Exploring Quantum Physics

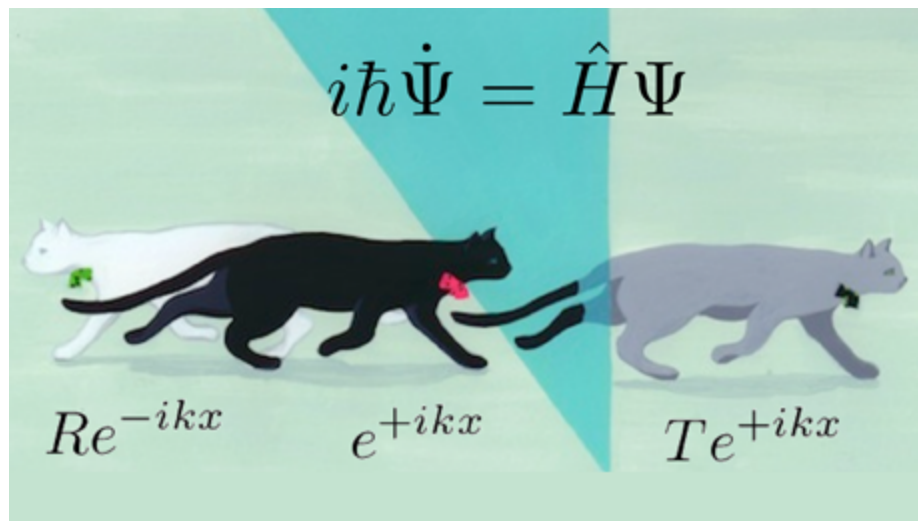**Coursera, Spring 2013   Instructors: Charles W. Clark and Victor Galitski**

Symmetry in Quantum Physics
Part I. Introduction

Symmetry in quantum physics

Werner Karl Heisenberg
1901-1976
1932 Nobel Prize in Physics
"for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen".
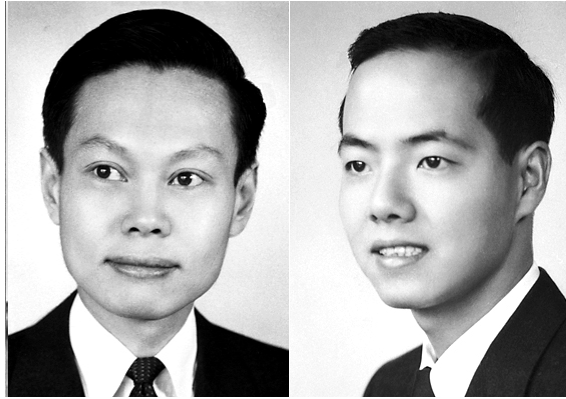
Single-particle aspects

- Parity
- Angular momentum
- 4-dimensional symmetry of hydrogen atom
- Spin – detailed treatment by
          Ian Applebaum next week
- Isobaric spin
- Time reversal
- Gauge invariance

Many-particle aspects

- Bosons: Bose-Einstein condensation
- Fermions: Hard dense gas at zero temperature
- Atomic shell structure

Symmetry in quantum physics

Chen Ning Yang   Tsung Dao Lee
     1922-   1926-

1957 Nobel Prize in Physics

"for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles".

Parity

A towering symmetry in atomic, molecular, optical, condensed matter, nuclear and particle physics.

It is maximally violated in weak interactions!

The photon, an odd-parity particle, is now understood to be partnered with the W and Z bosons in the "electroweak theory"

Symmetry in quantum physics

Parity violation observed at the National Bureau of Standards, 1956

NIST
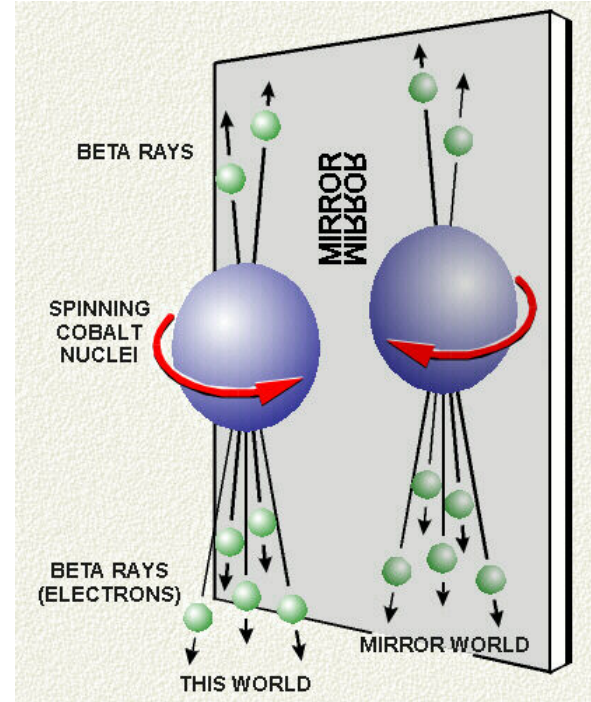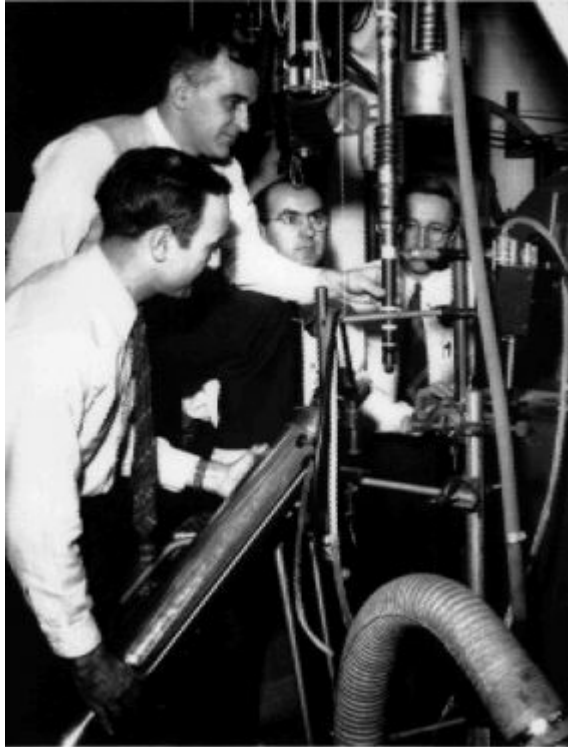
Symmetry in quantum physics

Eugene Paul Wigner
1902-1995
1963 Nobel Prize in Physics
"for his contributions to the theory of
the atomic nucleus and the
elementary particles, particularly
through the discovery and application
of fundamental symmetry principles".

Angular momentum

The grand organizing principle of molecular, atomic, nuclear and particle physics.

Some of Wigner's important contributions:
- Angular momentum algebra
- Wigner-Eckert theorem
- Isobaric spin
- Nuclear structure
- Random matrix theory
- Time reversal

$$\begin{pmatrix} j_1 & j_2 & j_3 \\ m_1 & m_2 & m_3 \end{pmatrix} = (-1)^{j_1 - j_2 - m_3} \Delta(j_1 j_2 j_3) \left((j_1 + m_1)!(j_1 - m_1)!(j_2 + m_2)!(j_2 - m_2)!(j_3 + m_3)!(j_3 - m_3)! \right)^{\frac{1}{2}}$$
$$\times \sum_s \frac{(-1)^s}{s!(j_1 + j_2 - j_3 - s)!(j_1 - m_1 - s)!(j_2 + m_2 - s)!(j_3 - j_2 + m_1 + s)!(j_3 - j_1 - m_2 + s)!},$$

Symmetry in quantum physics

Atomtronics application:
time-reversal noninvariant device – the circulator
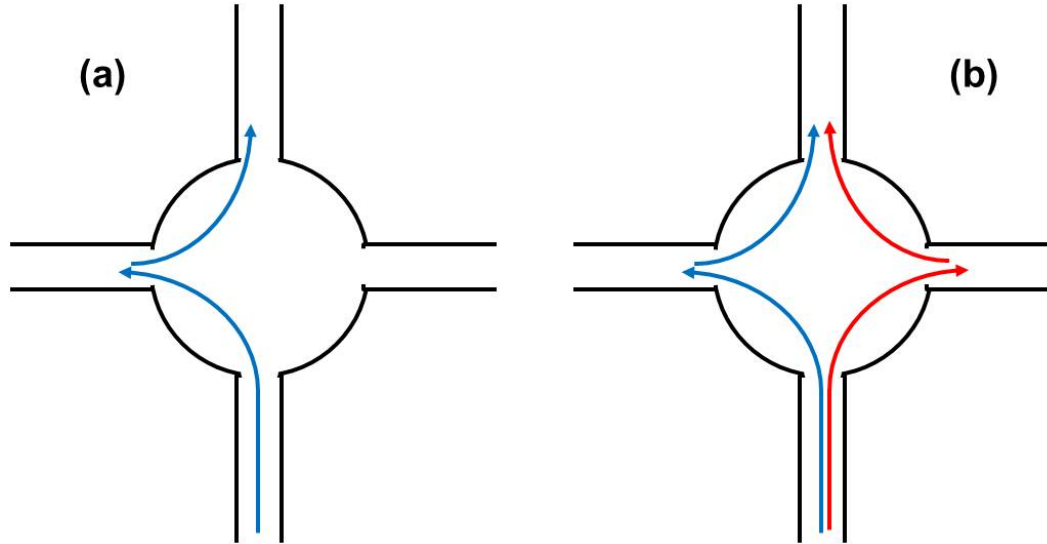
Symmetry in quantum physics

Wolfgang Pauli
1900-1958
1945 Nobel Prize in Physics
"for the discovery of the
Exclusion Principle, also called
the Pauli Principle".

The Pauli Exclusion Principle

Manifestly a *symmetry* principle, requiring that the wavefunction of a many-particle system be antisymmetric under the interchange of any two fermions.

Quantum particles appear to reside in one of the two great families: fermions, or bosons for which the wavefunction is symmetric under exchange.

This has profound importance in practical understanding of matter. It is a consequence of *symmetry* which stands apart from specific dynamical principles and sometimes transcends them.

Symmetry in quantum physics

Symmetry – a Global Framework

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Sheldon Lee
Glashow
1932-

Abdus Salam
1926-1996

Steven
Weinberg
1933-

1979 Nobel Prize in Physics "for their contributions to the
theory of the unified weak and electromagnetic interaction
between elementary particles, including, inter alia, the
prediction of the weak neutral current"

The Standard Model

SU(3)×SU(2)×U(1) gauge symmetry

36 quarks, 12 leptons, 8 gluons
photon, W, Z and Higgs bosons

Remarkably successful!