Explaining CP violation using General Relativity

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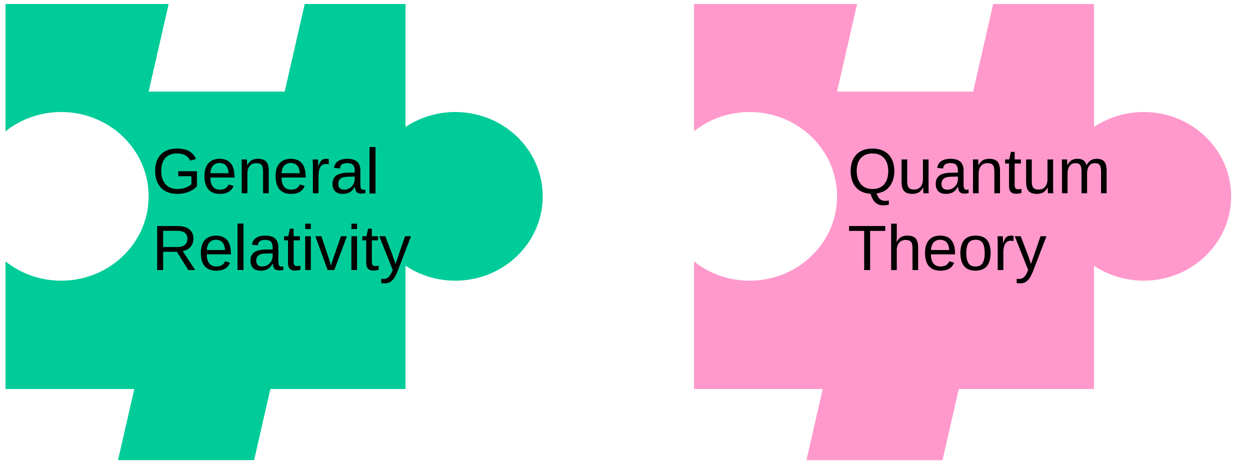
Parity Violation….

The biggest scientific blunder of the 20^{th} century

Plan…

- Motivation
- Parity and Parity violation *… a fresh look*
- CP violation … *a brief look*
- General Relativity ……. *and the Kerr Metric*
- The connection … *and a prediction*

Motivation….



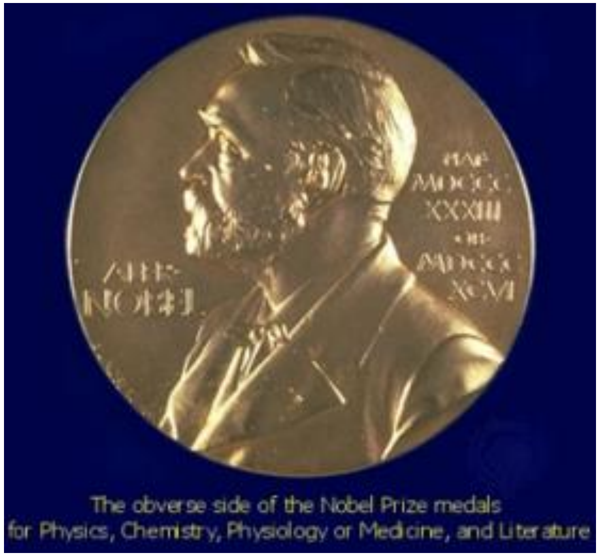
- ~~Quantum gravity~~
- ~~String theory~~
- A gravitational theory of quantum mechanics

A gravitational explanation for quantum theory

- Aims to explain
  - QM
  - Particle spectrum
  - Fundamental interactions
- Predictions
  - No graviton (Gravity waves are just classical waves)
  - Spin-half
  - *Parity is conserved*

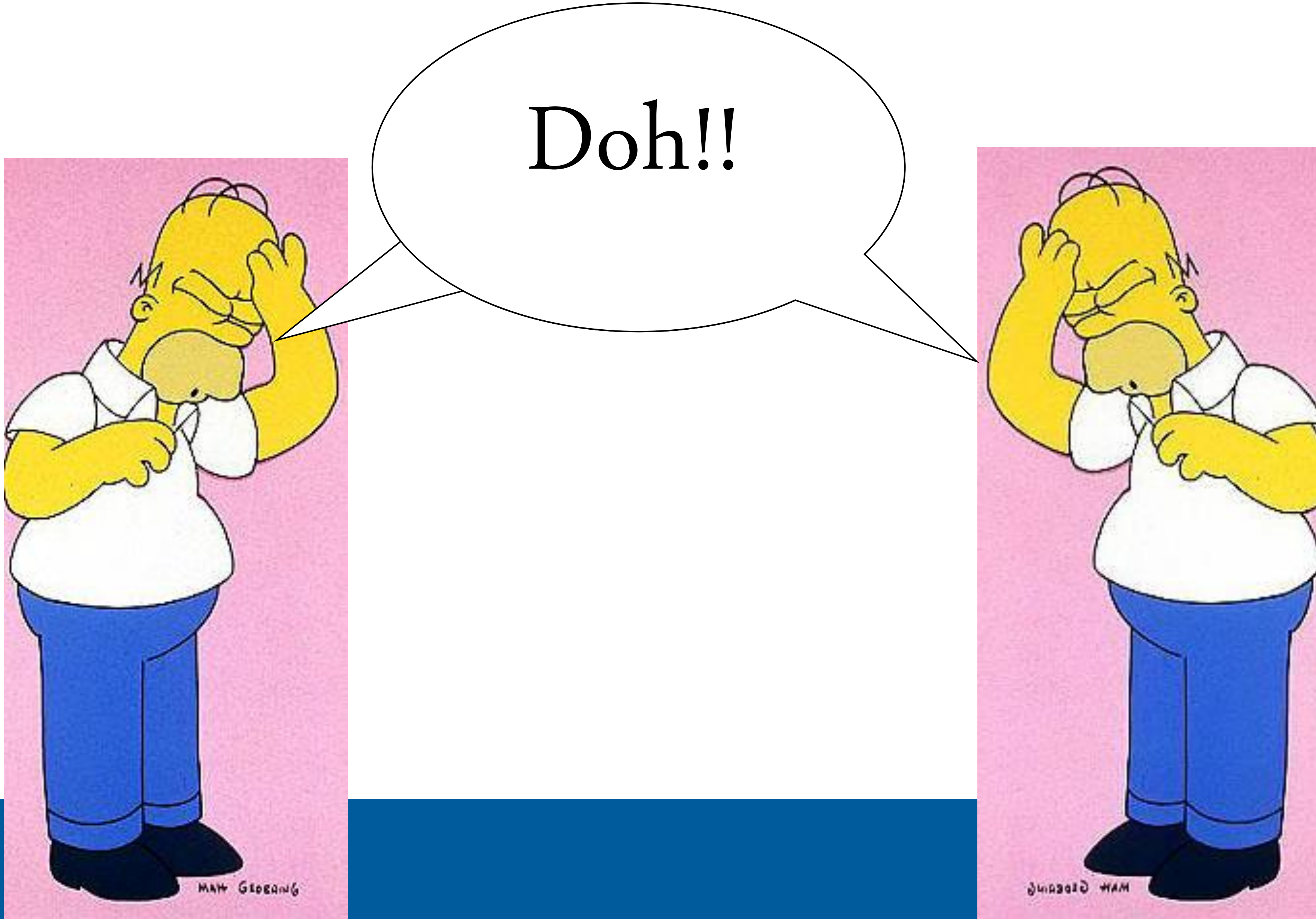
Doh !

Parity is violated - FACT



All the books say so.

The Nobel Prize Committee say so.


Doh!!

Where have they gone wrong?

- Exactly what has been observed?
- Exactly what has been violated?
- What, exactly, is the definition of Parity?

Space Inversion

Inversion = reflection + 180° rotation

$$P: \begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} \rightarrow \begin{pmatrix} -x \\ -y \\ -z \\ t \end{pmatrix}$$

$$\mathbf{x} \rightarrow \mathbf{-x}$$

$$t \rightarrow t$$

$$\mathbf{v} = \dot{\mathbf{x}} \rightarrow \mathbf{-v}$$

$$\mathbf{a} = \ddot{\mathbf{x}} \rightarrow \mathbf{-a}$$

$$\boldsymbol{\omega} = \mathbf{r} \times \mathbf{v} \rightarrow \boldsymbol{\omega}$$

Axial or Pseudo vector

Psuedo vectors don't exist?

- Angular momentum is a bi-vector:
- Base vectors:

  $$\boldsymbol{dx} \wedge \boldsymbol{dy}, \boldsymbol{dy} \wedge \boldsymbol{dz}\ \boldsymbol{and}\ \boldsymbol{dz} \wedge \boldsymbol{dx}$$

- Isomorphic to ***dx,dy,dz***
- But different transformation properties.
- $\mathbf{P}_{TOT} = \mathbf{P}_{Lin} + \kappa\mathbf{P}_{ang}$ is nonsense
- $L = G^{\mu\nu}G_{\mu\nu} + \frac{\theta}{32\pi^2}\ \epsilon^{\mu\nu\alpha\beta}G_{\mu\nu}G_{\alpha\beta}$ is also nonsense

Parity in Newtonian Mechanics

Before	After	Parity conserved
$\mathbf{F} = m\mathbf{a}$	$\mathbf{F} = m(-\mathbf{a})$	✗
	$-\mathbf{F} = m(-\mathbf{a})$	✓
	$-\mathbf{F} = (-m)(-\mathbf{a})$	✗
	$\mathbf{F} = (-m)(-\mathbf{a})$	✓

$E = \frac{1}{2}m v^2$ $\qquad$ $(\pm)E = \frac{1}{2}(\pm m) v^2$

Parity in Newtonian Mechanics

P operator is *chosen*:

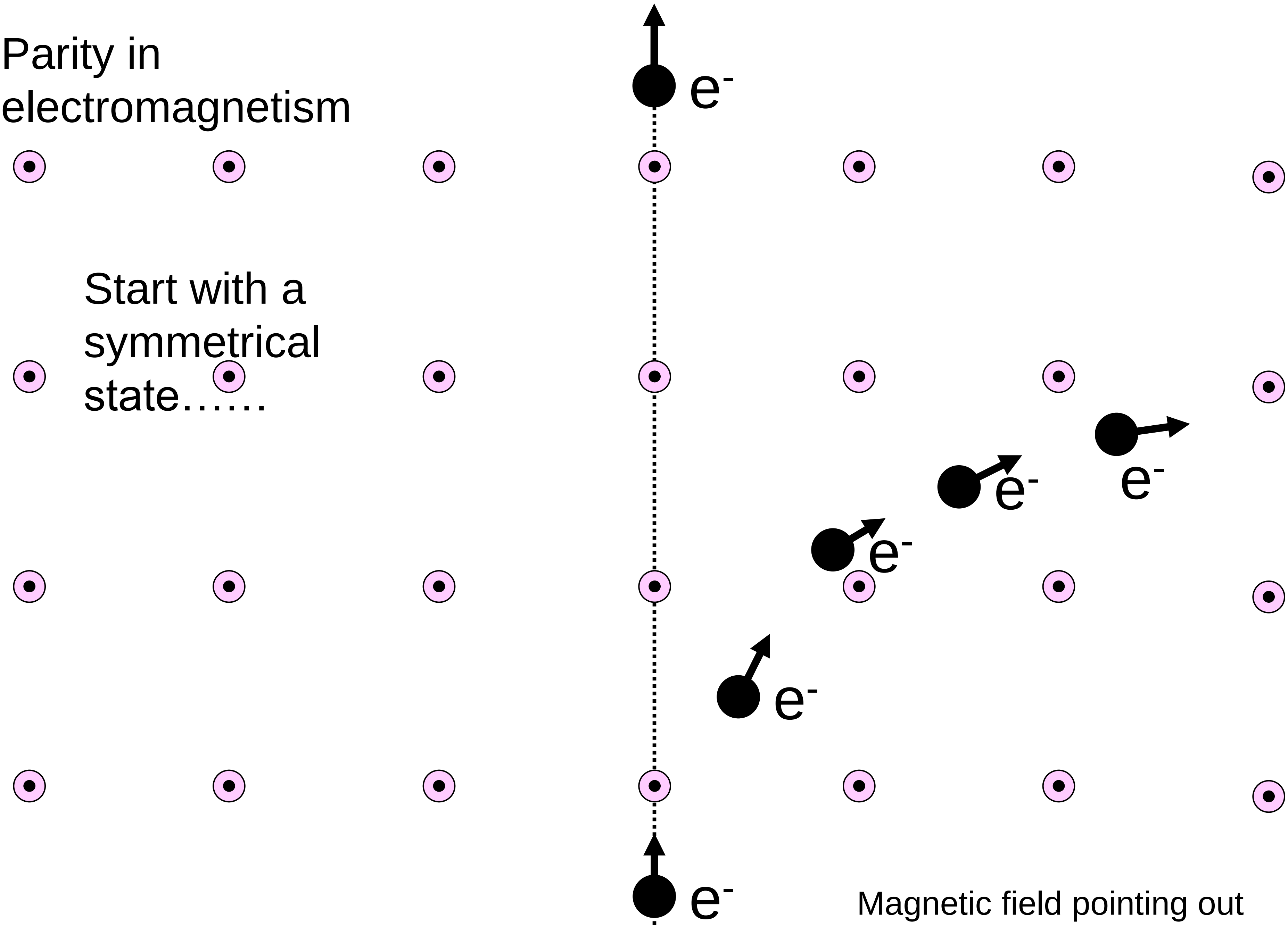
1) For simplicity
2) To conserve parity
3) Supported by: $E = mc^2$

   Special Relativity: (*t*-component of the energy momentum 4-vector)

   General Relativity: $m = \frac{1}{16\pi c^2} \oiint \partial_k g_{jk} - \partial_j g_{kk} dS_j$

Parity in electromagnetism

Start with a symmetrical state……



Parity in Electromagnetism

Before	After	Parity conserved
F = q(**E** + **v** x **B**)	**-F** = q(-**E** + -**v** x (-**B**))	✗
	-F = q(-**E** + -**v** x **B**)	✓
	-F = -q(**E** + -**v** x **B**)	✗
	-F = -q(**E** + -**v** x (-**B**))	✓

Note:

$$q = \oiint \mathbf{E}.\hat{\mathbf{n}}\,dS$$

Parity in Electromagnetism

P operator is *chosen*:

1) To conserve parity
2) For simplicity

In this order

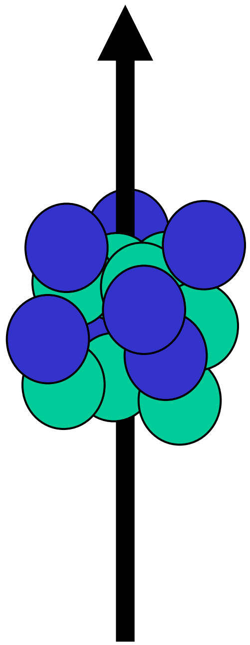
3) Supported by the covariant formulation:

$$\mathbf{F} = \begin{pmatrix} 0 & E_x & E_y & E_z \\ -E_x & 0 & -B_z & B_y \\ -E_y & B_z & 0 & -B_x \\ -E_z & -B_y & B_x & 0 \end{pmatrix}$$

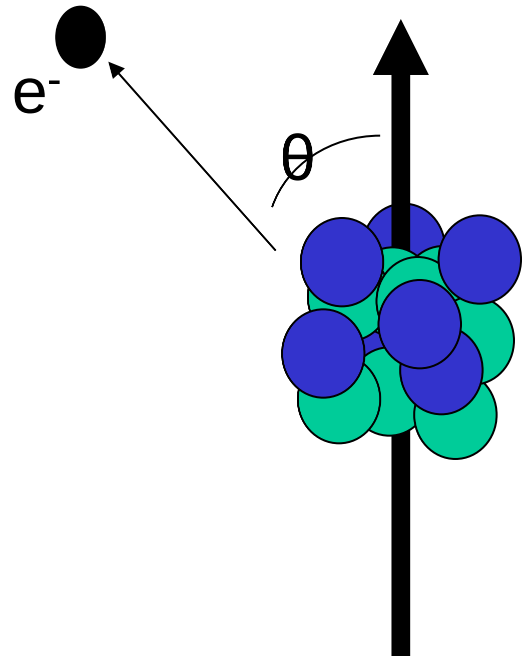
$$\frac{d\mathbf{p}}{d\tau} = q\,\mathbf{F}.\mathbf{v}$$

Start with a symmetrical state

Look for an asymmetric outcome



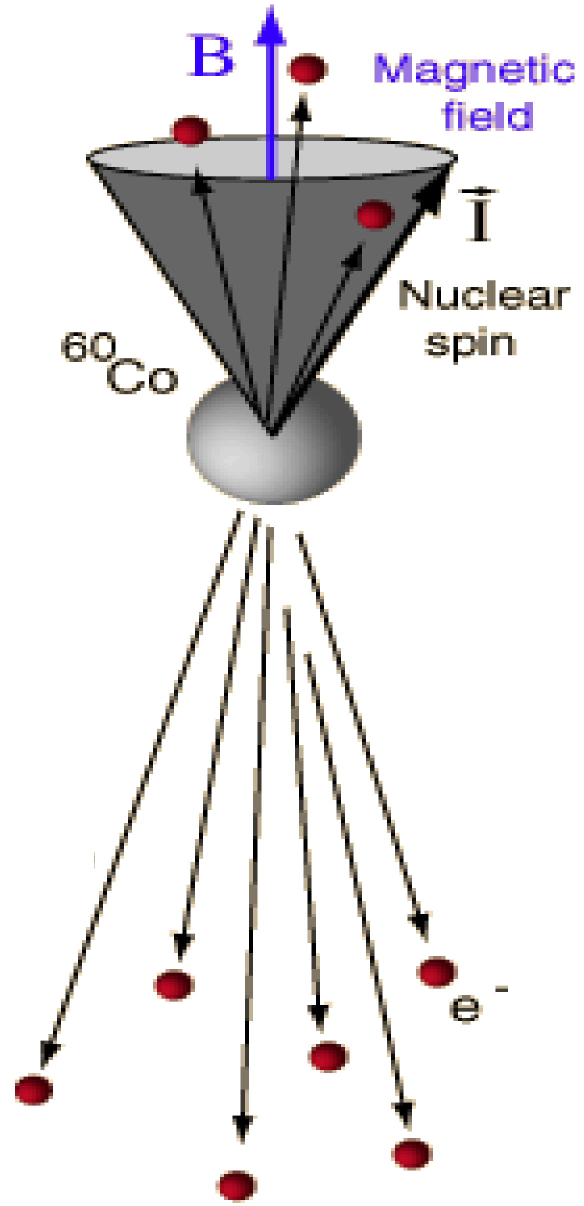
^{60}Co



$^{60}Ni + e^- + \nu_e$

$$I(\theta)d\theta = k\,(1 + \alpha\cos\theta\,)\sin\theta d\theta$$

Beta emission is preferentially in the direction opposite the nuclear spin, in violation of conservation of parity.



actual result

$$I(\theta)d\theta = k\,(1 - v/c \cos\theta)\sin\theta d\theta$$

“We see from this analysis that the logical path from the observed asymmetry to the inferred nonconservation of parity in β decay is considerably more complex than the popular presentations would indicate.”

L. E. Ballentine:

The assumption that the Cobalt nucleous is symmetrical is not only non-trivial -

it may well be wrong !

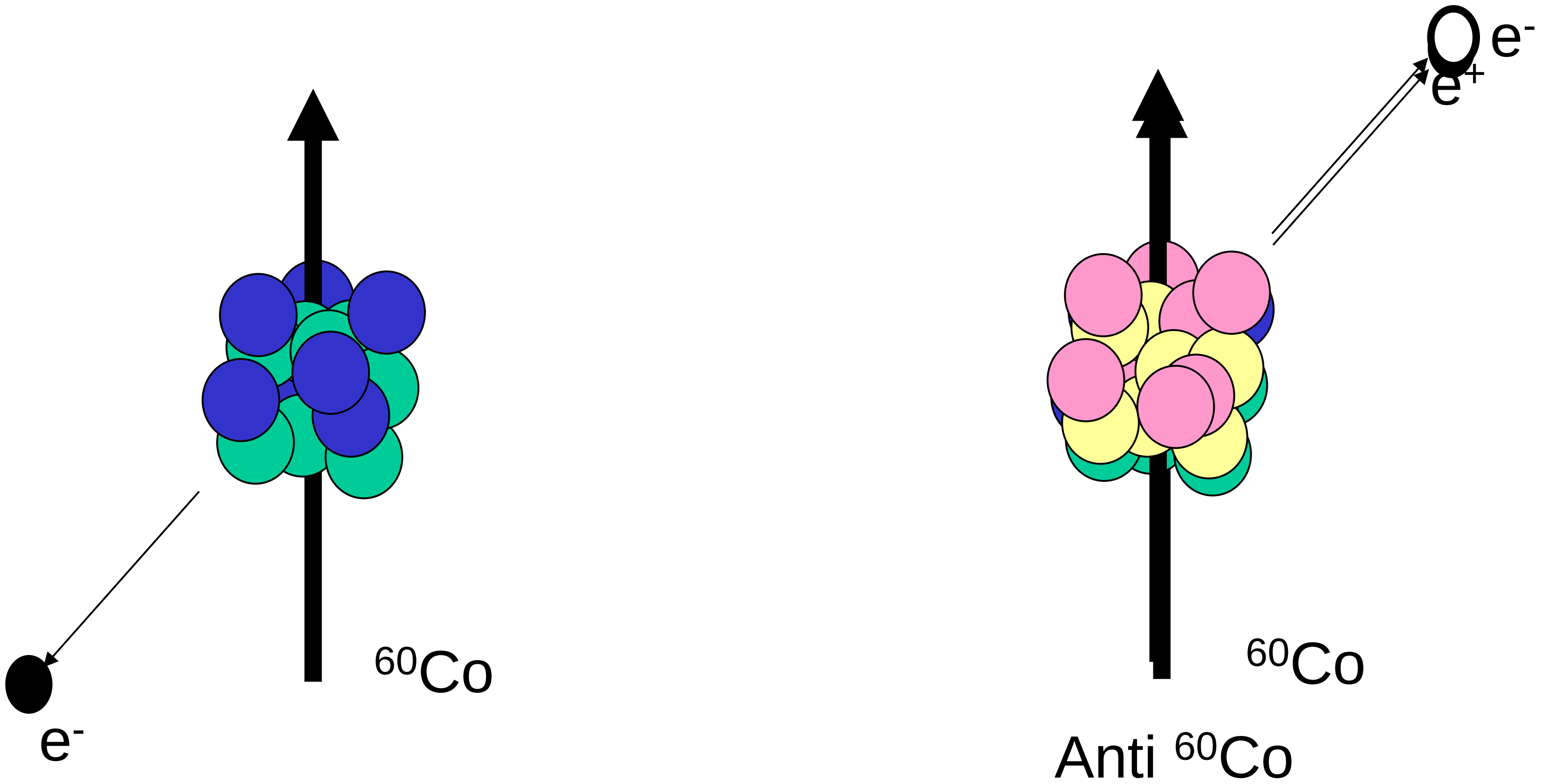
Effect of Parity

The **Parity Operator** gives the transformation due to an **inversion** of the **spatial** coordinates.

We do not have a free choice of P operator.

What are the transformations in beta decay?

What is the mirror image of a Cobalt atom?



(not to scale)

Claim:

The real parity operation is what we call CP

Particles are intrinsically anti-symmetric.

Parity is conserved in the weak interactions…

……….. almost

CP violation is the real mystery

Can it be defined away?

Could it be an external influence?

CP INVARIANCE AND THE 2π DECAY MODE OF THE K_2^o *

J. BERNSTEIN **, N. CABIBBO and T. D. LEE ***
CERN, Geneva, Switzerland

Received 20 August 1964

In a recent experiment Christenson et al.[1] have found definite indications that the long lived component of the K^o, the $K^o{}_2$, decays into two π mesons

$$K_2^o \to 2\pi . \qquad (1)$$

The most direct interpretation of their experiment is to assume that *CP* invariance is violated[2] in this decay and hence in the weak interactions in general. However, it is important to realize that this experiment involves an entirely new domain of phenomena, those involving extremely small energies. The experiment of Christenson et al. is capable of detecting energy differences of the order of 10^{-8} eV. No other experiment in particle physics, up to now, has exhibited such sensitivity to small energies. On the other hand, none of the other experiments[3] on weak interactions that might have shown *CP* violation has done so. Therefore it is not unnatural to try to explain the new experiments in some other way. In this note we shall attempt to reconcile the two assumptions:

i) *CP* invariance holds for *all* interactions:
ii) the long lived component of the K^o, in (local) vacuum, or at least in what is usually called "vacuum", decays into 2π's.

Up to now vacuum is particle physics has been taken to mean the absence of neighbouring material objects, although not necessarily that of long range fields such as gravitational or electromagnetic fields. These conventional fields, which are produced by distant bodies such as Milky Way and the other galaxies, are sufficiently well understood so that one can assume, with some confidence, that their effects on the K^o, $\overline{K}^o$ system can be neglected, either because they are too small (we have in mind the possible electromagnetic conversion between $K^o{}_1$ and $K^o{}_2$ due to the difference in the charge radius of K^o and $\overline{K}^o$) or because they have the same effect on particles and antiparticles (e.g., gravitational forces).

In this note we postulate that there is a new long range, extremely weak, field which can be neglected so long as one does not measure energies as small as those measured in the experiment of Christensen et al. This field, we assume, produces a potential energy which is equal in magnitude and opposite in sign for K^o and $\overline{K}^o$, say $\frac{1}{2}V$ for K^o but $-\frac{1}{2}V$ for $\overline{K}^o$. This new interaction is *CP* conserving and if we could maintain a given K^o and $\overline{K}^o$ system, but transform the environment into its *CP* conjugate state, then this potential energy would reverse sign †.

* Work supported in part by the U.S. Atomic Energy Commission. the Army Research Office (Durham) and the National Science Foundation.
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† During the completion of this paper, we learnt of a preprint by J. S. Bell and J. K. Perring, who have in-

General Relativity
Our *ONLY* theory of Space and time

$$G(x) = 8\pi T(x)$$

Curvature of Space and Time

Energy, Momentum and Stress Tensor

- Accepted and understood
- Non-linear equations
- Local equations - Does not prescribe the topology
- Describes a curved spacetime
- Allows closed timelike curves CTCs

The metric

$$ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2$$

$$ds^2 = -c^2dt^2 + dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)$$

Schwarzschild metric

$$ds^2 = -\left(1 - \frac{r_s}{r}\right)c^2dt^2 + \left(1 - \frac{\mathrm{r_s}}{\mathrm{r}}\right)^{-1}\mathrm{dr}^2 + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)$$

General case:

$$ds^2 = g_{\mu\nu}\, dx^\mu\, dx^\nu$$

The Kerr metric

$$ds^2 = -\left(c^2 - \frac{2GMr}{\rho^2}\right)dt^2 + \frac{\rho^2}{\Delta^2}dr^2$$

$$+\rho^2\, d\theta^2$$

$$+(r^2 + \frac{J^2}{M^2c^2} + \frac{2GJ^2r}{c^4\rho^2M}\sin^2\theta)\sin^2\theta d\phi^2$$

$$+\frac{4GrJ}{c^2\rho^2}\sin^2\theta dt d\phi$$

Where:

$\rho^2 = r^2 + \frac{J^2}{M^2c^2}\cos^2\theta$ and $\Delta^2 = r^2 - \frac{2GM}{c^2}r + \frac{J^2}{M^2c^2}$

$$g_{t\phi} \approx 4GJ/c^2 r \sin^2\theta$$

- One component of a second rank tensor
- Measures the asymmetry.
- t and ϕ are symmetry directions (they define killing vector fields)

- … but also define an invariant scalar field.

Relative magnitudes

	Earth	Sun	Galaxy	
r	$6.3\ 10^{6}$	$1.5\ 10^{11}$	$2.5\ 10^{20}$	*m*
J	$7\ 10^{3}$	$2\ 10^{41}$	10^{66}	$kg\ m^2\ s^{-1}$
$g_{t\Phi}$	3	$3\ 10^{3}$	10^{20}	$m^2 s^{-1} rad^{-1}$
h_{tx}	10^{-15}	10^{-14}	10^{-9}	*dimensionless*

Hypothesis

- Particles are intrinsically antisymmetric.
- They interact with the asymmetric gravitational potential to produce an apparent CP violation effect

Predictions:

- CP violation is local, not universal.
- It varies according to the $g_{t\phi}$ term of the metric.
- There is a $\sin^2\theta$ variation in the magnitude with respect to the galactic plane.
- Earth based experiments may give anisotropic results for CP violation.

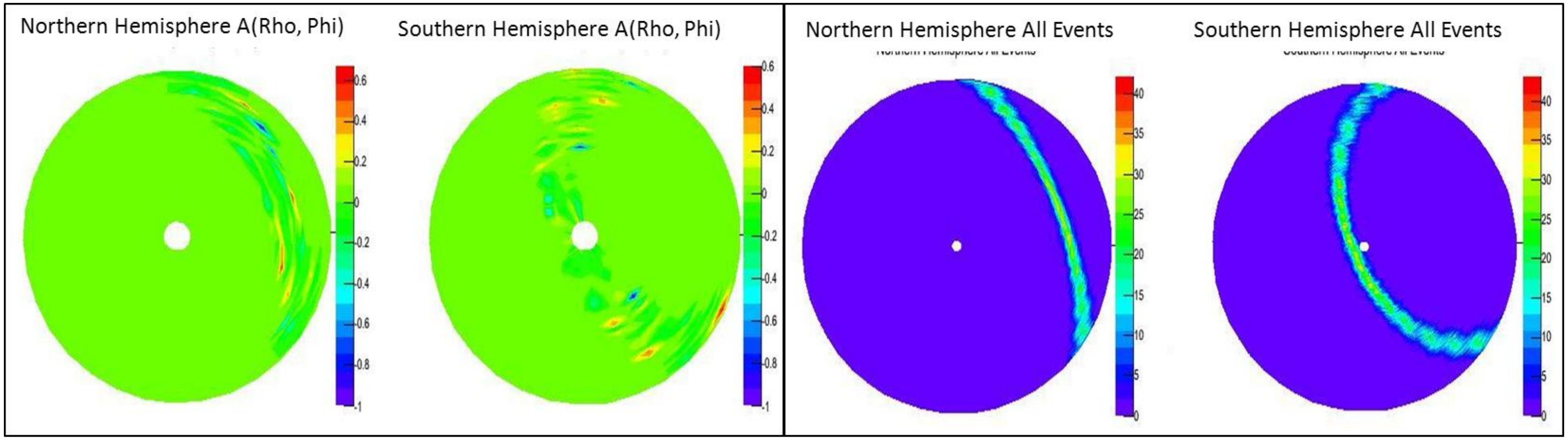
The Quest

- Choose a CP violating reaction
- Collect associated directional parameters
- Correct for the Earth's rotation
- Plot on a galactic co-ordinate system

Results so far.......

$B0 \rightarrow J/\psi K_s$ $\overline{BO} \rightarrow J/\psi K_s$

Plots of asymmetry vs B0 momentum direction



Lambert projections of the asymmetry amplitude (left) and all meson trajectories (right).

David Goude. University of Warwick 2012

Can you do better?