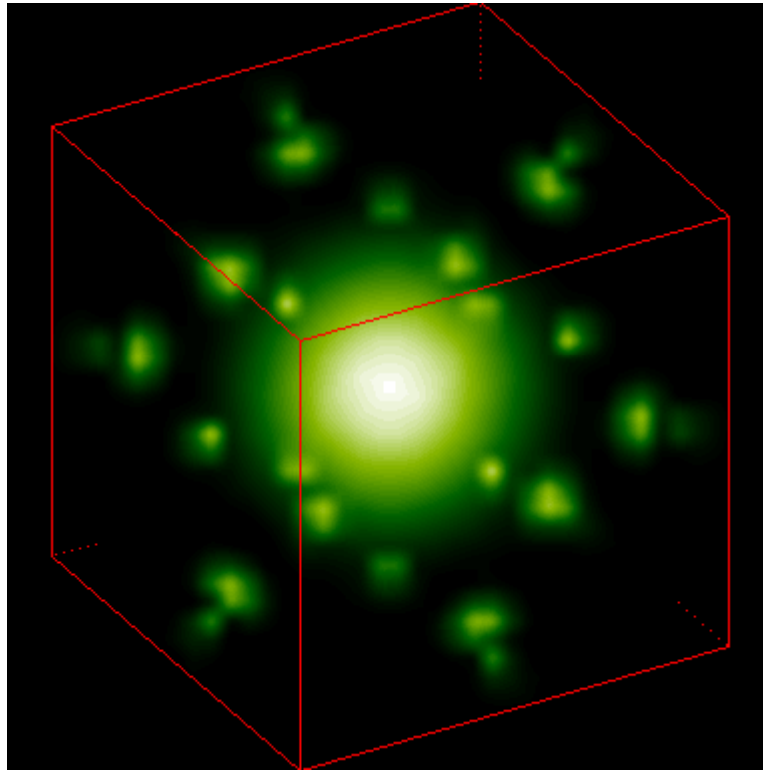


Solid State Physics (3.23)



kevin gotrik

may 2, 2011

The big picture is important

- How are humans able to understand the matter that we can touch and see?

Sometimes it seems to me that a bond between two atoms has become so real, so tangible, so friendly, that I can almost see it. Then I awake with a little shock, for a chemical bond is not a real thing. It does not exist. No one has ever seen one. No one ever will. It is a figment of our own imagination.... Here is a strange situation. The tangible, the real, the solid, is explained by the intangible, the unreal, the purely mental. Charles A. Coulson

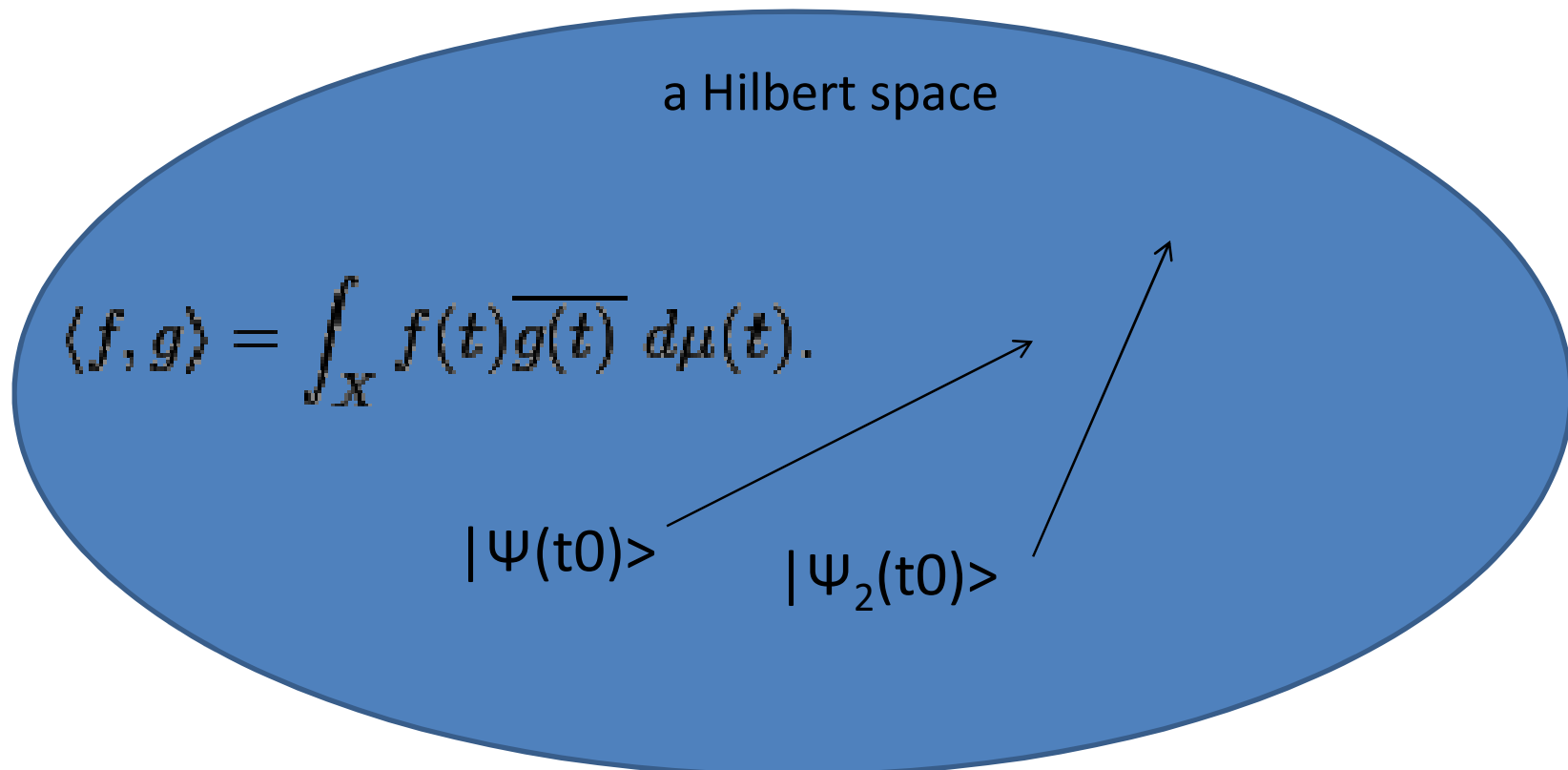
- One of these mental frameworks is quantum mechanics.

Quantum Mechanics

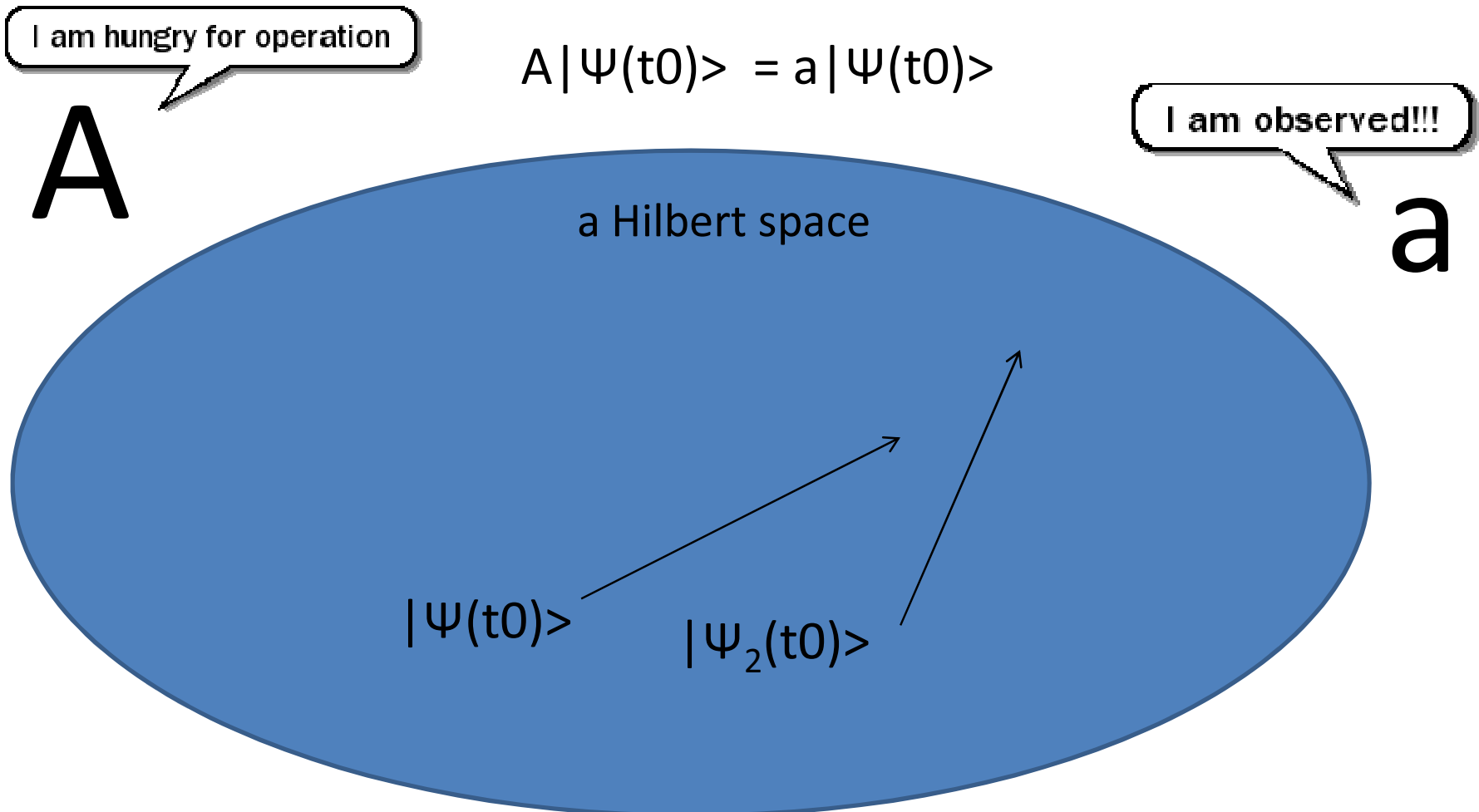
- **I think I can safely say that nobody understands quantum mechanics. -Richard Feynman**
- Postulates of Quantum Mechanics:

- 1) The information about a quantum state can be represented by a ket $|\Psi(t_0)\rangle$ which belongs to a Hilbert space and behaves ‘nicely’ (continuous, etc.)

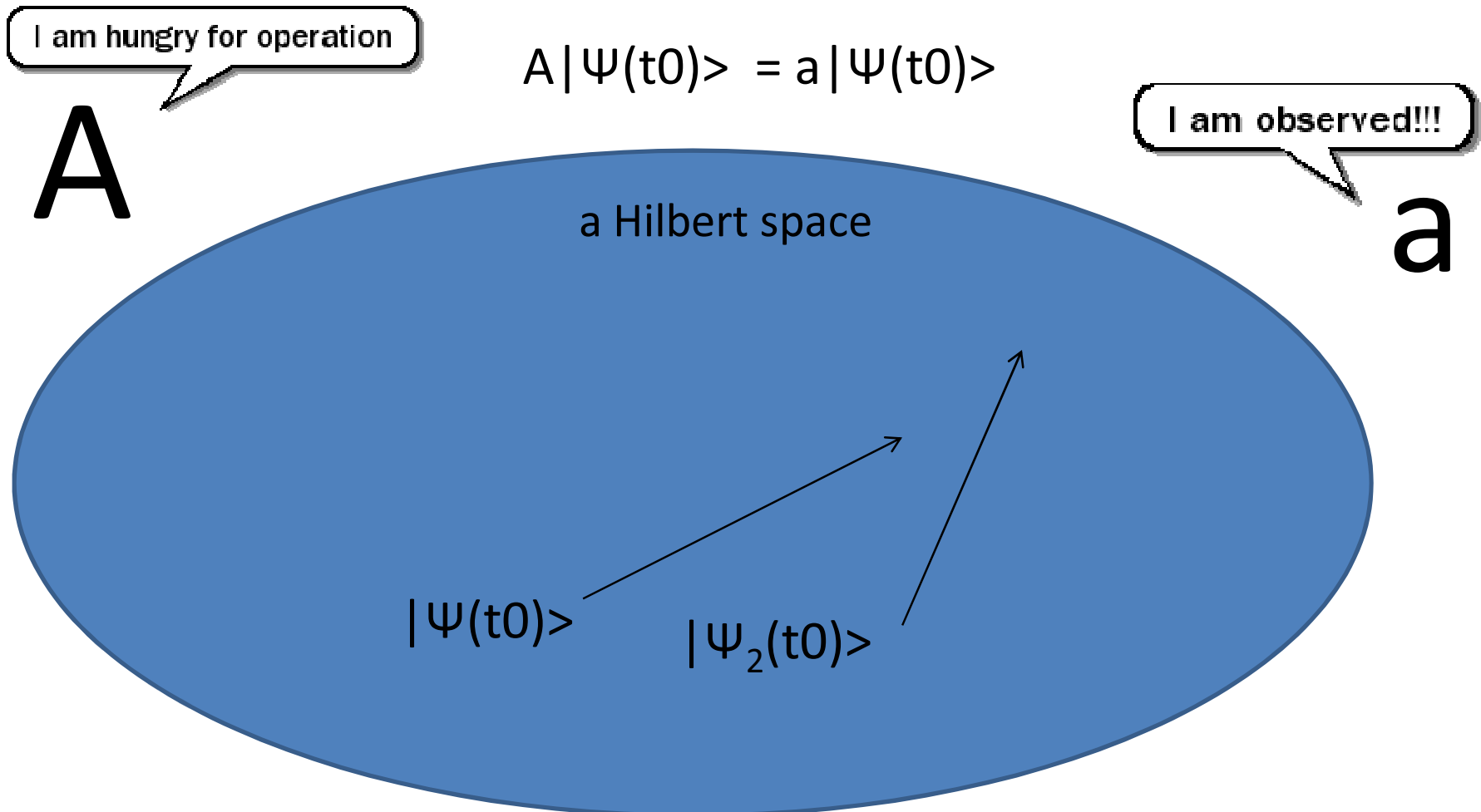
Euclidean vector space space $\mathbf{a} \cdot \mathbf{b} = \sum_{i=1}^n a_i b_i = a_1 b_1 + a_2 b_2 + \dots + a_n b_n$



- 2) Every observable (position, momentum, energy) can be mathematically represented by a Hermitian operator, A .



- 3) The only possible observation is an eigenvalue of the operator . ‘We can predict all possible outcomes!’



- 4) The probability of obtaining a certain observation is $P(a_n) = |\langle \Psi | u_n \rangle|^2$

The chance of you observing me in the lab/reality is...

a

$$|\langle \Psi | u_n \rangle|^2$$

I am the eigenvector, and I am the basis

u_n

$$\psi = \sum c_n u_n$$

- 5) Measurements disturb the quantum state and the state will remain fixed immediately after.



If you observe me I will stay

a

- 6) the Schroedinger eq. is true. This can not be derived, it was the result of ingenious mathematical intuition.

*I don't like it, and I'm sorry I ever had anything to do with it.
(Erwin Schrodinger talking about Quantum Physics)*



A

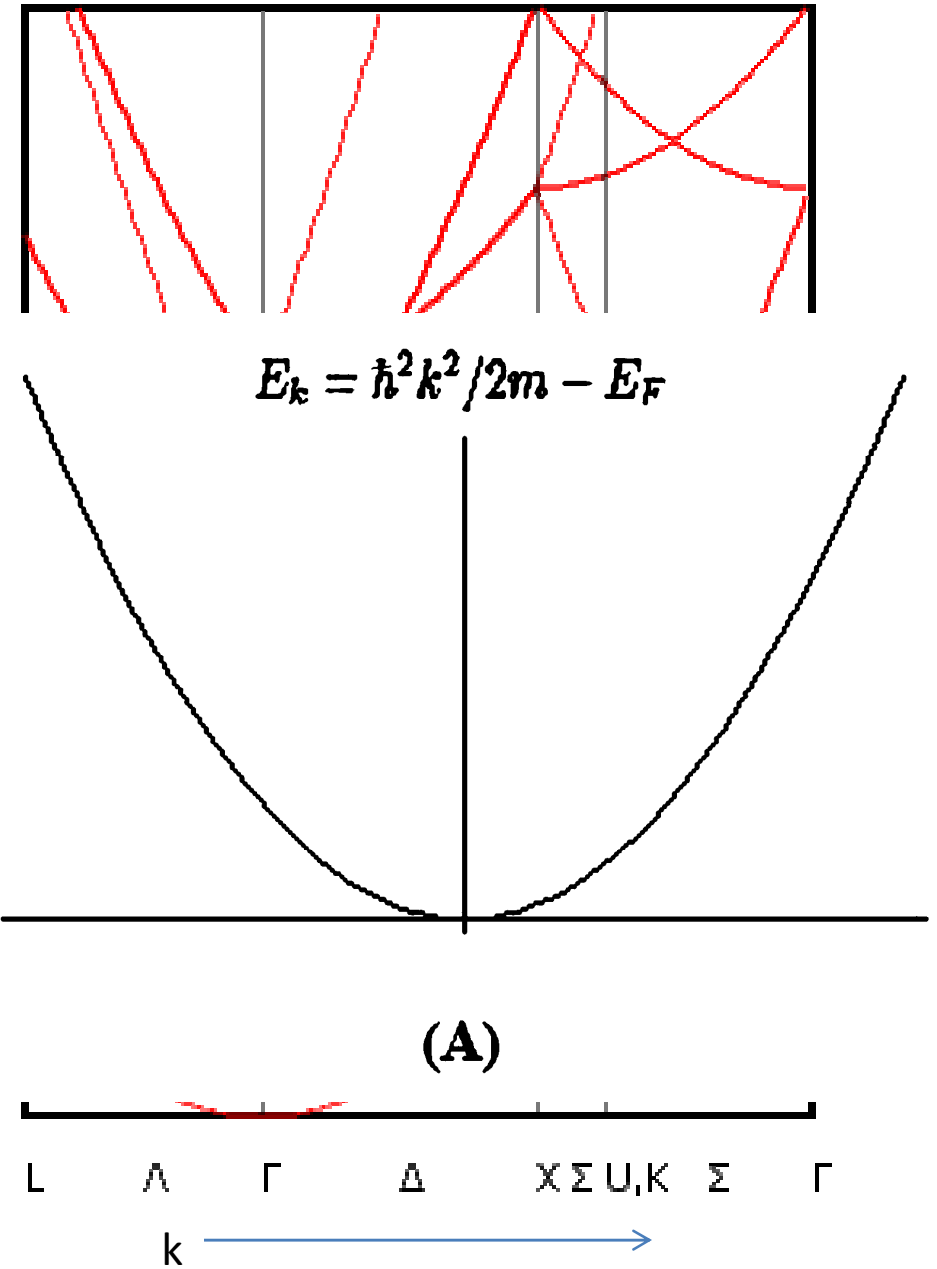
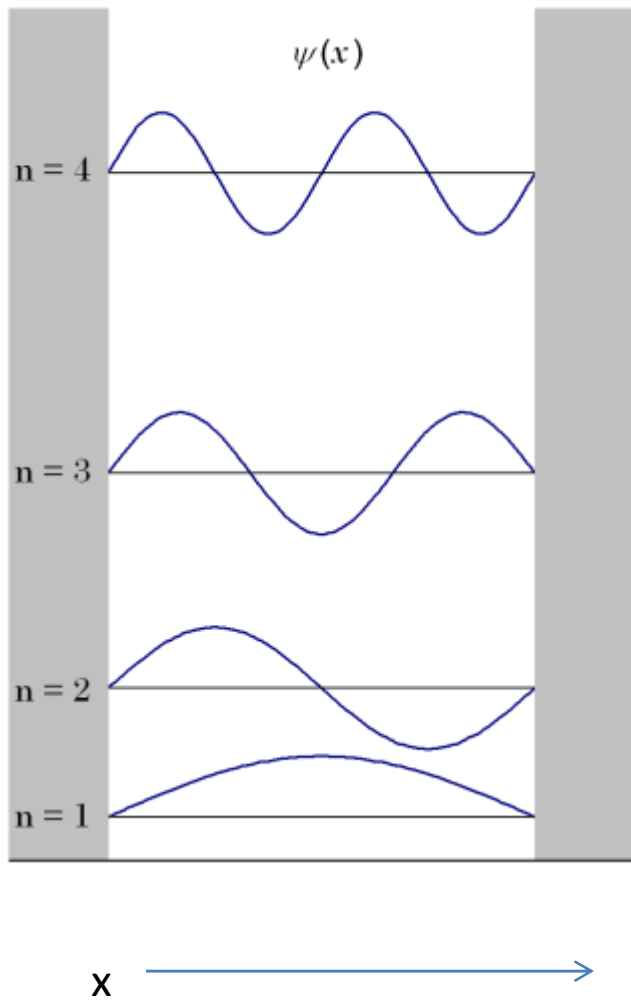
A → H

$$H \psi = i \hbar (\partial/\partial t) \psi$$

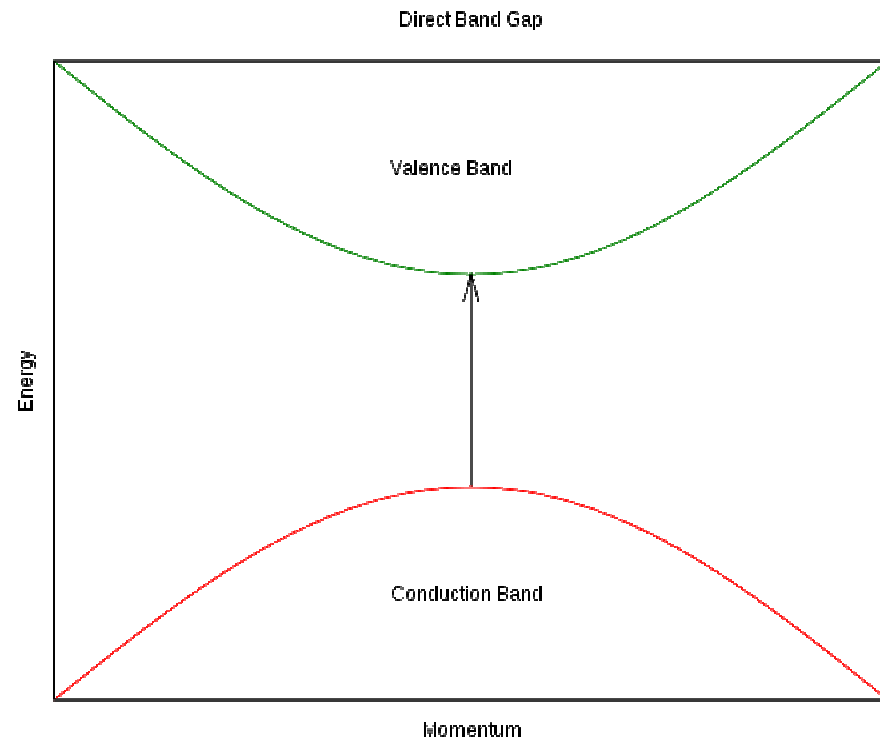
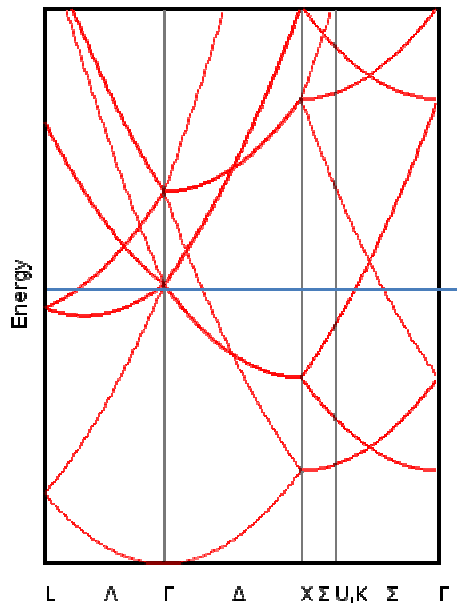
	Hamiltonian	e-values	e-functions
Free Particle	$\hat{H} = \frac{\hbar^2}{2m} \frac{\partial^2}{\partial x^2}, V(x) = 0$	$E_\alpha = \frac{\hbar^2 k_\alpha^2}{2m}, k_\alpha = \sqrt{\frac{2mE_\alpha}{\hbar^2}}$	$u_\alpha(x) = \begin{cases} e^{-ik_\alpha x} \\ e^{ik_\alpha x} \end{cases}$

What about real materials?

Particle in a box + free \rightarrow crystal



Where the electrons are determines electronic / optical properties



Electronic Properties

- Si technology mostly interested in changing conductivity. With band gap engineering we have $>10^{10}$ control! We do this by manually adding carriers. Interfaces give us devices.

Optical Properties

- The number, energy level of electrons and how they are able to move in a material also affects their permittivity, ϵ , which changes index of refraction.

Optical properties

- More math! Quantum + Maxwell's equations.

Microscopic

$$\nabla \times \vec{e} = -\frac{\partial \vec{b}}{\partial t}$$

$$\nabla \times \vec{b} = \vec{j} + \frac{1}{c^2} \frac{\partial \vec{e}}{\partial t}$$

$$\nabla \cdot \vec{e} = \rho$$

$$\nabla \cdot \vec{b} = 0$$

\vec{j} : microscopic electric current density
 ρ : microscopic charge density

$\langle \rangle$ Spatial Averaging

$$\vec{E}(\vec{r}, t) = \langle \vec{e}(\vec{r}, t) \rangle$$

$$\vec{B}(\vec{r}, t) = \langle \vec{b}(\vec{r}, t) \rangle$$



Macroscopic

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

$$\nabla \cdot \vec{D} = \rho_{ext}$$

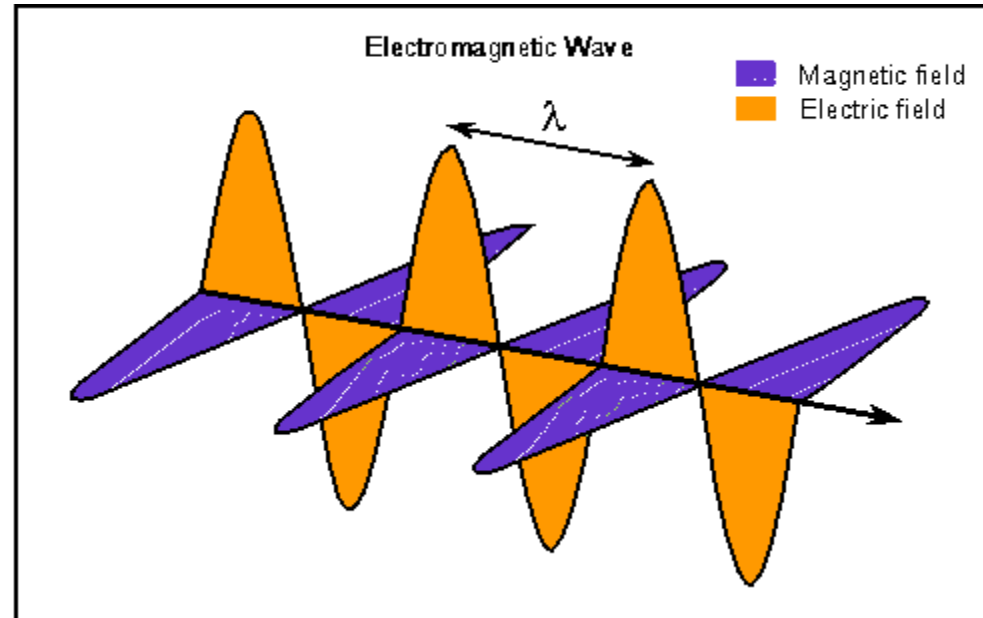
$$\nabla \cdot \vec{B} = 0$$

$$\vec{D} = \vec{E}$$

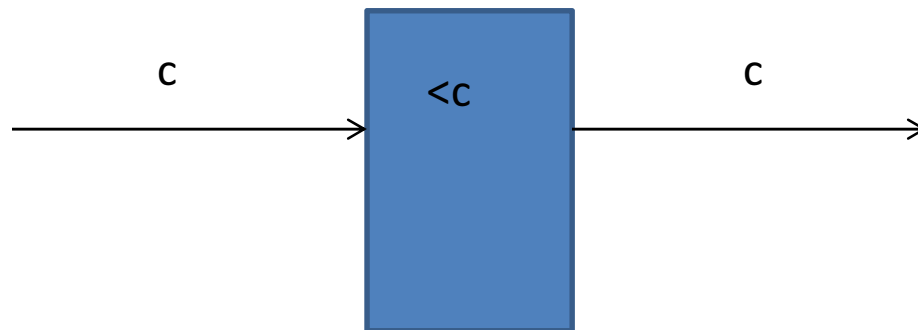
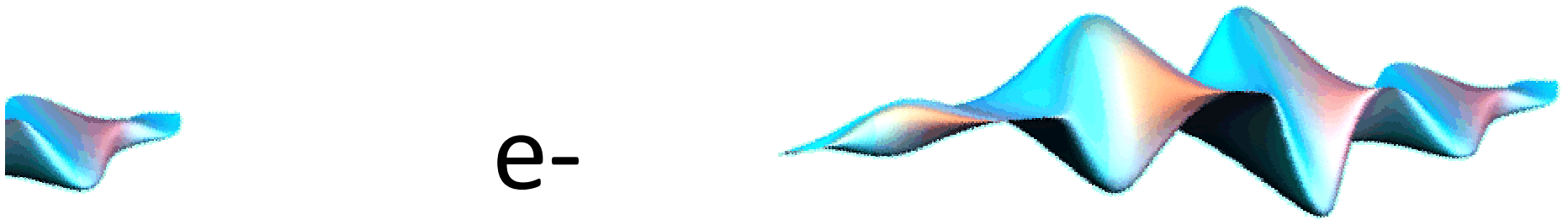
$$\vec{B} = \vec{H}$$

Optical properties

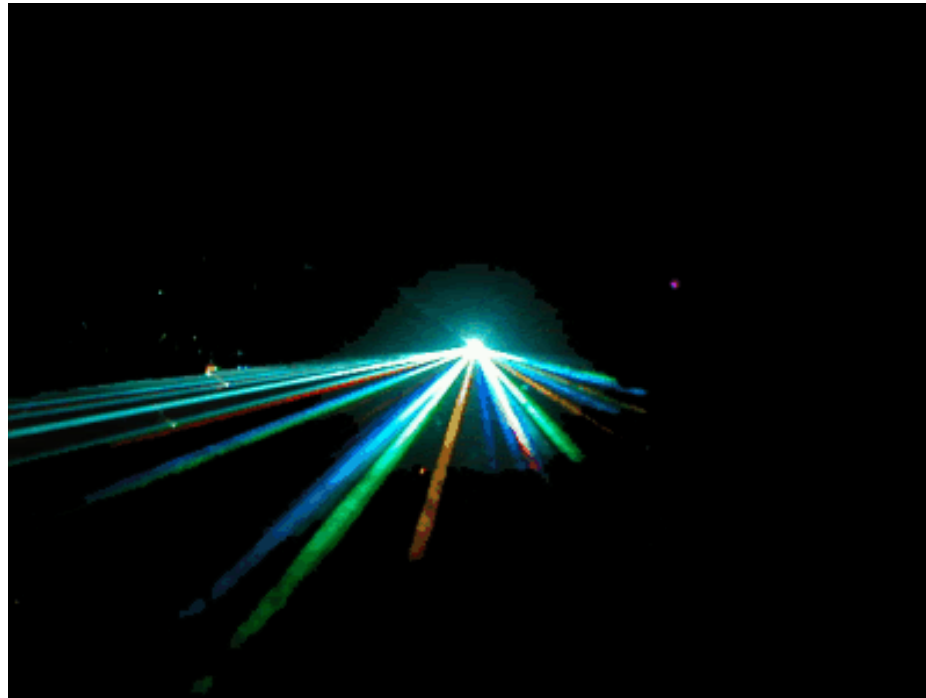
Maxwell's equations give us insight into what a photon is: a self-sustaining electromagnetic wave (B and E are coupled)



When light interacts with materials, electrons play the deciding role in optical properties.

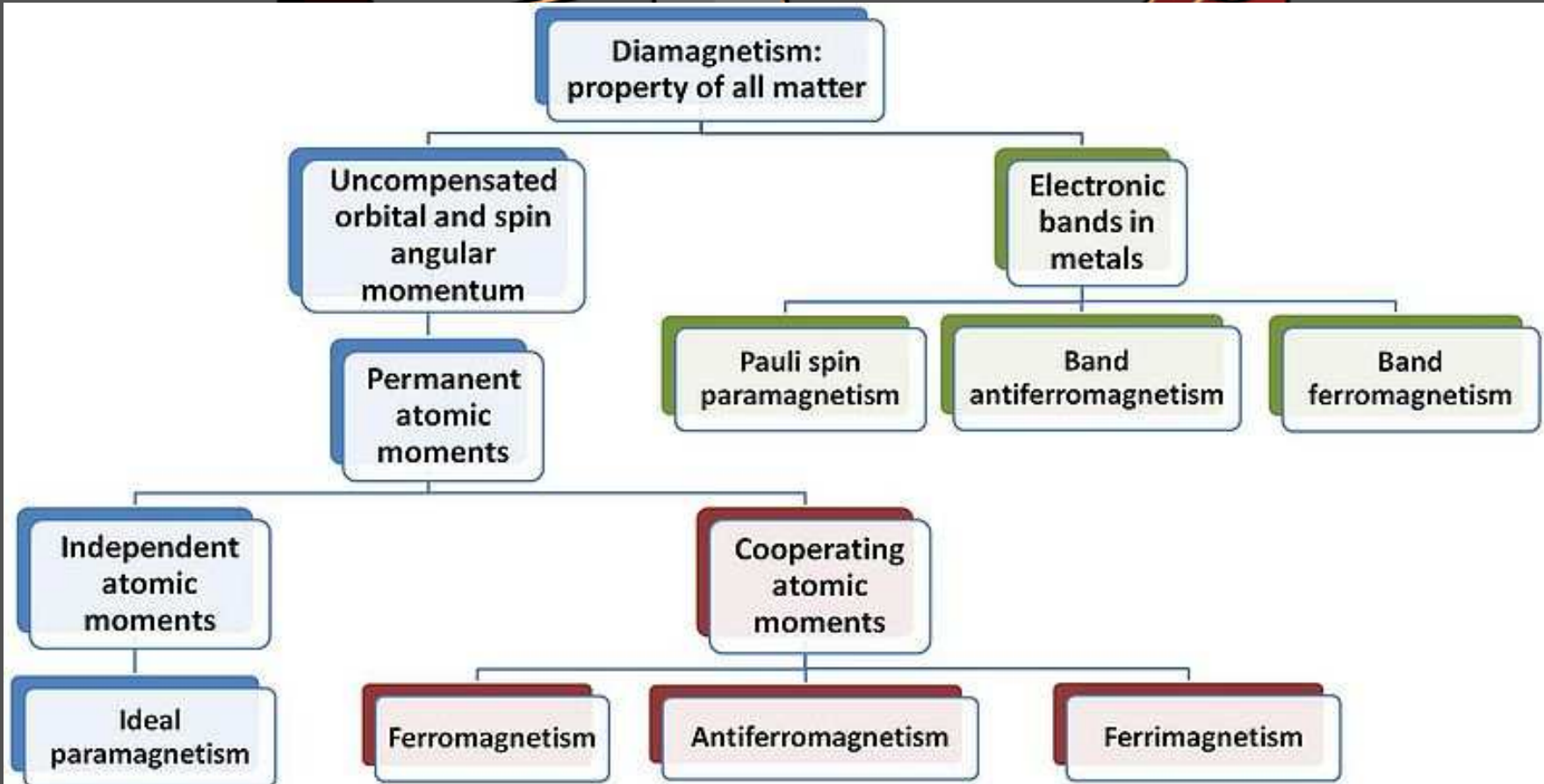


Optical properties
No light no party.



Magnetic Properties

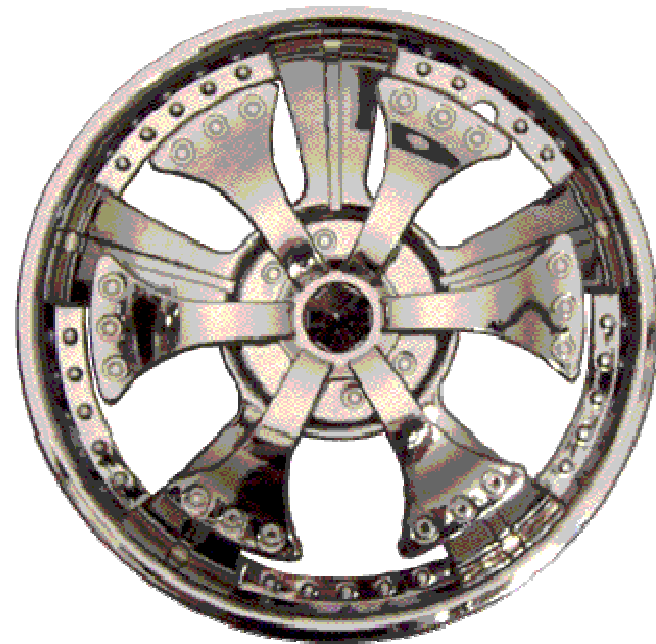
- Also from electrons in the form of spin and from Maxwell's equations.



Thank you!

electrons are important!

electrons don't stop



The end