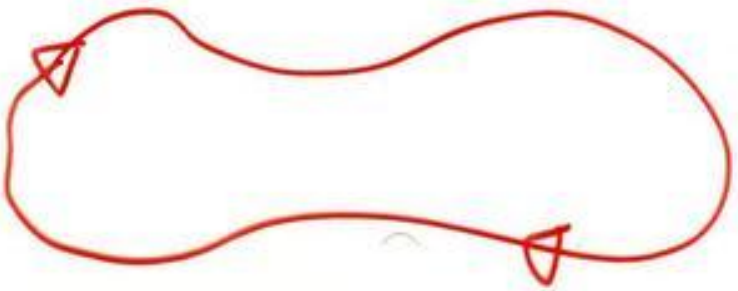
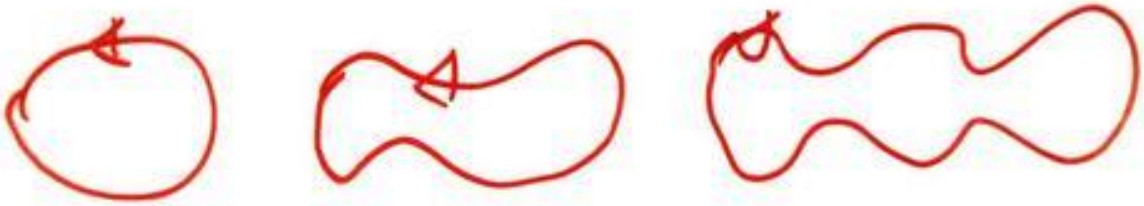
"STRING THEORY," A MODERN APPROACH TO ELEMENTARY PARTICLES ACCORDING TO WHICH PARTICLES ARE MADE OF LITTLE STRINGS



IS REMINISCENT OF MANY OF DIRAC'S IDEAS ....

MOST OBVIOUSLY ABOUT RELATIVISTIC EXTENDED OBJECTS

BUT ALSO ABOUT OTHER MATTERS SUCH AS THE UNITY OF PHYSICS



...

IT WAS ORIGWATED SOMEWHAT INADVERTENTLY AROUND 1970

...

ONE PROBLEM FACED BY THE THEORY IN ITS EARLY DAYS WAS THAT IT DESCRIBED ONLY ONE KIND OF PARTICLES IN NATURE (THE "BOSONS") AND NOT THE SECOND KIND OF PARTICLE, INVENTED BY FERMI AND DIRAC AND CALLED "FERMIONS" OR FERMI-DIRAC

THESE FERMI-DIRAC PARTICLES

INCLUDE MANY OF THE MOST

FAMILIAR ONES, SUCH AS THE

ELECTRON
PROTON
NEUTRON

AND THEY ARE THE

PARTICLES THAT ARE DESCRIBED

BY THE CELEBRATED

"DIRAC EQUATION"

G.J.K.

$3\frac{1}{2}$

DIRAC'S EQUATION

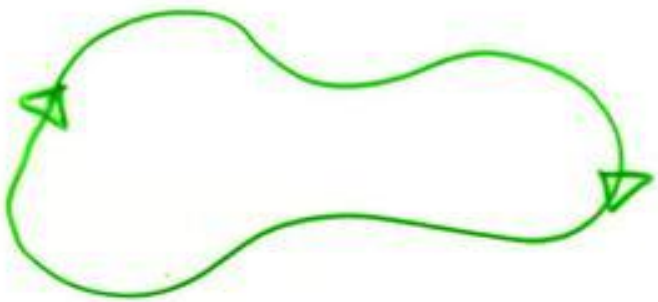
$$(i\gamma^{\mu}\partial_{\mu} - m)\psi = 0$$

γ^{μ} — DIRAC MATRICES

DESCRIBES PARTICLES - LIKE ELECTRONS - THAT AVOID EACH OTHER - PRODUCING THE STABILITY OF MATTERS

IN 1970, PIERRE RAMOND DISCOVERED HOW TO INCLUDE FERMIONS IN STRING THEORY

HIS IDEA WAS TO LET "DIRAC MATRICES" LIVE ON A STRING



IN THE PROCESS, HE DISCOVERED A NEW EQUATION, THE

"DIRAC-RAMOND EQUATION"

WHICH IS A KIND OF STRINGY EXTENSION OF DIRAC'S ORIGINAL EQUATION

THE DIRAC-RAMOND EQUATION

TURNED OUT TO BE ONE OF

THE SEEDS OF SOMETHING

POSSIBLY MUCH BIGGER...

A NEW WAY OF THINKING

ABOUT SPACETIME

OUR CONCEPTS OF SPACE AND TIME WERE TRANSFORMED EARLY IN THE TWENTIETH CENTURY BY EINSTEIN

unify space and time
in "spacetime"

explain gravity as a
consequence of curvature
of spacetime due to
matter

AFTERWARDS, DIRAC AND HIS CONTEMPORARIES AND SUCCESSORS CHANGED ALMOST EVERYTHING ELSE IN PHYSICS, BUT EINSTEIN'S CONCEPTS OF SPACETIME SURVIVED, DOWN TO THE PRESENT.

PHYSICISTS KNOW THAT EINSTEIN'S CONCEPTION OF SPACETIME CANNOT BE THE WHOLE STORY — IT DOESN'T WORK AT THE SUBATOMIC LEVEL. BUT WHAT IS MISSING?

THE DIRAC-RAMOND EQUATION

WAS A SEED OF A NEW

PERSPECTIVE ON SPACETIME...

IT WAS ONE OF THE SEEDS

OF

SUPERSYMMETRY

AND BEYOND THAT, A KEY

INGREDIENT W THE EMERGENCE OF

SUPERSTRINGS

WHAT IS SUPERSYMMETRY?

IN EINSTEIN'S DAY, PHYSICS ONLY DEALT WITH QUANTITIES THAT CAN BE MEASURED BY NUMBERS

pressure

temperature

electric field

IN EVERYDAY LANGUAGE, WE MEASURE SPACE AND TIME BY NUMBERS

"it is now 2 o'clock"

"we are 300 meters above sea level"

AND THIS IS ONE BIT OF COMMON SENSE THAT EINSTEIN PRESERVED....

WITH QUANTUM MECHANICS, WE LEARNED THAT IN NATURE THERE ALL ASO MORE SUBTLE THINGS LIKE DIRAC'S BELOVED

SPIN OF THE ELECTRON

THAT CANNOT BE DESCRIBED BY NUMBERS - THEY ARE MORE NATURALLY DESCRIBED USING "MATRICES" AND "QUANTUM STATES"

INFINITESIMAL OR QUANTUM VARIABLES - RELATED TO FERMI-DIRAC PARTICLES THE WAY NUMBERS ARE RELATED TO THE BOSONS - APPEAR EVERYWHERE IN OUR MODERN DESCRIPTION OF PHYSICS - EXCEPT IN OUR UNDERSTANDING OF SPACETIME, WHERE EINSTEIN'S IDEAS STILL PREVAIL.

SUPERSYMMETRY, HOWEVER,

INTRODUCES NEW QUANTUM

"DIMENSIONS" IN THE STRUCTURE

OF SPACETIME - BEGINNING

THE PROCESS OF UPDATING

EINSTEIN'S THEORY IN THE LIGHT

OF QUANTUM MECHANICS.

IF SUPERSYMMETRY IS RIGHT,

THE PARTICLES WE KNOW HAVE

COUSINS OR "SUPERPARTNERS"

THAT ARISE FROM

VIBRATIONS OF THE KNOWN

PARTICLES IN THE

"QUANTUM DIMENSIONS"

BUT IS SUPERSYMMETRY RIGHT? AND BEYOND THAT, WHAT ABOUT THE DIRAC-RAMOND EQUATION AND SUPERSTRING THEORY?

AT LEAST FOR SUPERSYMMETRY, THERE ARE CLUES FROM EXPERIMENT THAT IT MAY BE RIGHT AND THAT CLEAR PROOF MAY BE CLOSE

ONE CLUE COMES FROM THE MEASURED STRENGTHS OF THE MAIN PARTICLE PHYSICS FORCES - THE STRONG, WEAK, AND ELECTROMAGNETIC FORCES.

WHILE DIRAC AND HIS CONTEMPORARIES PUZZLED OVER THE "FINE STRUCTURE CONSTANT"

$$\frac{e^2}{\hbar c} = \frac{1}{137.\ldots}$$

IN MODERN PARTICLE PHYSICS THERE ARE THREE SUCH CONSTANTS. THEIR MEASURED VALUES - AS DETERMINED MOST PRECISELY BY THE LEP ACCELERATOR AT CERN - AGREE BEAUTIFULLY WITH A PREDICTION BASED ON SUPERSYMMETRY

A SECOND CLUE COMES FROM WHAT DIRAC CALLED THE "PROBLEM OF LARGE NUMBERS"

WHY $\frac{M_{GRAVITY}}{M_{PROTON}} \simeq 10^{19}$

MORE MODERN VERSION:

WHY $\frac{M_{GRAVITY}}{M_{W,Z}} \simeq 10^{17}$

THE MOST SUCCESSFUL KNOWN EXPLANATION USES SUPERSYMMETRY.

BUT TO REALLY BE SURE THAT SUPERSYMMETRY IS RIGHT – AND TO LEARN HOW IT WORKS – WE NEED TO ACTUALLY DISCOVER THE NEW SUPERSYMMETRIC PARTICLES

FOR THIS, ACCELERATORS NEED TO REACH THE ENERGY

$$E = Mc^2$$

AT WHICH THE NEW PARTICLES CAN BE MADE ....

IF WE'VE READ THE CLUES CORRECTLY, THE NECESSARY ENERGY SHOULD BE QUITE CLOSE ...

SUPERSYMMETRY MIGHT BE WITHIN REACH OF THE FERMILAB ACCELERATOR (IN ILLINOIS) WHICH RECENTLY RESUMED OPERATION WITH MORE INTENSE PARTICLE BEAMS ...

IF NOT, THE DISCOVERY REALLY SHOULD BE MADE AT THE LARGE HADRON COLLIDER (LHC) DUE TO START AT CERN IN 2007

IF WE DO FIND

SUPERSYMMETRY, WE'LL FIND

A WORLD OF SURPRISES

-SINCE PHYSICISTS REALLY DON'T

KNOW WHAT TO EXPECT

CONCERNING THE DETAILS OF

SUPERSYMMETRIC PARTICLE

MASSES AND COUPLINGS

IT'LL TAKE YEARS OF

EXPERIMENTAL WORK TO UNRAVEL

- AND PROBABLY HIGH PRECISION

INSTRUMENTS LIKE THE

LINEAR ELECTRON/POSITRON COLLIDER, WHICH IS

NOW ON THE DRAWING BOARDS

IN THE PROCESS, WE CAN

HOPE FOR CLUES ABOUT

PHYSICS AT AN EVEN DEEPER LEVEL

....

AND PERHAPS EVEN LEARN IF SUPERSTRING THEORY AND THE DIRAC-RAMOND EQUATION ARE REALLY THE TWENTY-FIRST CENTURY HEIRS TO THE THEORIES OF EINSTEIN AND DIRAC.