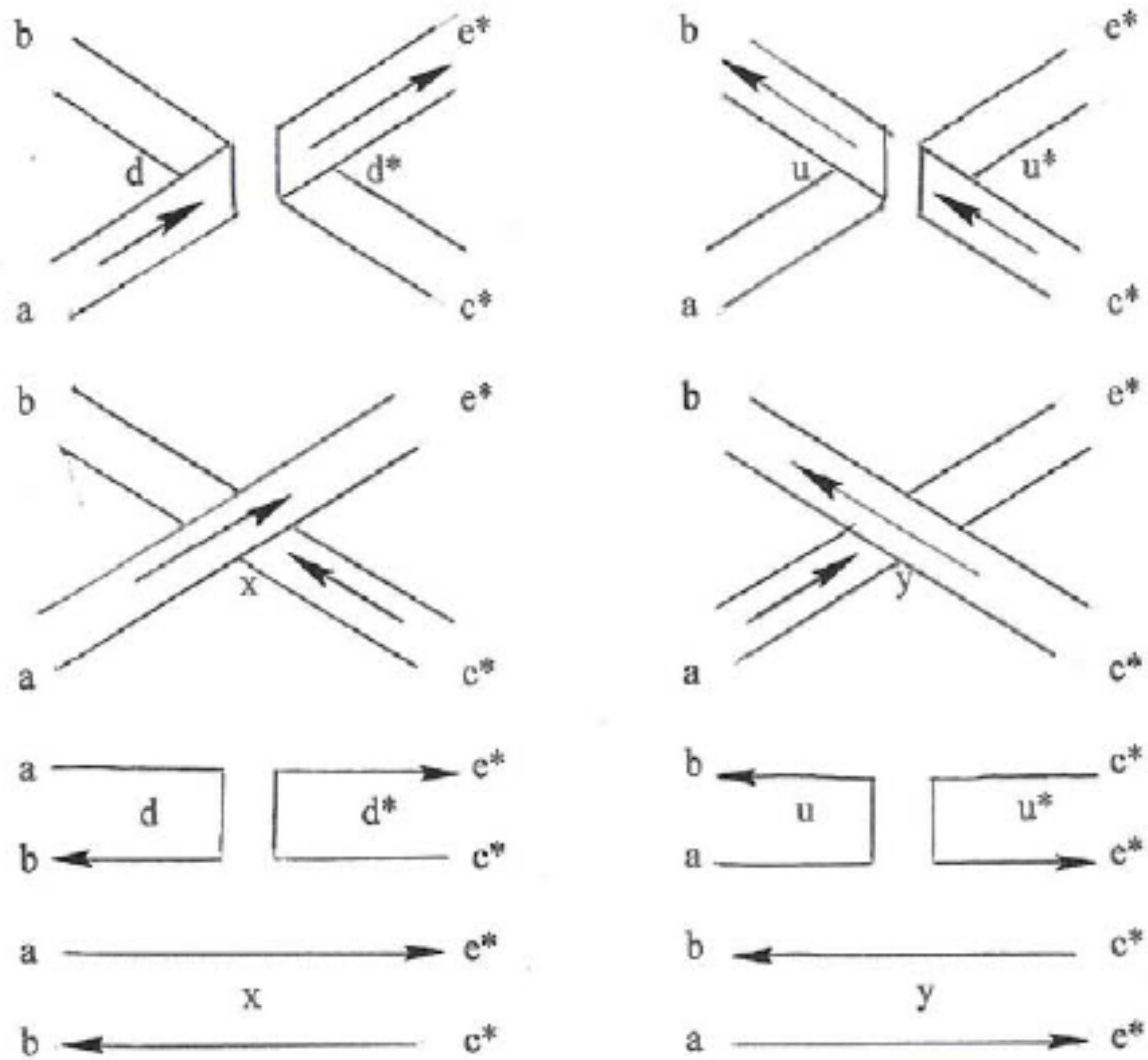


Figure 3b: Antiparticle Diagram for "γ Particle"


b
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c*
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u*
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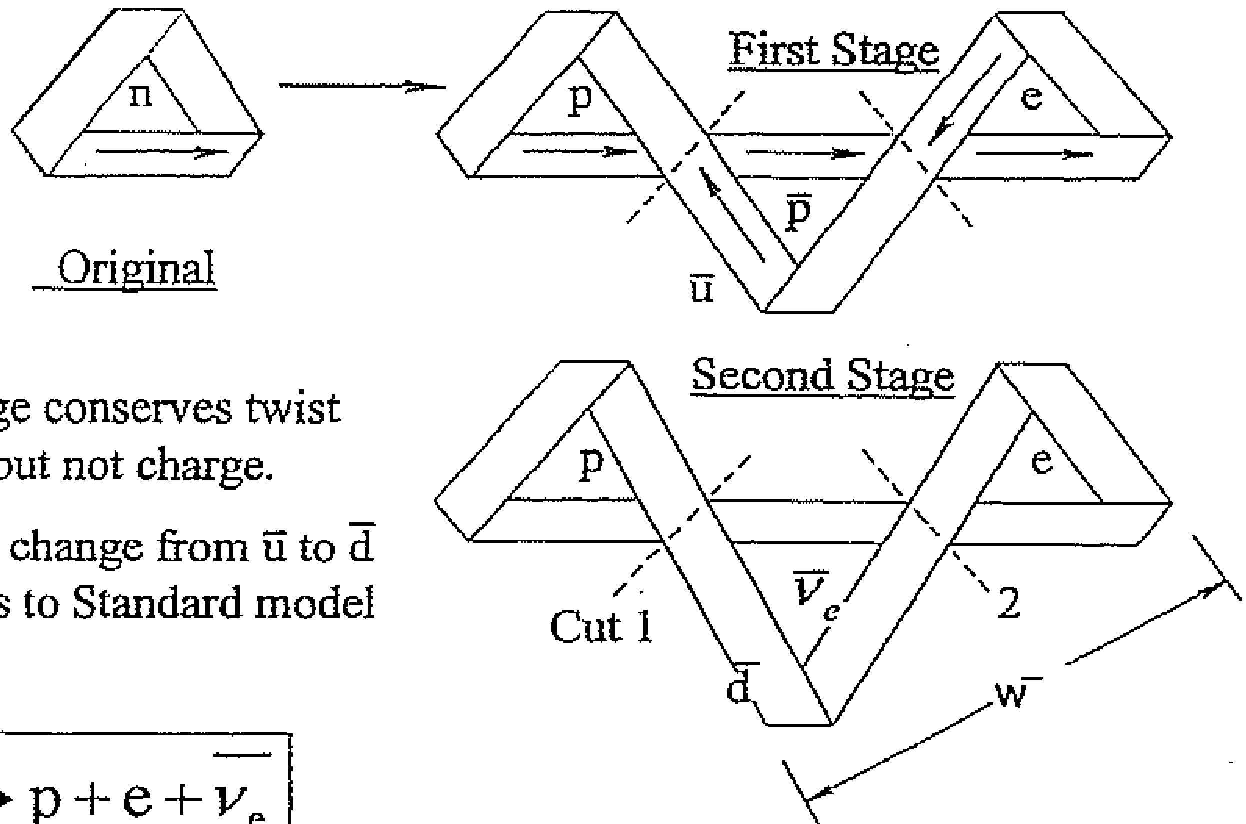


•First stage conserves twist and spin but not charge.

•Note the change from $\bar{u}$ to $\bar{d}$ analogous to Standard model process.

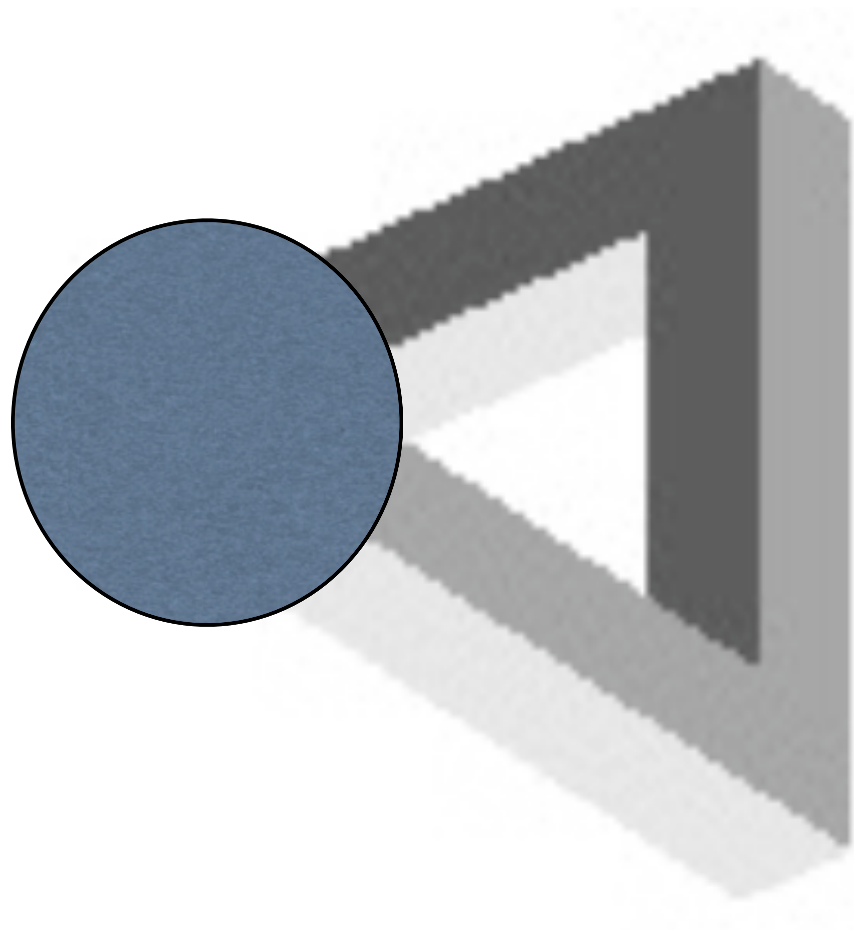
$$\boxed{n \rightarrow p + e + \overline{\nu_e}}$$

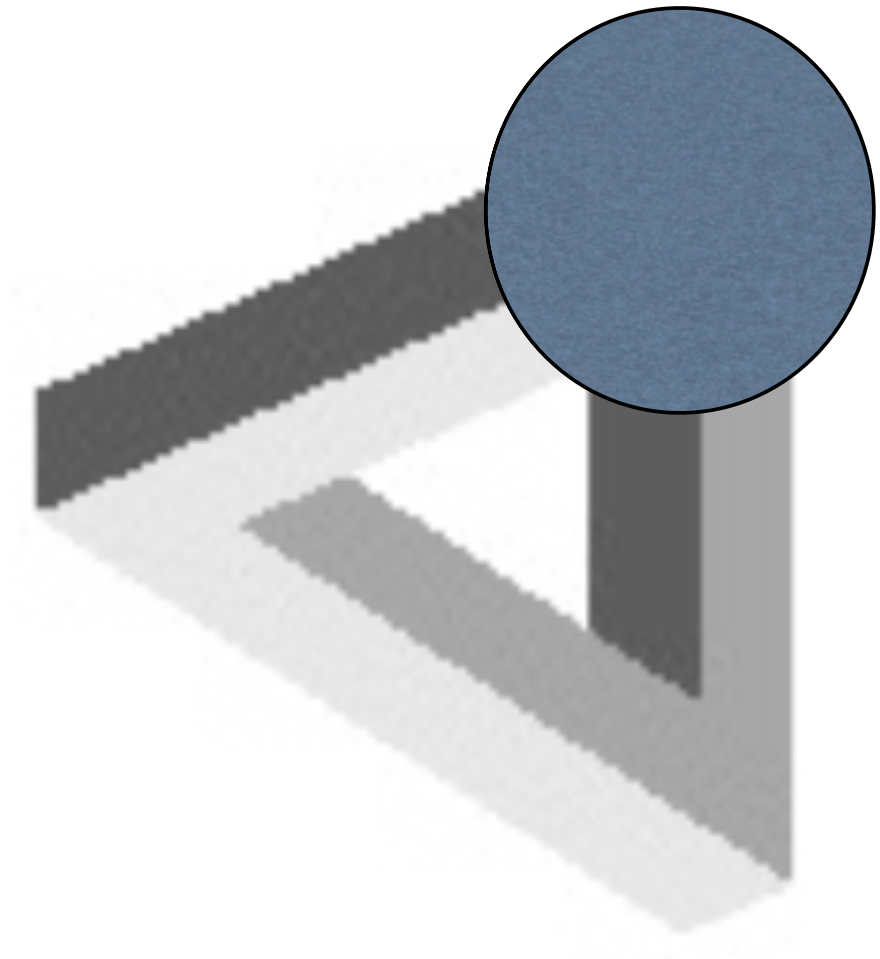
Figure 7: Neutron Decay Model

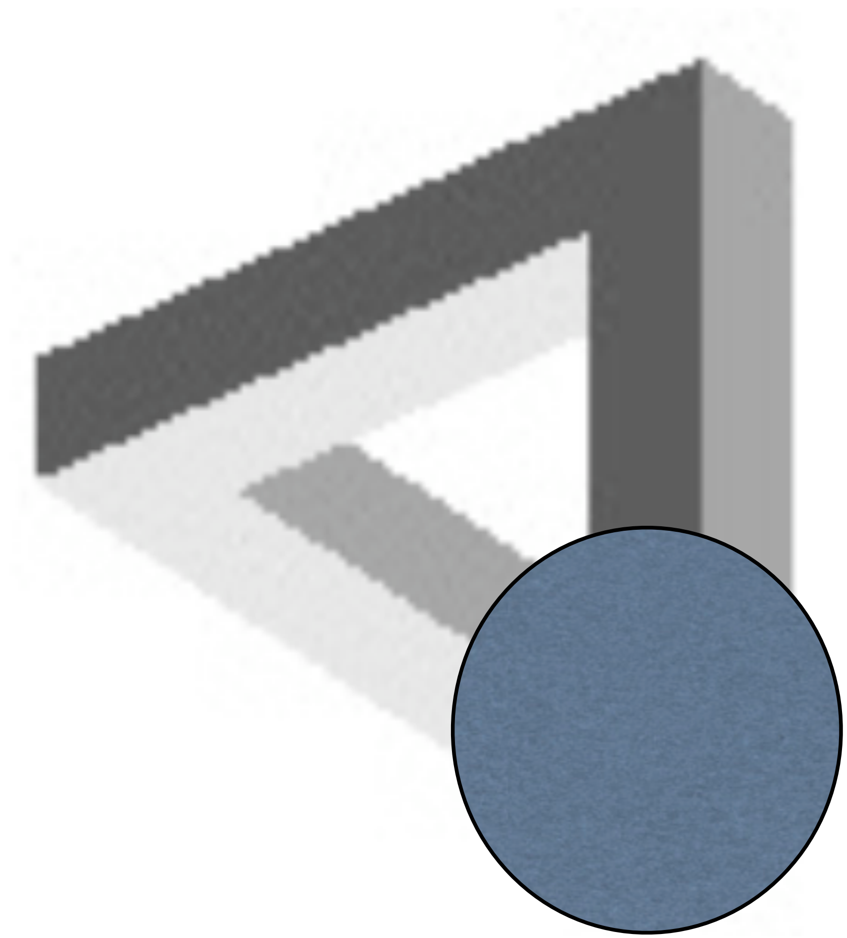
The Non-Locality of Impossibility

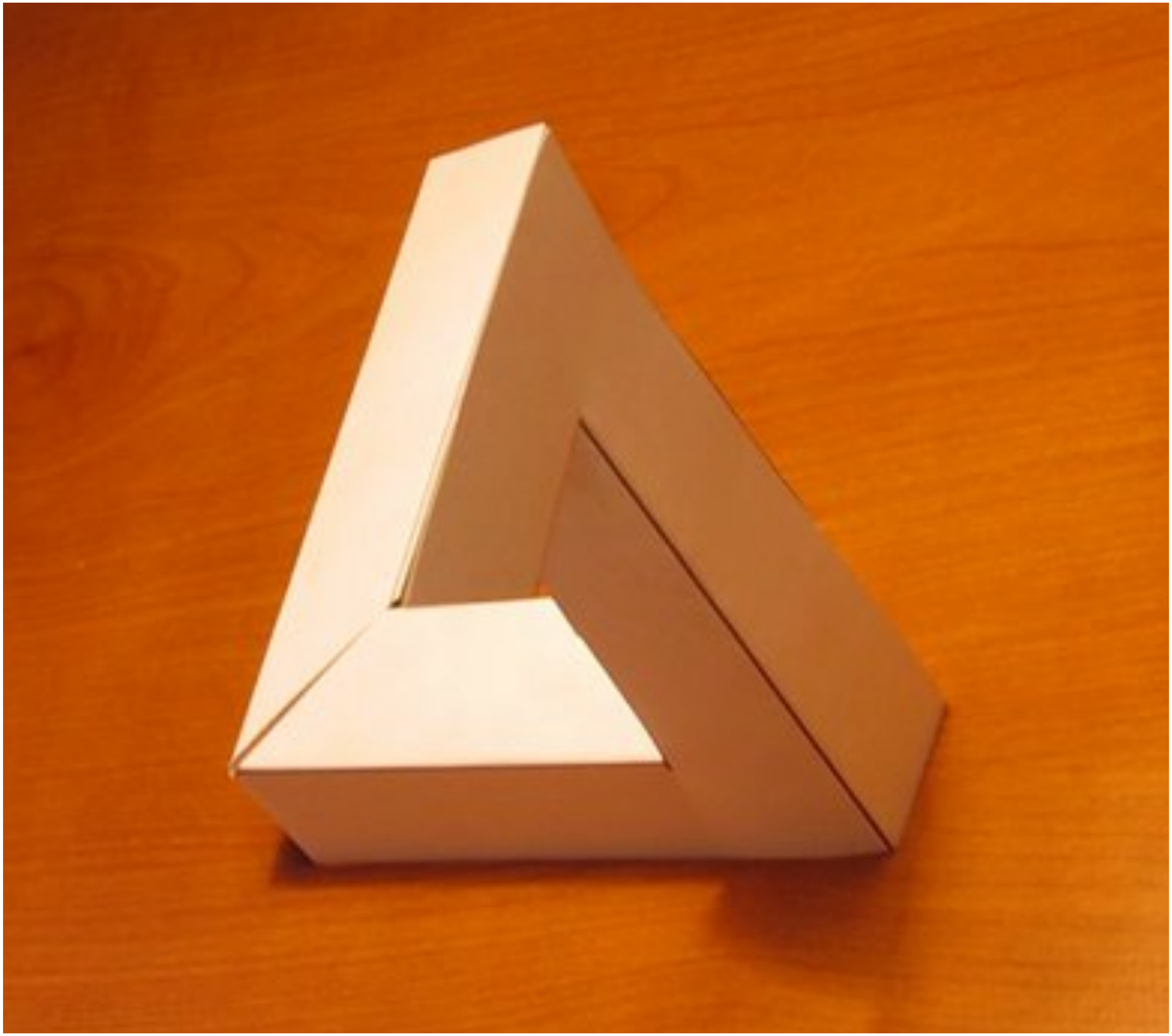
Analog: Imaginary Object ⟷ Quantum State

Observation ⟷ Selective Ignorance









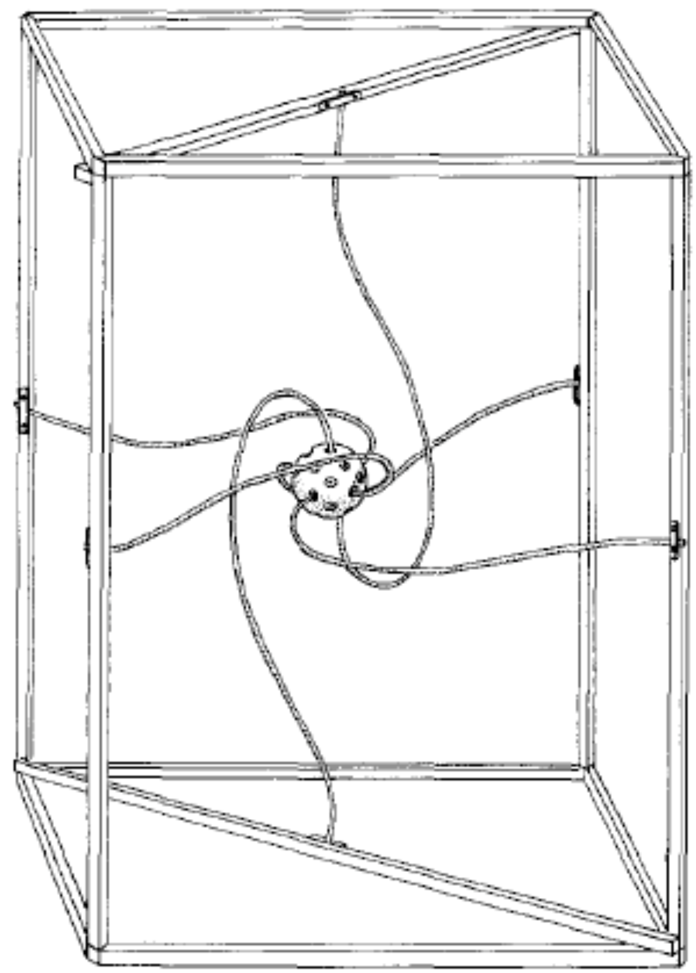
International Journal of Theoretical Physics, Vol. 19, No. 6, 1980

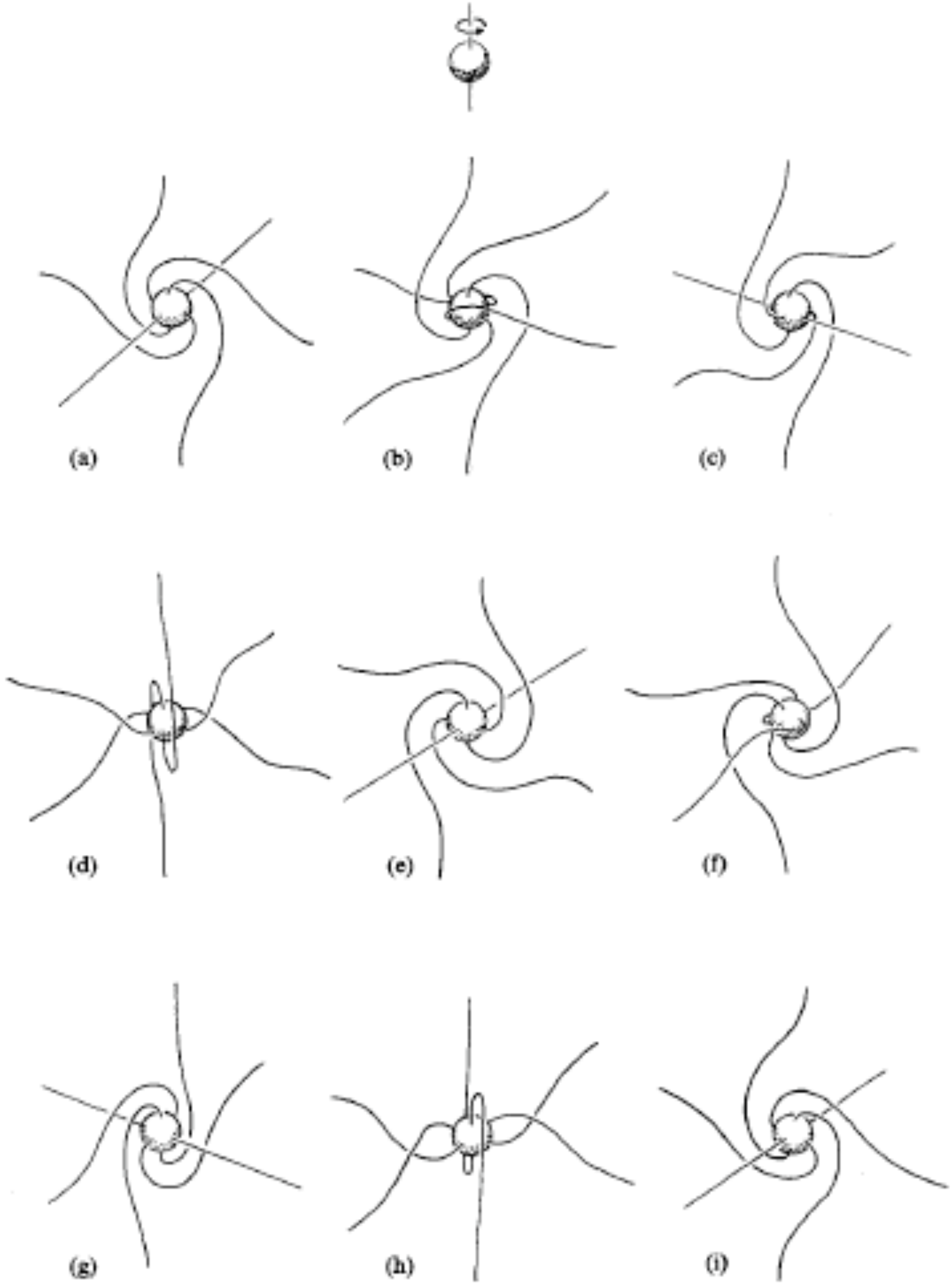
Geometric Model for Fundamental Particles

E. P. Battey-Pratt[1] and T. J. Racey

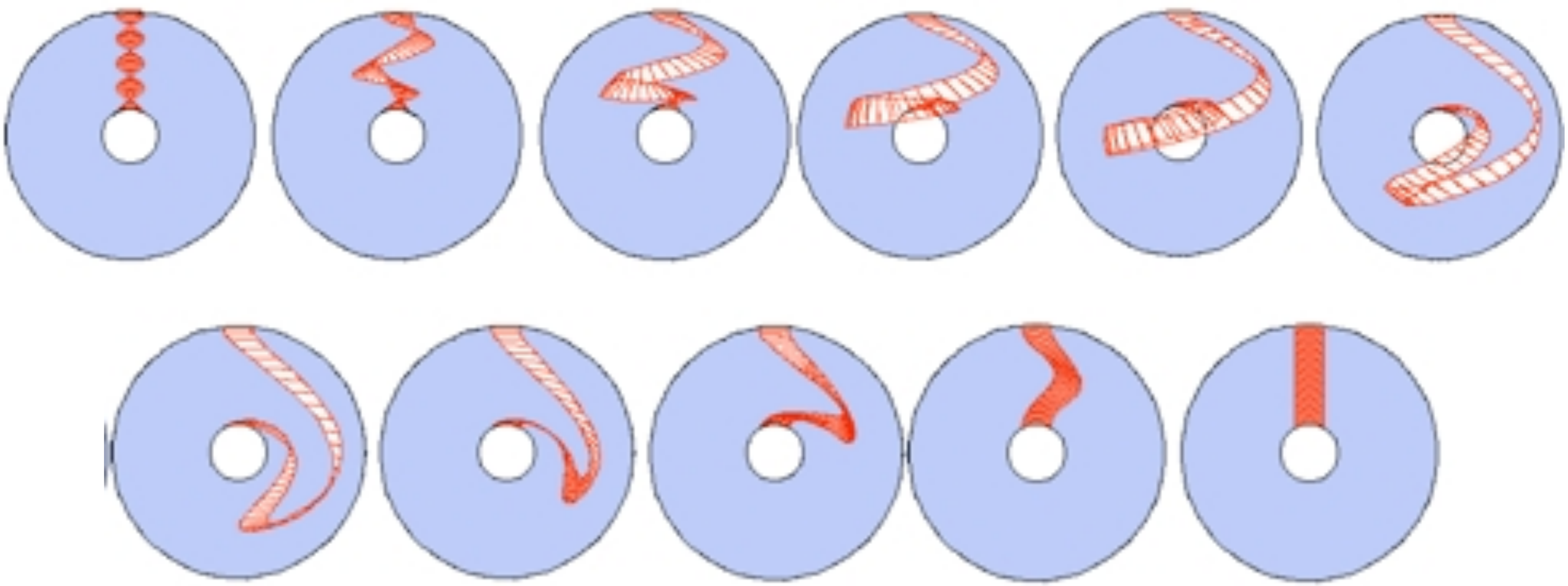
Received October 14, 1979

An attempt is made to show that fundamental particles are manifestations of the geometry of space-time. This is done by demonstrating the existence of a purely geometrical model, which we have called *spherical rotation*, that satisfies Dirac's equation. The model is developed and illustrated both mathematically and mechanically. It indicates that the mass of a particle is entirely due to the spinning of the space-time continuum. Using the model, we can show the distinction between spin-up and spin-down states and also between particle and antiparticle states. It satisfies Einstein's criteria for a model that has both wave and particle properties, and it does so without introducing a singularity into the continuum.

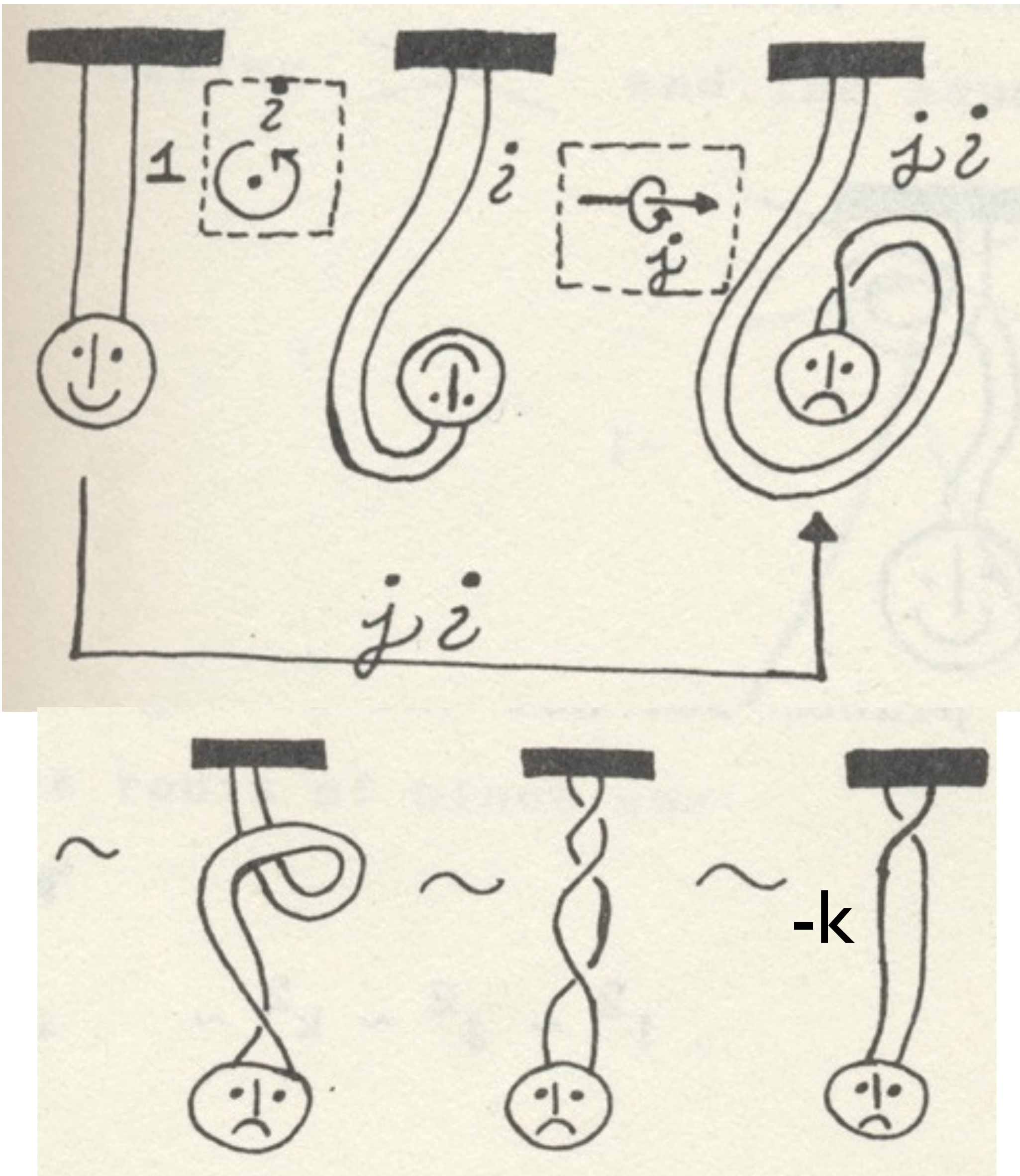



(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)

SU(2) versus SO(3) and the Dirac String Trick

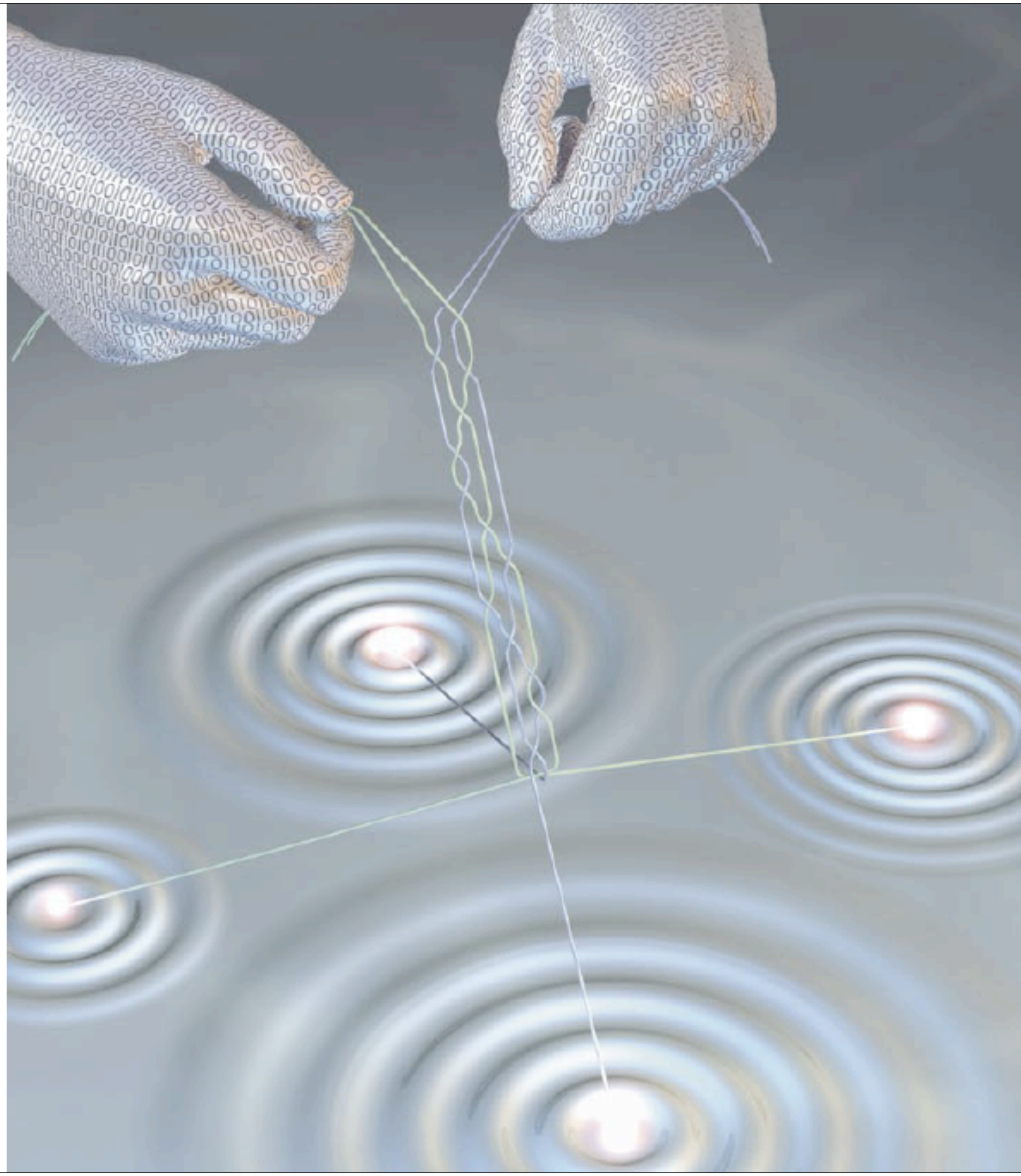


Orientation Entanglement Relation Corresponds to SU(2) Symmetry



$$i^2 = j^2 = k^2 =$$
$$ijk = -1$$


Air on the
Dirac Strings



Quantum Hall Effect

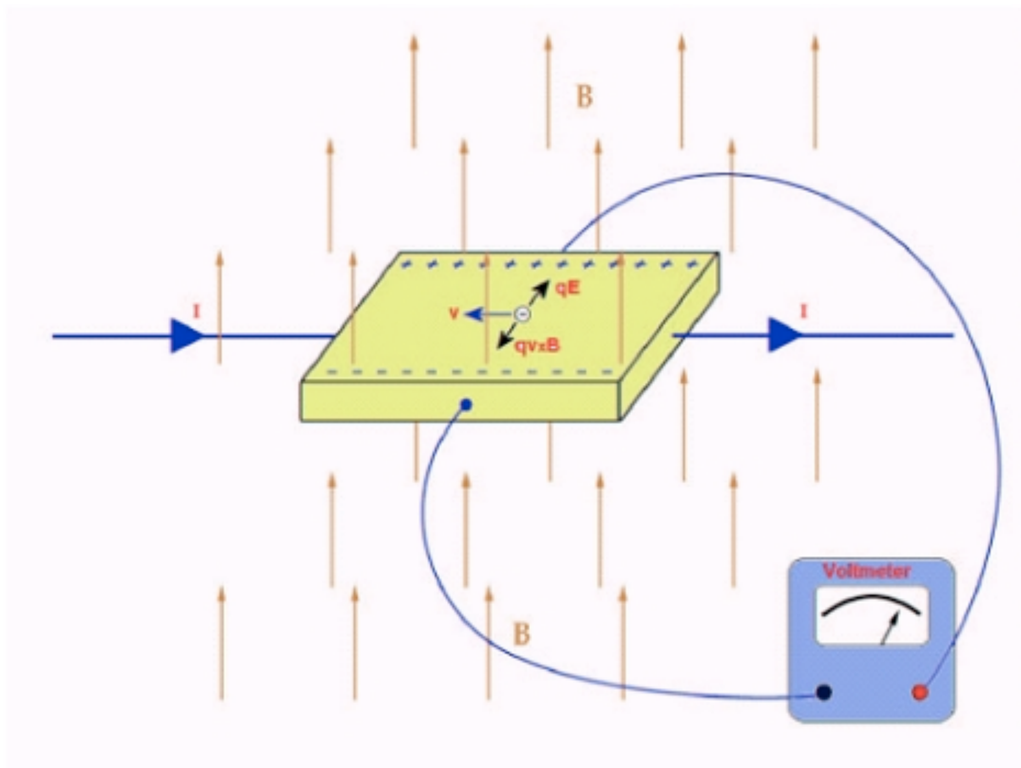


Figure 1: A schematics of the experimental setup of the Hall effect. A current driven through the conductor, drawn as a prism, leads to the emergence of voltage in the perpendicular direction. This is the Hall voltage, which Maxwell erroneously predicted to be zero.

United States
Patent Application Publication
Freedman et al.

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SYSTEMS AND METHODS FOR QUANTUM BRAIDING

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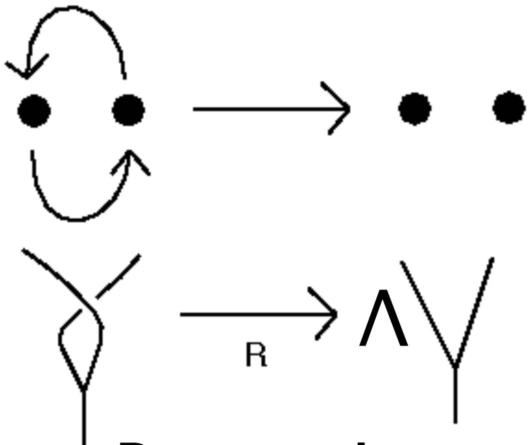
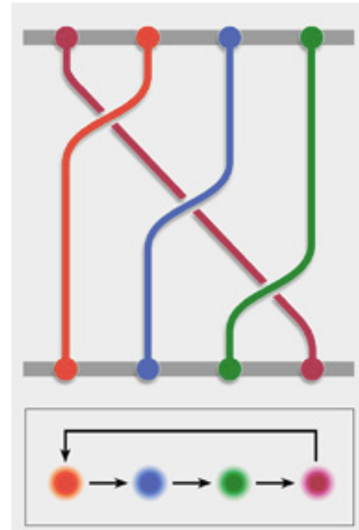
(52) **U.S. Cl.** **257/9**; 257/14

(57) **ABSTRACT**

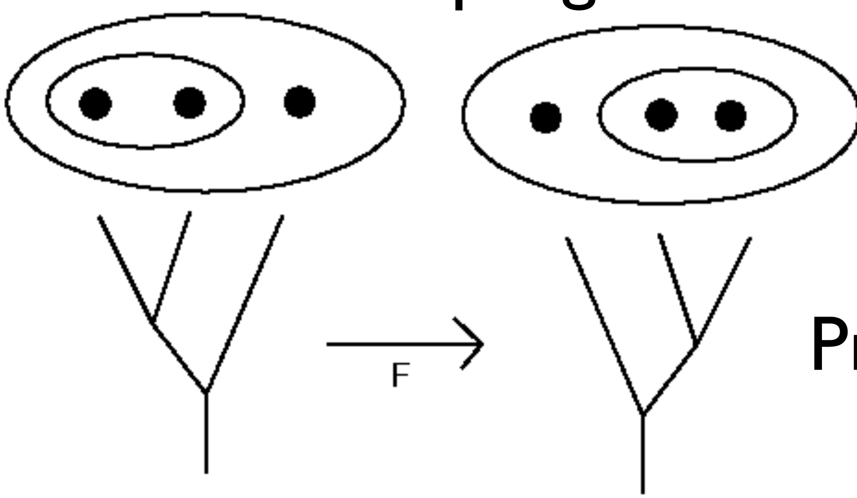
Apparatus and methods for performing quantum computations are disclosed. Such apparatus and methods may include identifying a first quantum state of a lattice having a system of quasi-particles disposed thereon, moving the quasi-particles within the lattice according to at least one predefined rule, identifying a second quantum state of the lattice after the quasi-particles have been moved, and determining a computational result based on the second quantum state of the lattice. A topological quantum computer encodes information in the configurations of different braids. The computer physically weaves braids in the 2D+1 space-time of the lattice, and uses this braiding to carry out calculations. A pair of quasi-particles, such as non-abelian anyons, can be moved around each other in a braid-like path. The quasi-particles can be moved as a result of a magnetic or optical field being applied to them, for example. When the pair of quasi-particles are brought together, they may annihilate each other or create a new anyon. A result is that an anyon may be present or not, which can be thought of as a "one" or "zero," respectively. Such ones and zeros can be interpreted to provide information.

Braiding Anyons

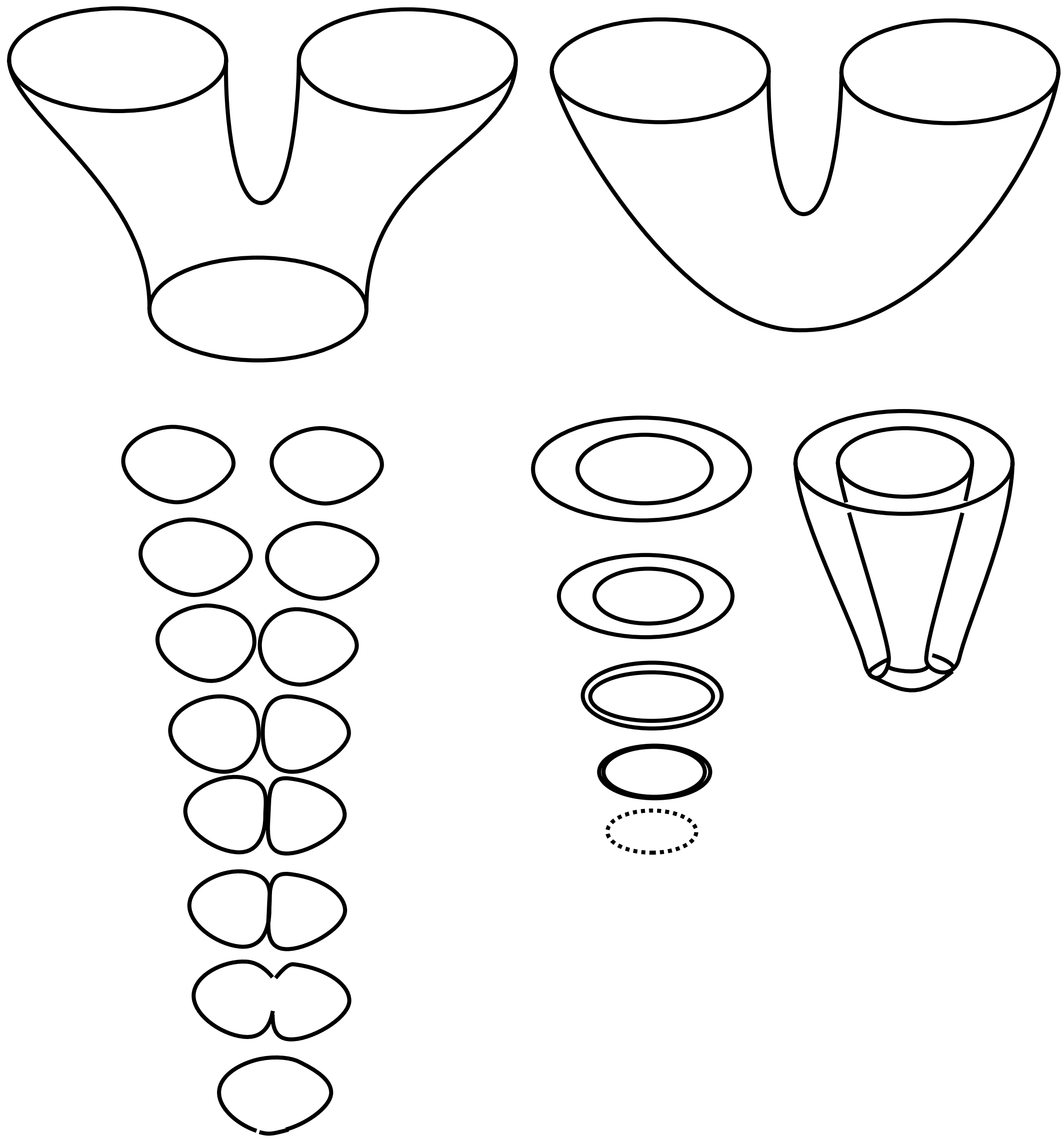




Recoupling

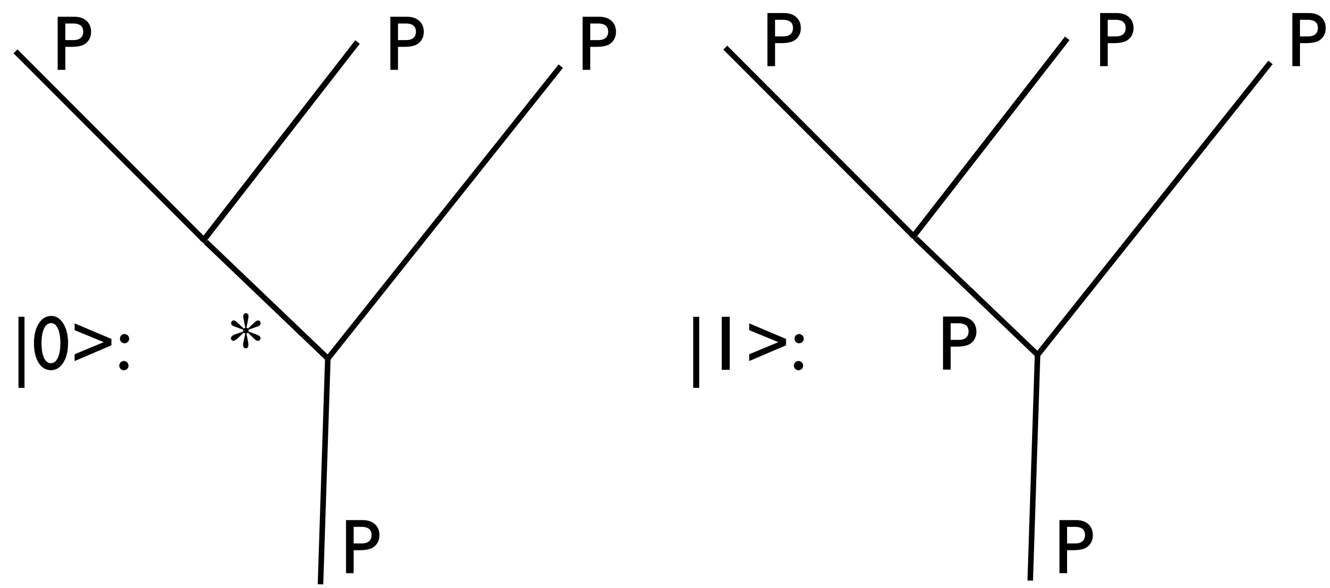


Process Spaces

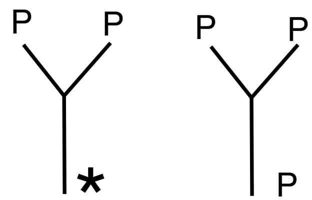


The process space with three input P's and one output P has dimension two.

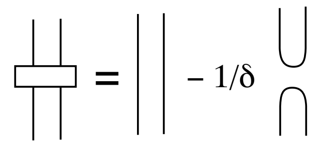
It is a candidate for a unitary representation of the three strand braids.



Fibonacci Model

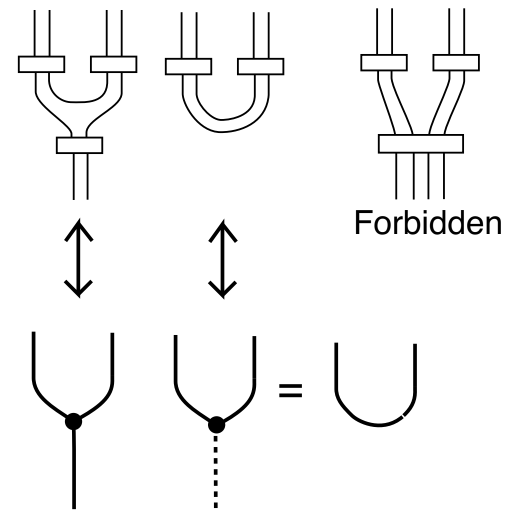


$$A = e^{3\pi i/5}.$$



$$\delta = -A^2 - A^{-2}$$

$$\Delta = \delta = (1+\sqrt{5})/2.$$



$$F = \begin{pmatrix} 1/\Delta & 1/\sqrt{\Delta} \\ 1/\sqrt{\Delta} & -1/\Delta \end{pmatrix} = \begin{pmatrix} \tau & \sqrt{\tau} \\ \sqrt{\tau} & -\tau \end{pmatrix}$$

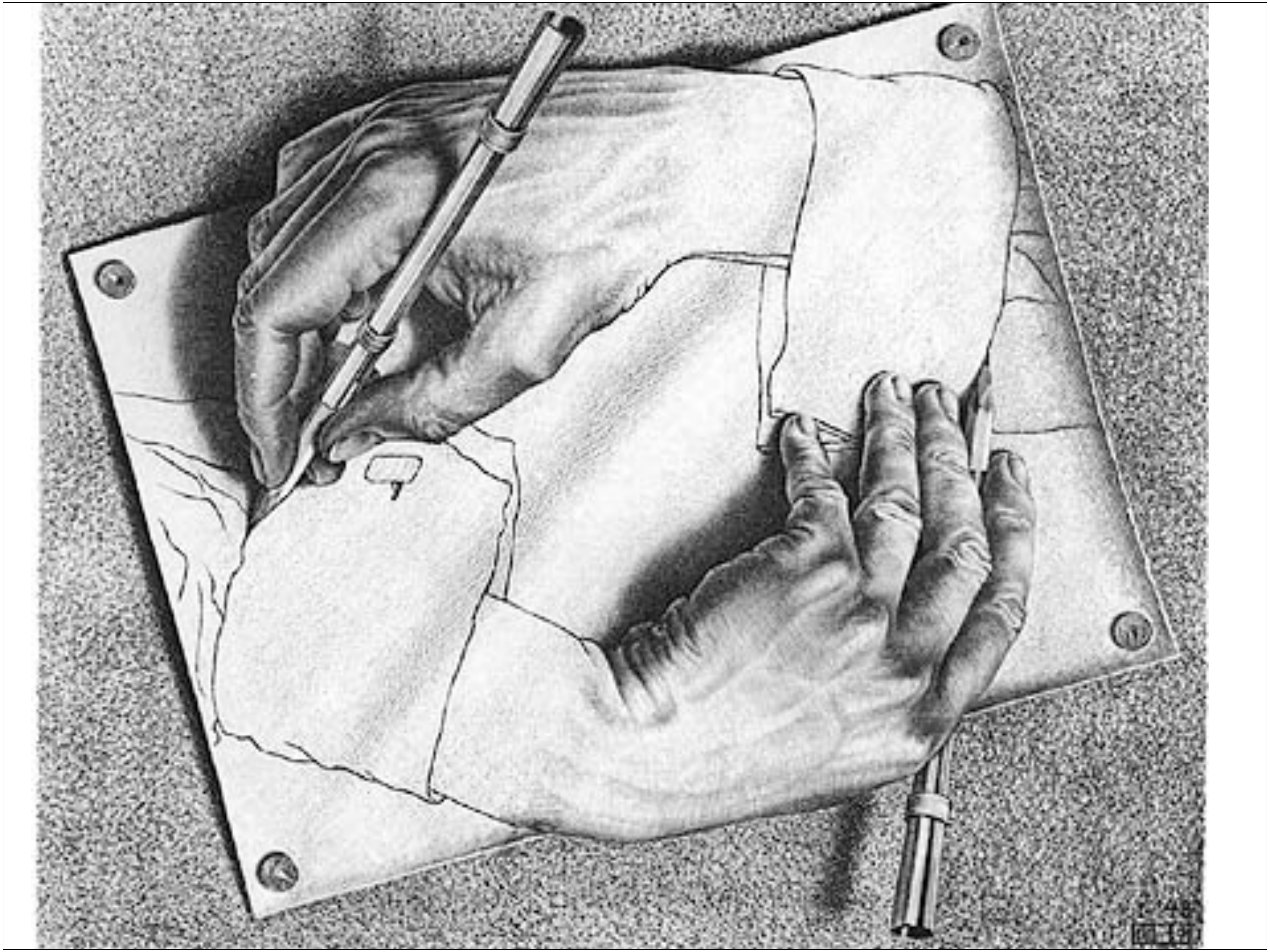
$$R = \begin{pmatrix} -A^4 & 0 \\ 0 & A^8 \end{pmatrix} = \begin{pmatrix} e^{4\pi i/5} & 0 \\ 0 & -e^{2\pi i/5} \end{pmatrix}.$$

Braid Representations Dense in Unitary Groups

Temperley Lieb Representation of Fibonacci Model

The Fibonacci Model yields a braid group representation that is universal for quantum computation. It is a braid group representation that is dense in the unitary groups.

The structure of this representation is also theoretically realized in the present models of the quantum Hall effect.



A topological model of composite preons

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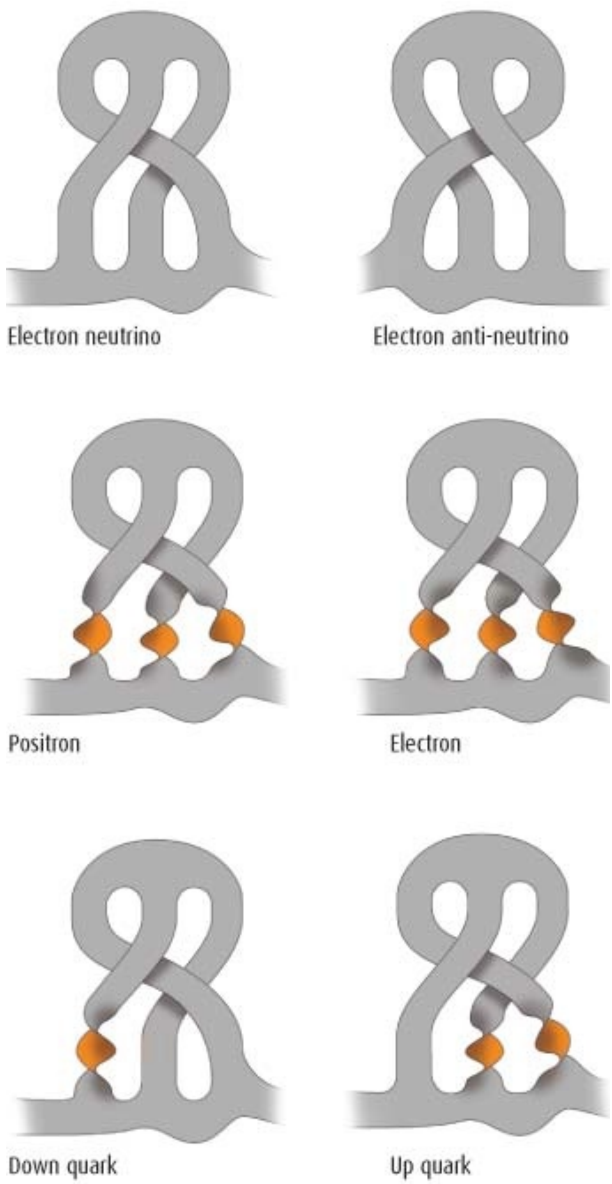
Centre for the Subatomic Structure of Matter, Department of Physics,
University of Adelaide, Adelaide SA 5005, Australia
(Dated: February 2, 2008)

We describe a simple model, based on the preon model of Shupe and Harari, in which the binding of preons is represented topologically. We then demonstrate a direct correspondence between this model and much of the known phenomenology of the Standard Model. In particular we identify the substructure of quarks, leptons and gauge bosons with elements of the braid group B_3. Importantly, the preonic objects of this model require fewer assumed properties than in the Shupe/Harari model, yet more emergent quantities, such as helicity, hypercharge, and so on, are found. Simple topological processes are identified with electroweak interactions and conservation laws. The objects which play the role of preons in this model may occur as topological structures in a more comprehensive theory, and may themselves be viewed as composite, being formed of truly fundamental sub-components, representing exactly two levels of substructure within quarks and leptons.

PACS numbers: 12.60.Rc, 12.10.Dm

BRAIDED SPACE-TIME

How the lightest family of particles in the standard model appear as braids. Each complete twist corresponds to $+\frac{1}{3}$ or $-\frac{1}{3}$ unit of electric charge depending on the direction of the twist



1) Unordered pairing: *Tweedles combine in pairs, so that their total twist is 0 modulo 2π, and the ordering of tweedles within a pair is unimportant.* The three possible combinations of UU, EE, and $UE \equiv EU$ can be represented as ribbons bearing twists through the angles $+2\pi$, -2π, and 0 respectively. A twist through $\pm 2\pi$ is interpreted as an electric charge of $\pm e/3$. We shall refer to such pairs of tweedles as *helons* (evoking their helical structure) and denote the three types of helons by H_+, H_-, and H_0.

2) Helons bind into triplets: *Helons are bound into triplets by a mechanism which we represent as the tops of each strand being connected to each other, and the bottoms of each strand being similarly connected.* A triplet of helons may split in half, in which case a new connection forms at the top or bottom of each resulting triplet. The reverse process may also occur when two triplets merge to form one triplet, in which case the connection at the top of one triplet and the bottom of the other triplet "annihilate" each other.

The arrangement of three helons joined at the top and bottom is equivalent to two parallel disks connected by a triplet of strands. In the simplest case, such an arrangement is invariant under rotations through angles of $2\pi/3$, making it impossible to distinguish the strands without arbitrarily labelling or colouring them. However we can envisage the three strands crossing over or under each other to form a braid. The three strands can then be distinguished by their relative crossings. We will argue below that braided triplets represent fermions, while unbraided triplets provide the simplest way to represent gauge bosons.

3) No charge mixing: *When constructing braided triplets, we will not allow H_+ and H_- helons in the same triplet. H_+ and H_0 mixing, and H_- and H_0 mixing are allowed.*

4) Integer charge: *All unbraided triplets must carry integer electric charge.*

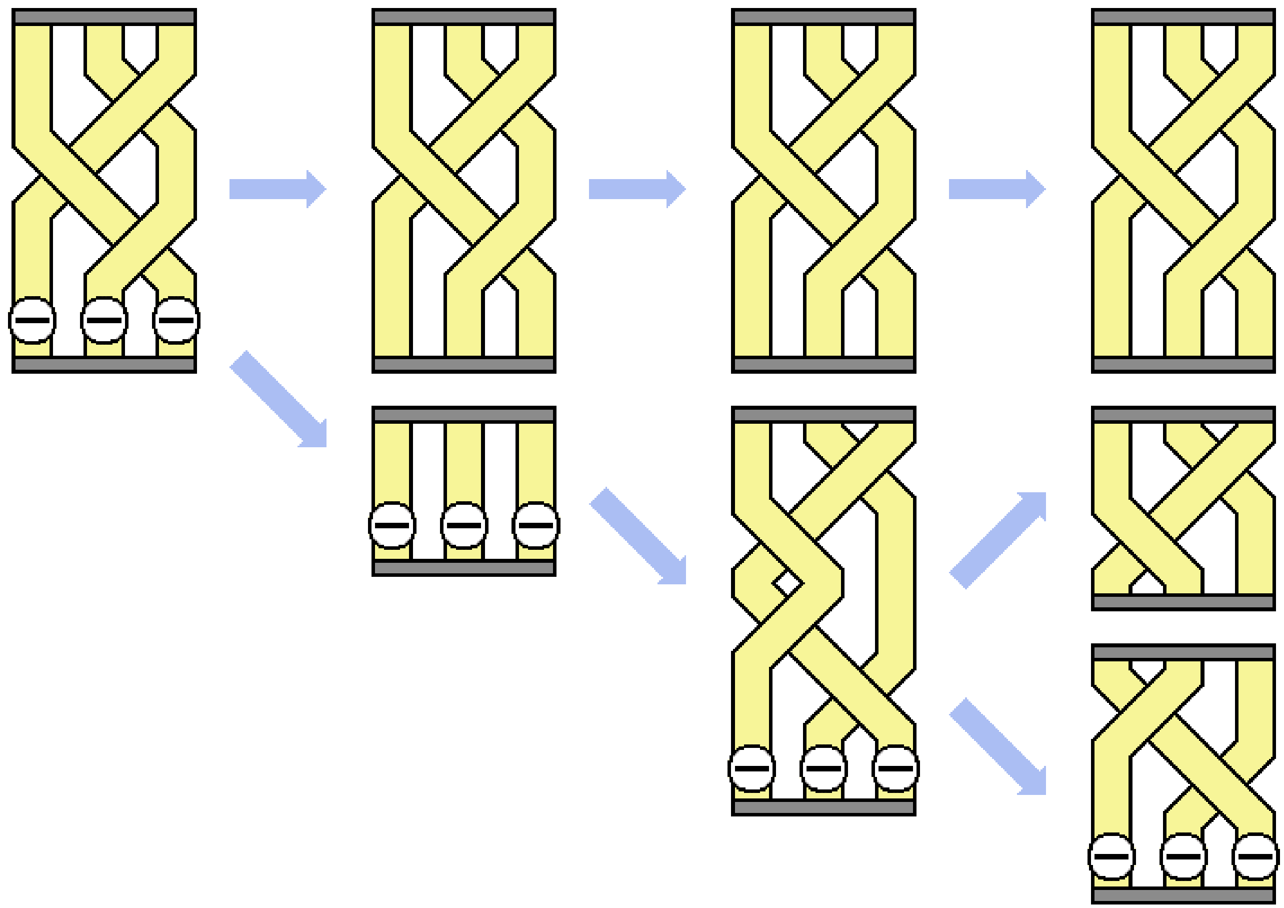


FIG. 2: A representation of the decay $\mu \rightarrow \nu_\mu + e^- + \overline{\nu_e}$, showing how the substructure of fermions and bosons demands that charged leptons decay to neutrinos of the same generation.

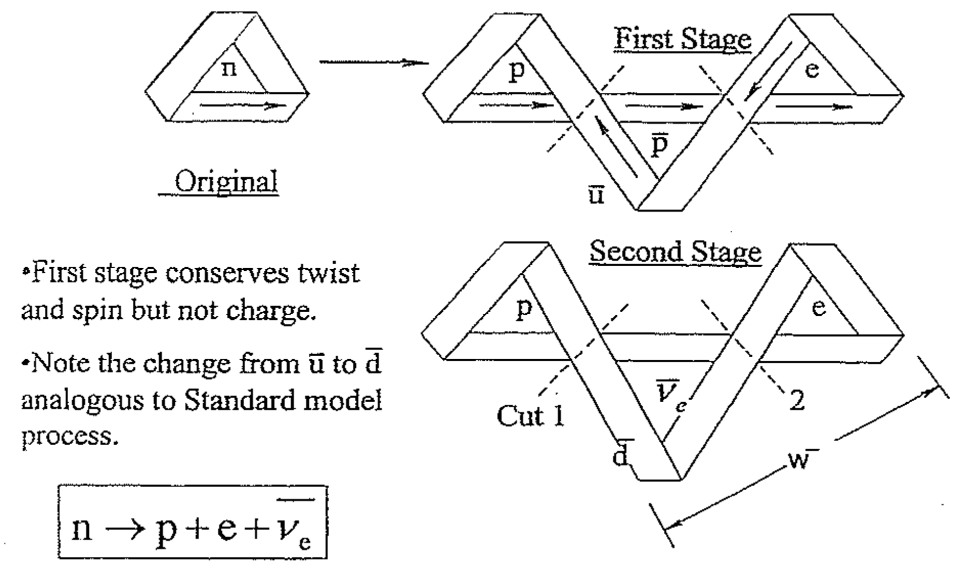
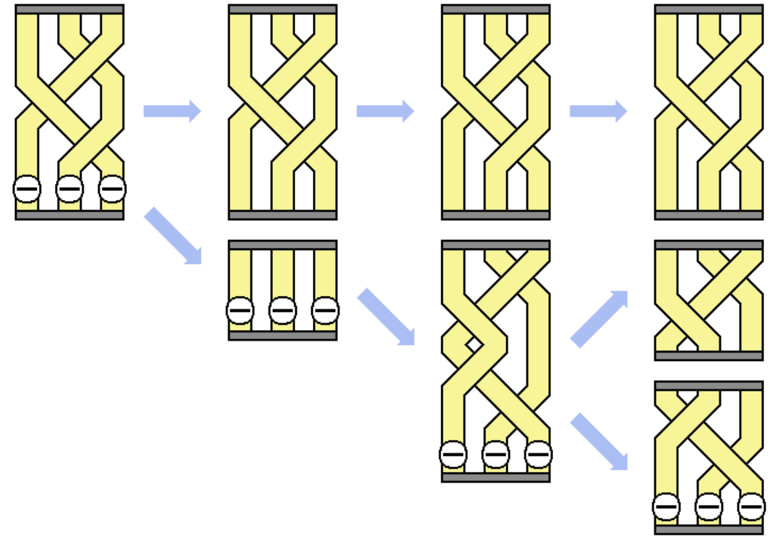


Figure 7: Neutron Decay Model

Avrin



Bilson-Thompson

Comparing Topological Formalisms

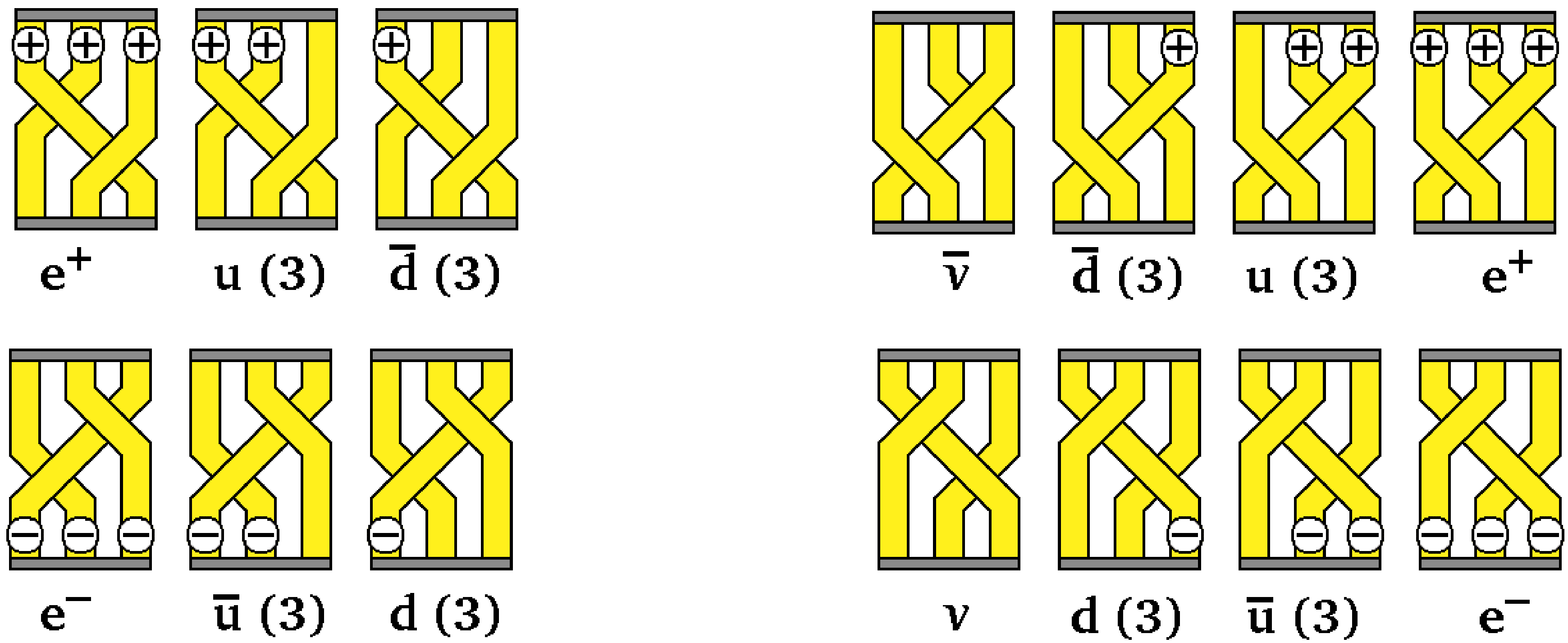


FIG. 1: The fermions formed by adding zero, one, two or three charges to a neutral braid. Charged fermions come in two handedness states each, while ν and $\overline{\nu}$ come in only one each. (3) denotes that there are three possible permutations, identified as the quark colours. The bands at top and bottom represent the binding of helons.

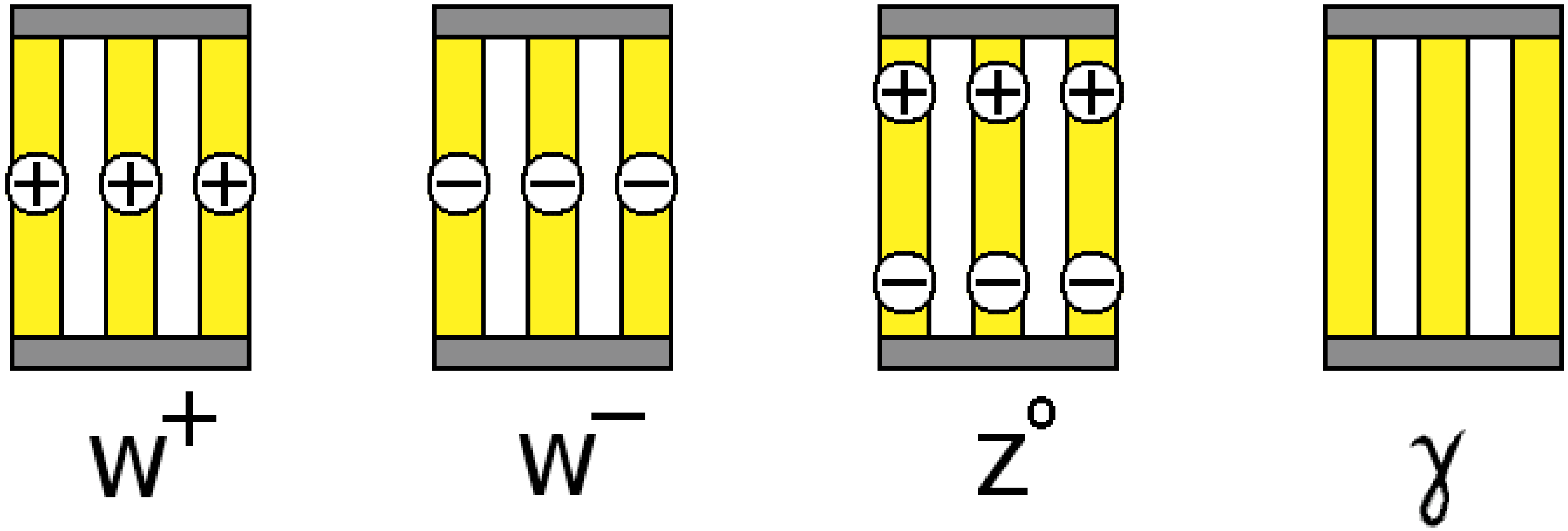


FIG. 3: The bosons of the electroweak interaction. Notice that the Z^0 and the photon can deform into each other.

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Braids as a representation space of SU(5)

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The Standard Model of particle physics provides very accurate predictions of phenomena occurring at the sub-atomic level, but the reason for the choice of symmetry group and the large number of particles considered elementary, is still unknown. Along the lines of previous preon models positing a substructure to explain these aspects, Bilson-Thompson showed how the first family of elementary particles is realized as the crossings of braids made of three strands, with charges resulting from twists of those strands with certain conditions; in this topological model, there are only two distinct neutrino states. Modeling the particles as braids implies these braids must be the representation space of a Lie algebra, giving the symmetries of the Standard Model. In this paper, this representation is made explicit, obtaining the raising operators associated with the Lie algebra of $SU(5)$, one of the earliest grand unified theories. Because the braids form a group, the action of these operators are braids themselves, leading to their identification as gauge bosons. Possible choices for the other two families are also given. Although this realization of particles as braids is lacking a dynamical framework, it is very suggestive, especially when considered as a natural method of adding matter to loop quantum gravity.

PACS numbers: 02.20.Sv, 12.10.Dm, 12.60.Rc
Keywords: Standard Model, grand unified theories, Lie algebra representations, braid groups

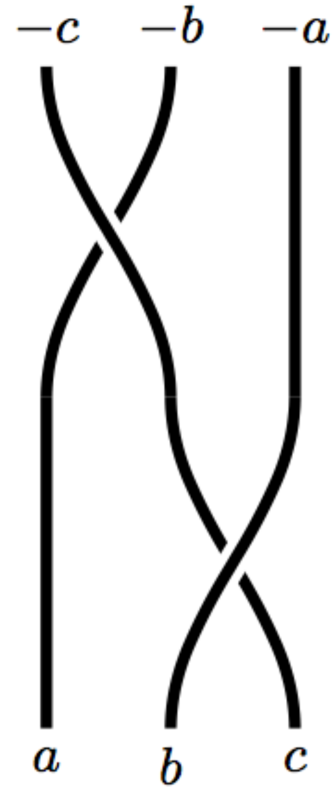


FIG. 7. Example of cancellation needed to make the Bilson-Thompson operator P_{BT} work consistently with the Lie algebra structure of the Standard Model. This illustration represents graphically the operations in (16) using the choice $\sigma_1^{-1}\sigma_2$ for the charge structure of $\overline{u}_L^i$. Here the charges $\{a, b, c\}$ at the bottom come from the action of α^i, while those of $\{-a, -b, -c\}$ at the top come from the action of $CP_{BT}(\alpha^i)$.

The Topology/Stability of the Fabric

It is interesting to note that three helons seems to be the minimum number from which a stable, non-trivial structure can be formed. By stable, we mean that a physical representation of a braid on three strands (e.g. made from strips of fabric) cannot in general be smoothly deformed into a simpler structure. By contrast, such a physical model with only two strands can always be untwisted.

Can we imagine these "particles" as bits of surface interacting in a "superficial spin foam".

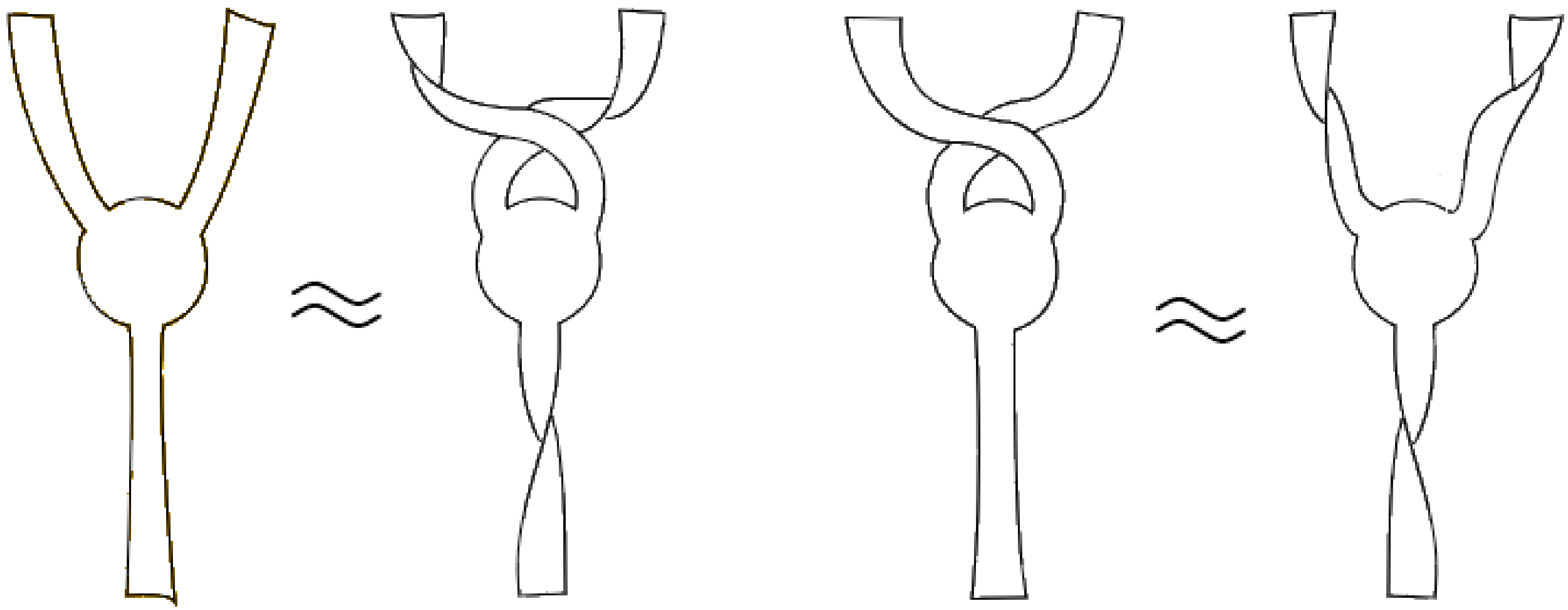
MR2567211 (2011d:81311) 81V25 (20F36 57M99 81V17 83C45)

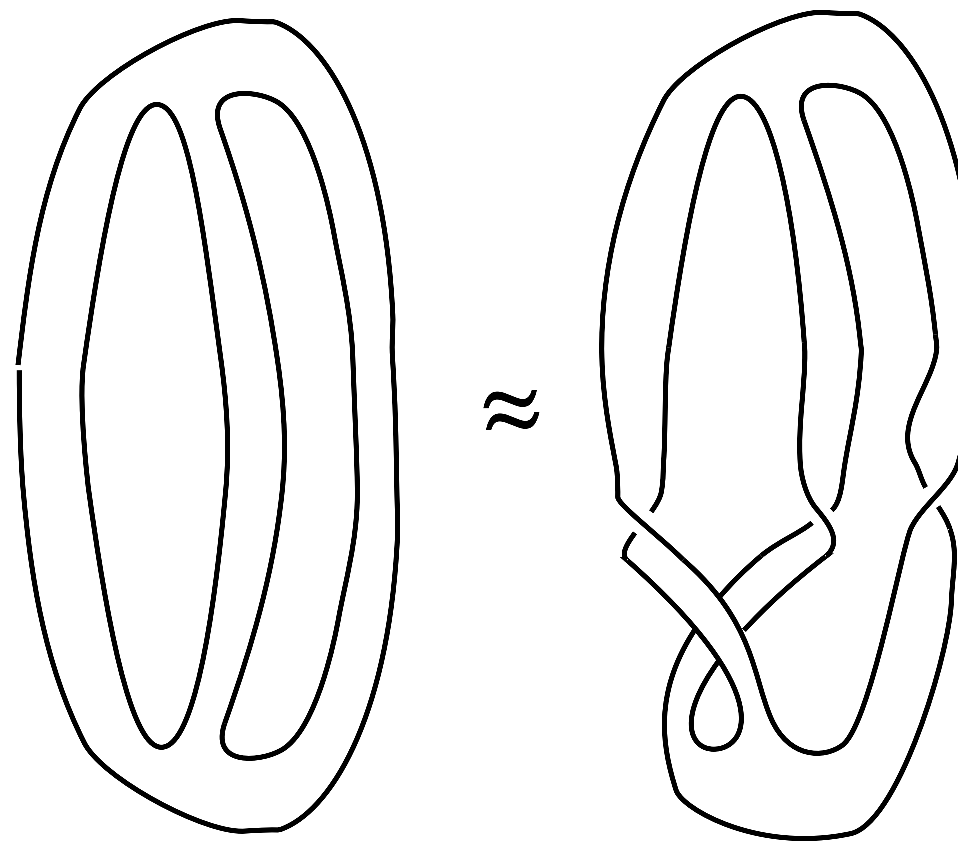
Bilson-Thompson, Sundance (3-PITP); **Hackett, Jonathan** (3-PITP);
Kauffman, Louis H. (1-ILCC-MS)

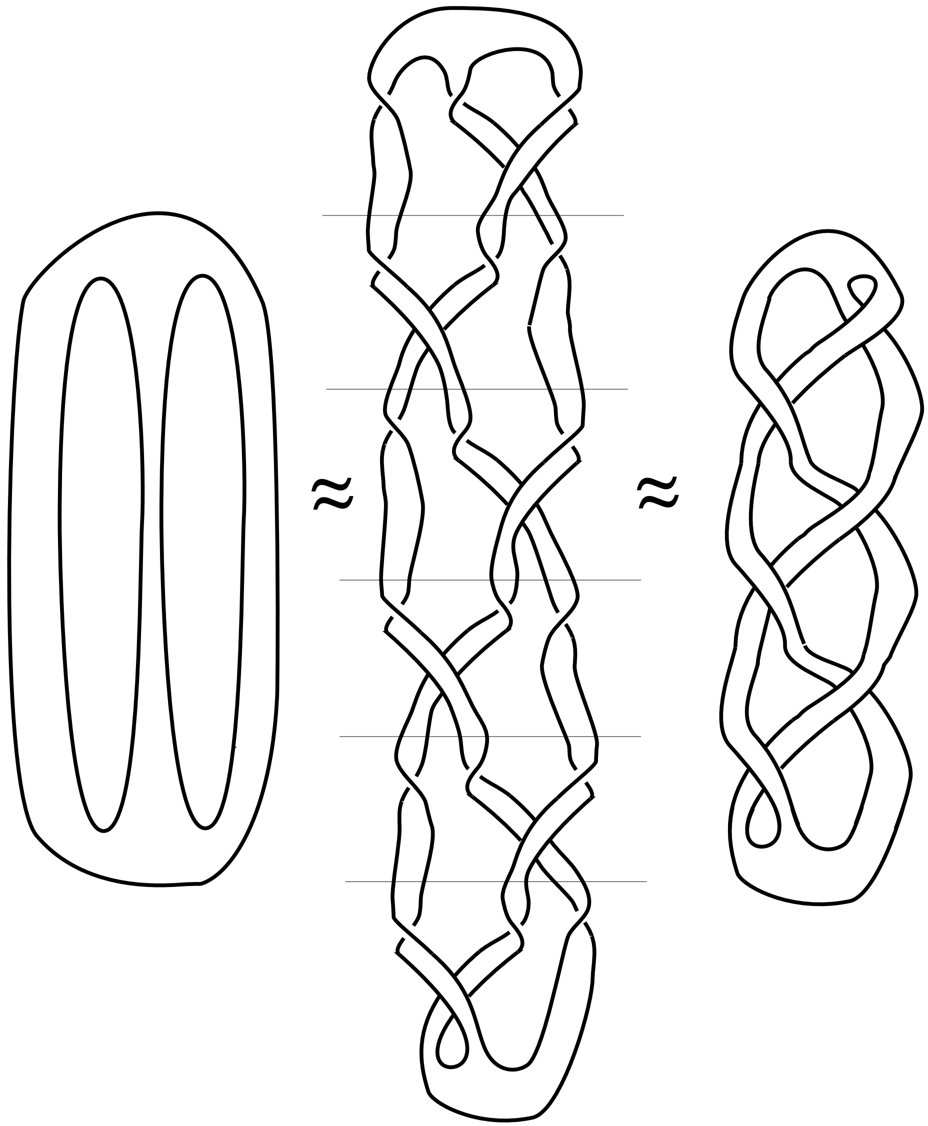
Particle topology, braids, and braided belts. (English summary)

J. Math. Phys. **50** (2009), *no. 11*, 113505, 16 *pp*.

Y Twist



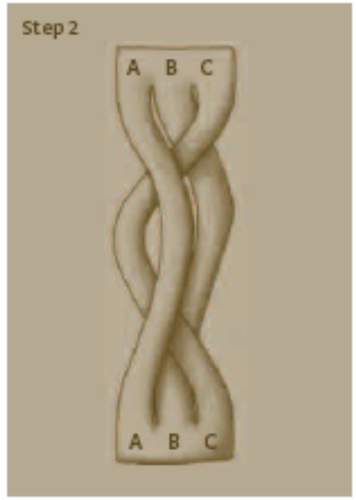




Twist Concatenation Makes Braided Belts

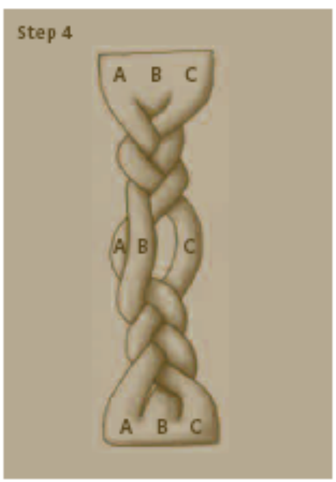
Begin by cutting two slits into a strip of leather.

Be careful not to cut all the way to the ends.



Holding the top flat,
pull string C
over string B,
and pull string A
over string C.

Next,
pull string B
over string A,
and pull string C
over string B.

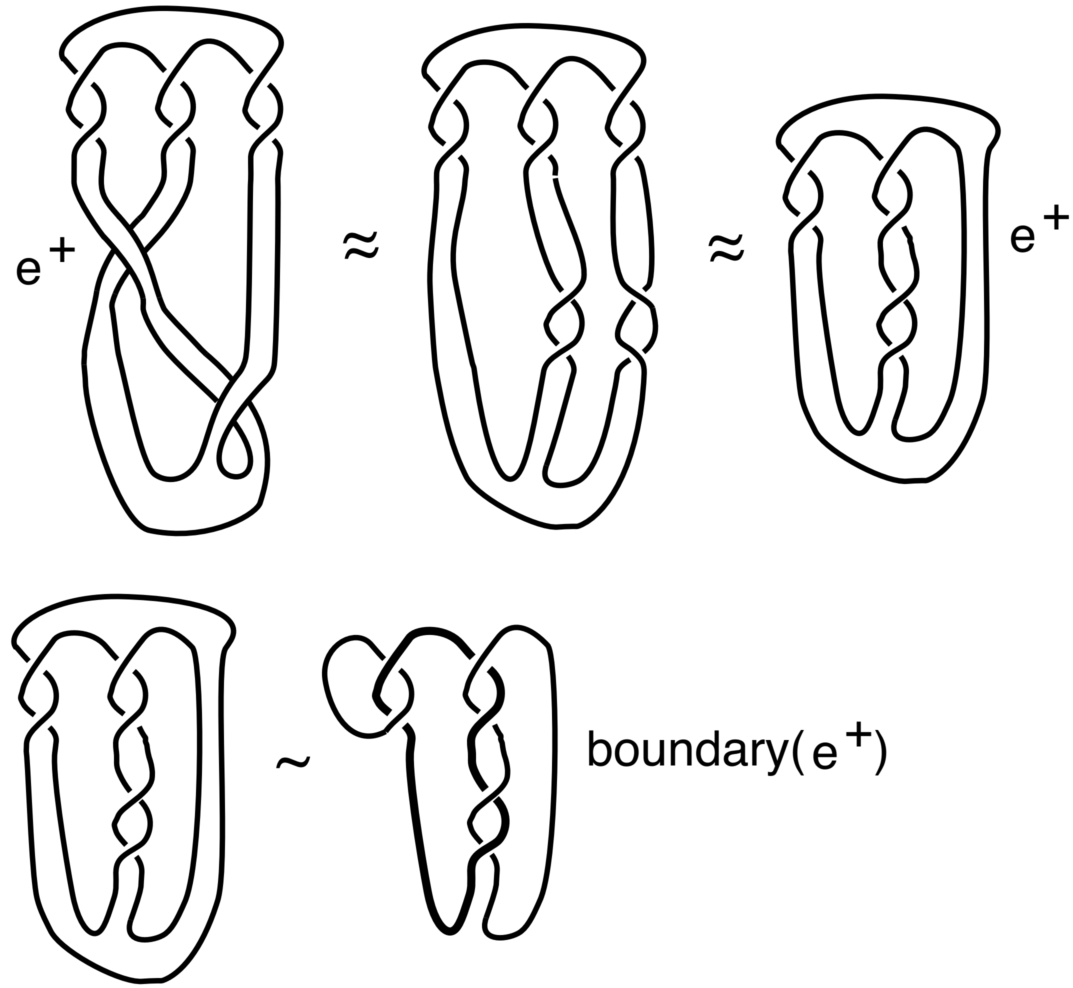


Now pull string A
over string C,
and pull string B
over string A.

Untangle the bottom
portion by sliding the
bottom end through
the open slits.

Continue this pattern
until the braid reaches
the bottom of the strip.

The Positron and Its Linked Boundary



$$e^{+} = [1,1,1]\sigma_1^{-1}\sigma_2 = [1,1,1][1/2,1/2,-1/2]P_{12}[1/2,-1/2,-1/2]P_{23}$$

$$= [1,1,1][1/2,1/2,-1/2][-1/2,1/2,-1/2]P_{12}P_{23} = [1,2,0]P_{12}P_{23}.$$

Apparent Moral:
There is topological
persistence in particle properties
for the surfaces.

To what extent do the surfaces
represent the elementary particles?
To what extent does the framed braid
and/or its algebraic representation
represent the
elementary particles?

The Big Question:
Is there simple knot theoretic
combinatorial topology at the base of the world?