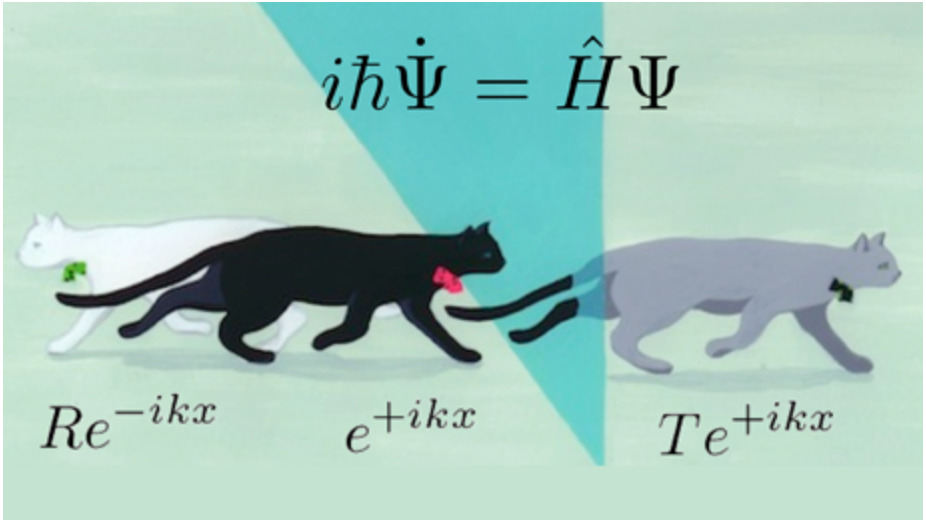
Exploring Quantum Physics

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

Symmetry in Quantum Physics

Part II. Parity and discrete symmetries



Symmetry in quantum physics

What constitutes a symmetry in quantum physics?

Suppose we have a solution to the Schrödinger equation $i\hbar\frac{\partial}{\partial t}\Psi = \hat{H}\Psi$

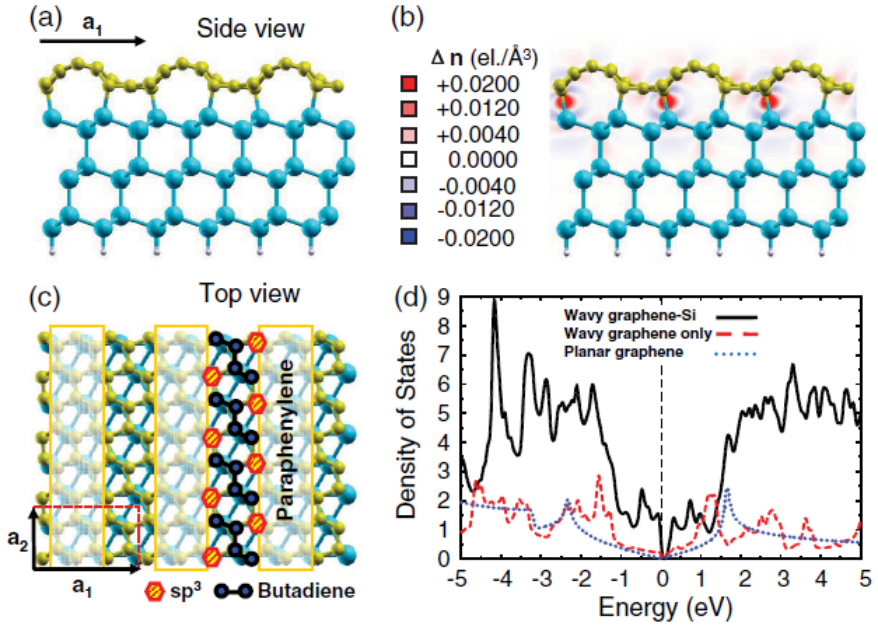
And there is an operator which satisfies $\left[\hat{U}, \hat{H}\right] = \hat{U}\hat{H} - \hat{H}\hat{U} = 0$

Then $i\hbar\frac{\partial}{\partial t}\hat{U}\Psi = \hat{H}\hat{U}\Psi$ so $\hat{U}\Psi$ is also a solution

We can require prospective solutions to be eigenfunctions of $\hat{U}$

Symmetry in quantum physics

Why this is useful

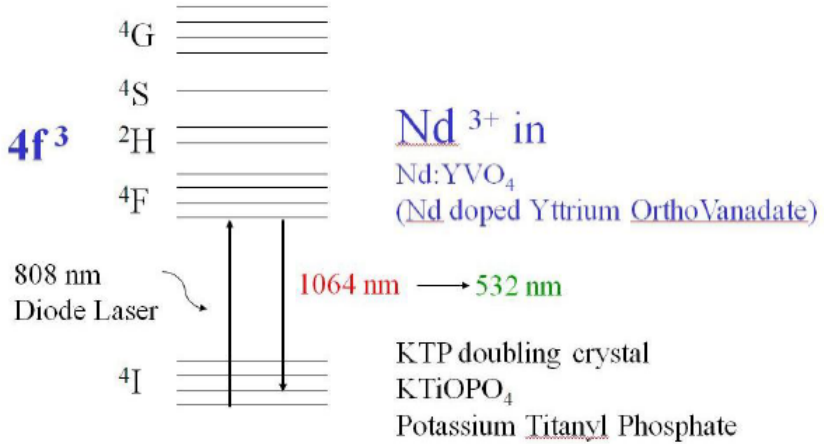


First-principles calculation of electronic structure of graphene, or interpreting its photoelectron spectrum or transport properties, is greatly simplified if one can treat one orbital symmetry at a time.

C. Tayran, et al. *PRL* **110**, 176805 (2013)

Symmetry in quantum physics

Why this is useful



I'm designing a laser system that needs to operate in a certain wavelength region. What optical sources are available, and whch are the strongest transitions?

J. Galang, et al. , "The Green Laser Pointer"
in Exploring Quantum Physics Additional Materials

Symmetry in quantum physics

Simplest discrete symmetry: coordinate inversion (parity)

$$\hat{H} = \sum_{j=1}^{N} \left[\frac{\hat{p_j}^2}{2M_j} + \sum_{k \neq j}^{N} V_{jk} \left(|\vec{r}_j - \vec{r}_k| \right) \right]$$

A Hamiltonian describing many particles interacting via pairwise central interactions: quite a good approximation to many real materials.

Definition of parity operator $P\Psi\left(\vec{r}_1, \vec{r}_2, ..., \vec{r}_n\right) = \Psi\left(-\vec{r}_1, -\vec{r}_2, ..., -\vec{r}_n\right)$

$$\left[\hat{P}, \hat{H}\right] = 0 \quad ?$$

Symmetry in quantum physics

Simplest discrete symmetry: coordinate inversion (parity)

The particles in the previous example have charges q_j, and we turn on an electric field , $\vec{E}$

$$\hat{H} = \sum_{j=1}^{N} \left[\frac{\hat{p_j}^2}{2M_j} - q_j \vec{E} \cdot \vec{r}_j + \sum_{k \neq j}^{N} V_{jk} \left(|\vec{r}_j - \vec{r}_k| \right) \right]$$

Definition of parity operator $P\Psi\left(\vec{r}_1, \vec{r}_2, ..., \vec{r}_n\right) = \Psi\left(-\vec{r}_1, -\vec{r}_2, ..., -\vec{r}_n\right)$

$$\left[\hat{P}, \hat{H}\right] = 0 \quad ?$$

Symmetry in quantum physics

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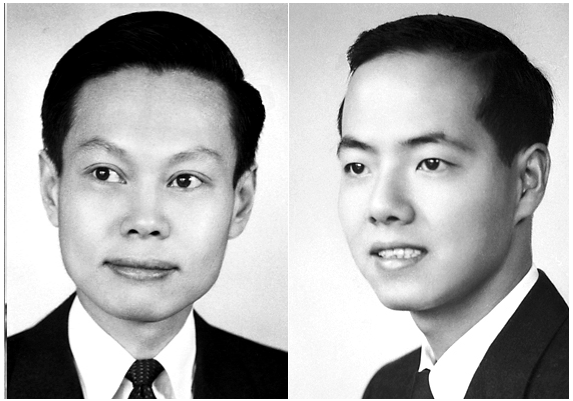

Chen Ning Yang 1922-

Tsung Dao Lee 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