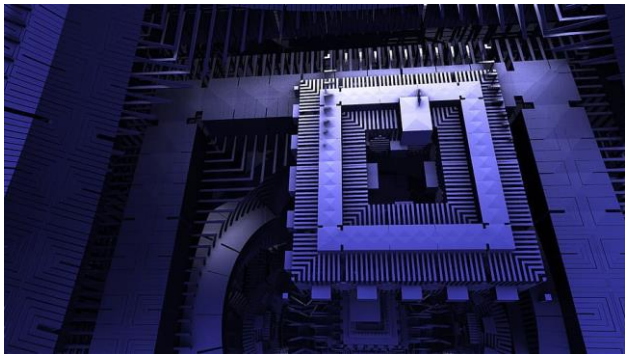
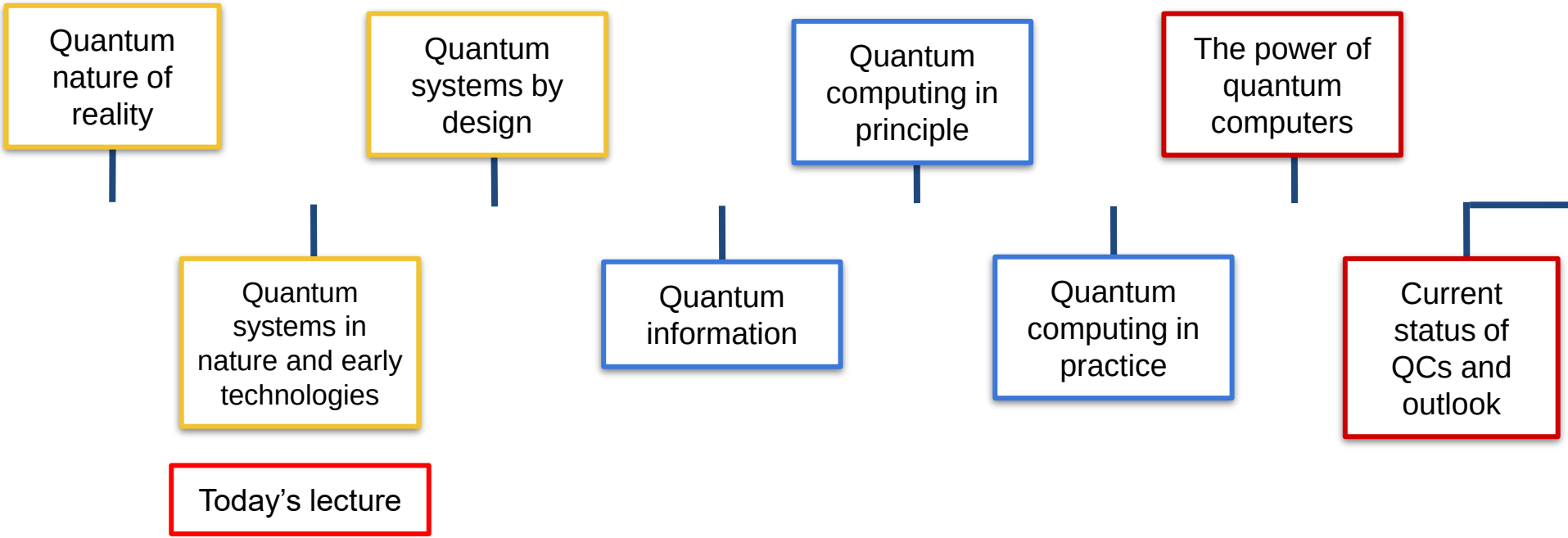
The rise of Quantum Machines



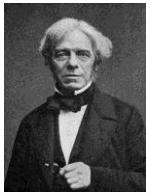
Department of Physics and Astronomy
Northwestern University

Roadmap


Quantum nature of reality
Quantum systems in nature and early technologies
Quantum systems by design
Quantum information
Quantum computing in principle
Quantum computing in practice
The power of quantum computers
Current status of QCs and outlook
Today's lecture

Timeline



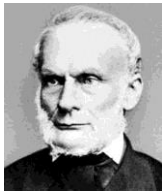
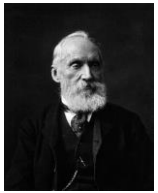

Electromagnetism

Behavior of atoms and their interaction with light

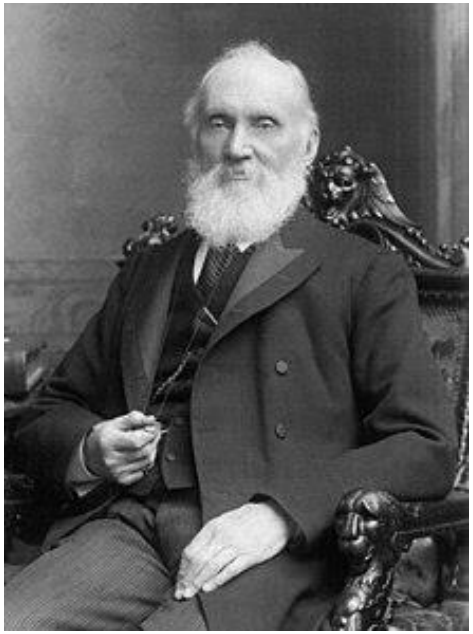
Mechanics

1600 1700 1800 1900 2000 today

Thermodynamics


Kelvin’s Clouds



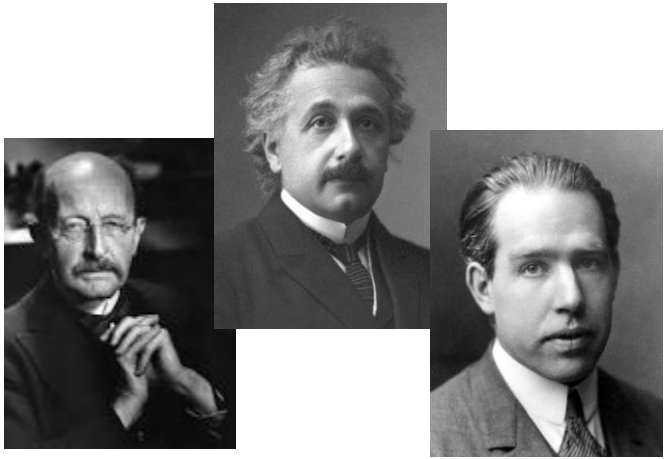
“*Nineteenth Century Clouds over the Dynamical Theory of Heat and Light*”:

I. The first came into existence with the undulatory theory of light, and was dealt with by Fresnel and Dr. Thomas Young; it involved the question, How could the earth move through an elastic solid, such as essentially is the luminiferous ether?

II. The second is the Maxwell-Boltzmann doctrine regarding the partition of energy.

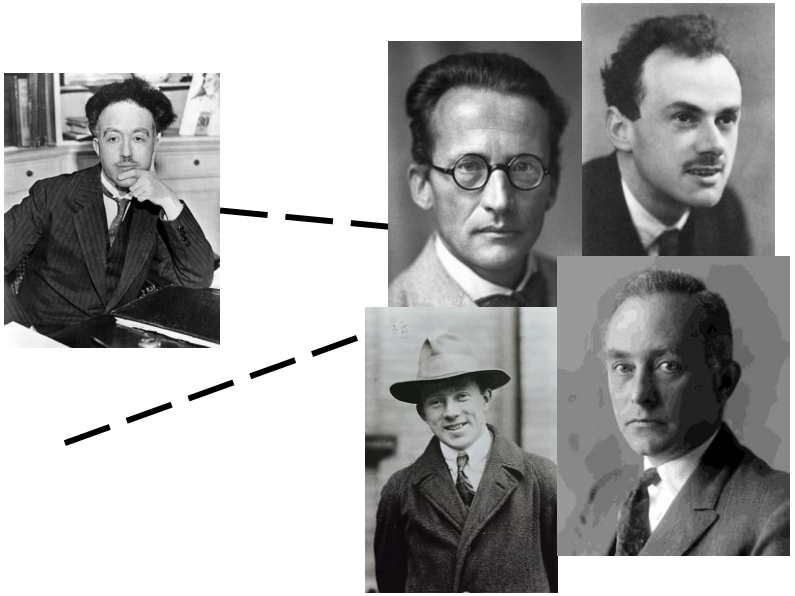
Realization of the quantum nature of reality

Old quantum theory



Solutions based on modifications of classical theories

Quantum mechanics

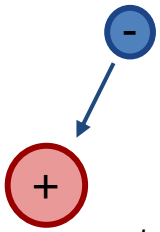


Discovery of underlying rules of quantum theory

Atomic spectra

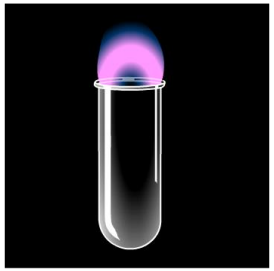
One of the first applications of quantum theory was the description of atoms and their interaction with light

Hydrogen atom

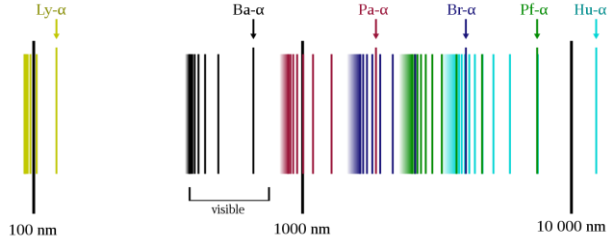


electron

proton



Effect of shining light on hydrogen atoms

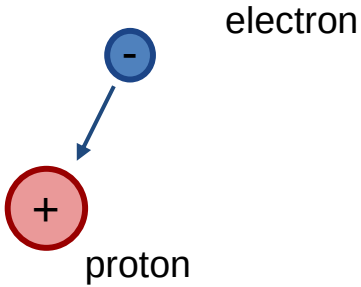


Discrete frequencies of emitted light

Explained partially by old quantum theory, and fully by modern quantum theory

Quantum states with definite energy

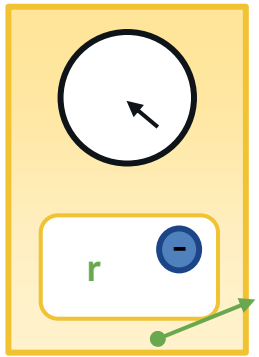
Hydrogen atom



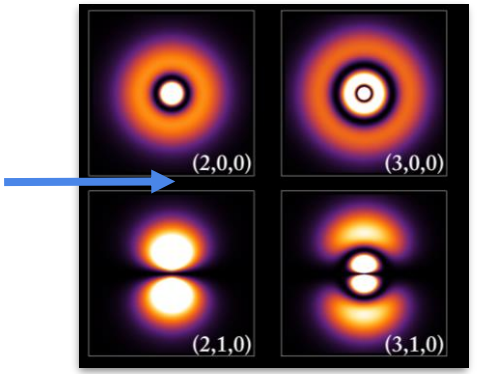
Discrete possible energy states

Photon emitted with corresponding frequency

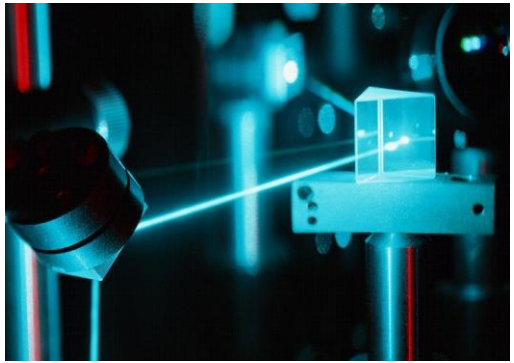
Probability amplitude for the electron to be at position **r**



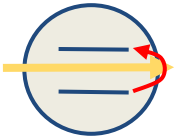
Spatial distribution of electron probability density



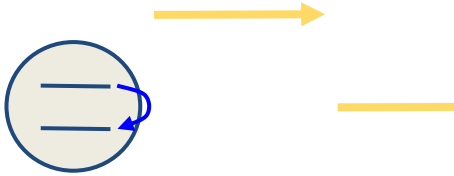
Application: lasers

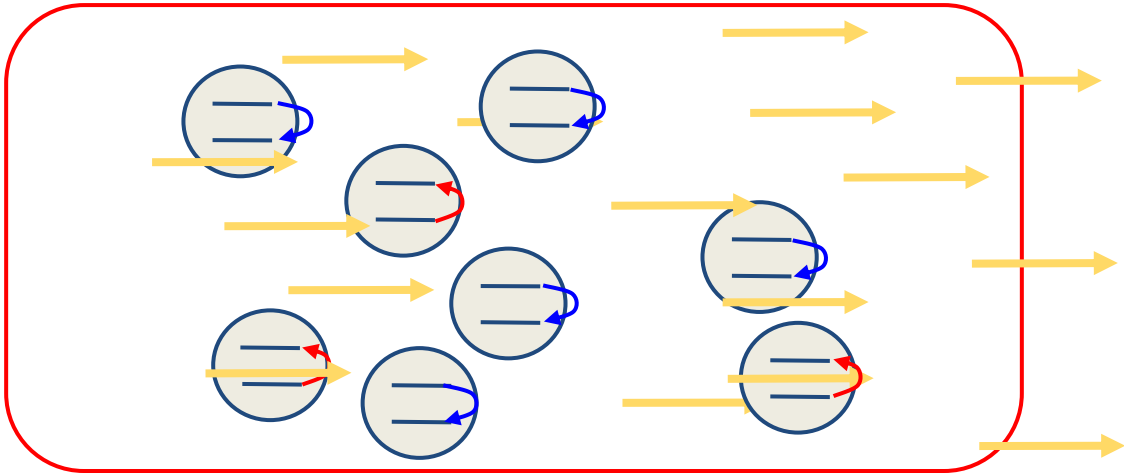


Absorption of photons



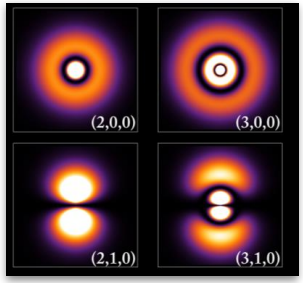
Emission of photons
induced by other photons



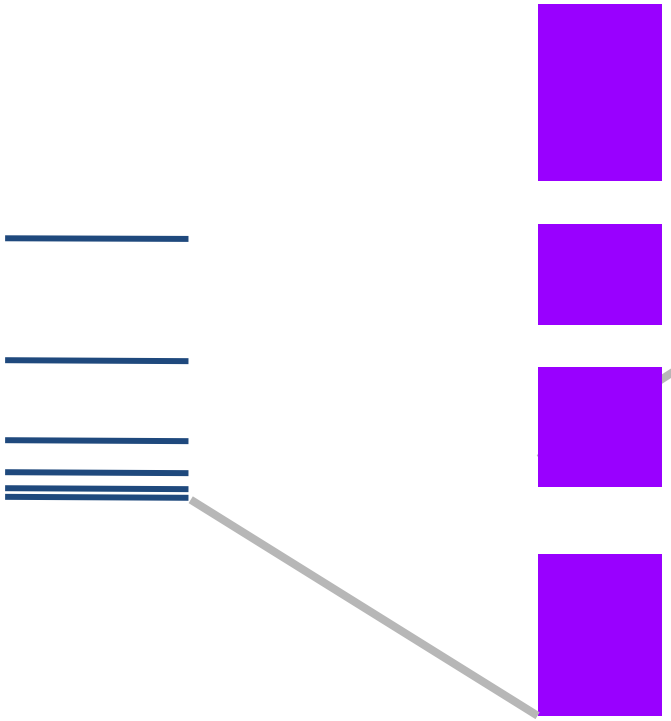


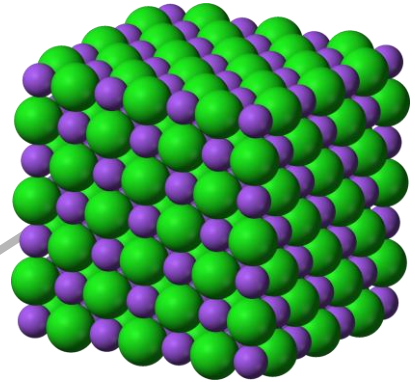
All photons produced have
the same properties:
frequency, phase

From atoms/molecules to solids



Energies of individual atoms

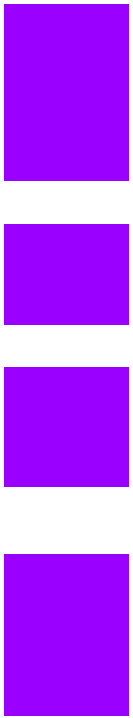




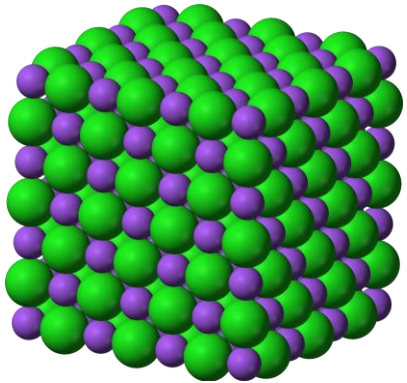
Energy bands in solids

Bring many atoms/molecules closer together: solids can form

From atoms/molecules to solids

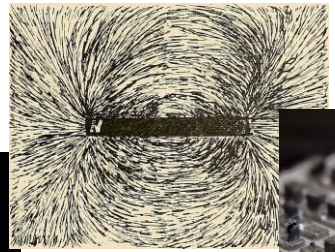


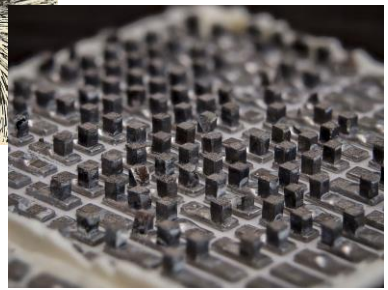
Energy bands in solids



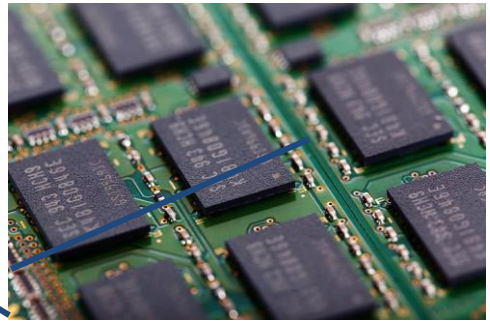
Phases of matter can form:

- Metals
- Semiconductors
- Insulators
- Magnets
- Superconductors
- Topological states

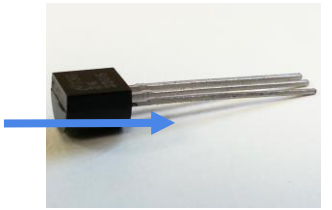




Application: transistors



Transistors

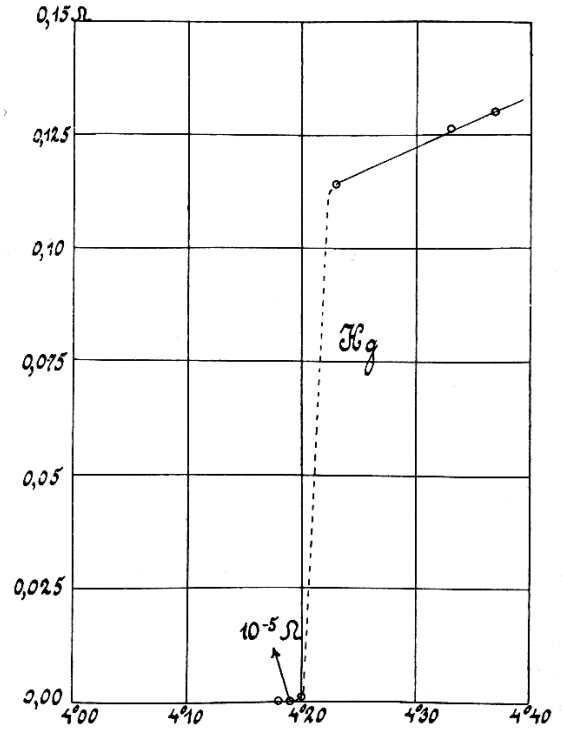


Made from semiconductors

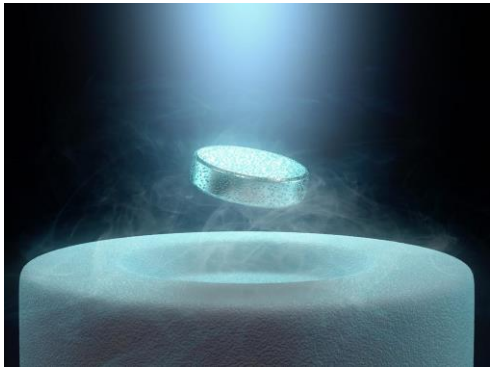
Created in Bell Labs in 1947

- Used to encode 1s and 0s in conventional computers.
- Today’s computers can have 100s of billions of transistors

Application: superconducting devices

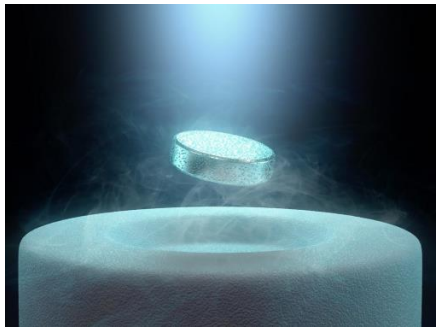


When a metal such as lead is cooled to temperatures around -452.47 F, it becomes a superconductor

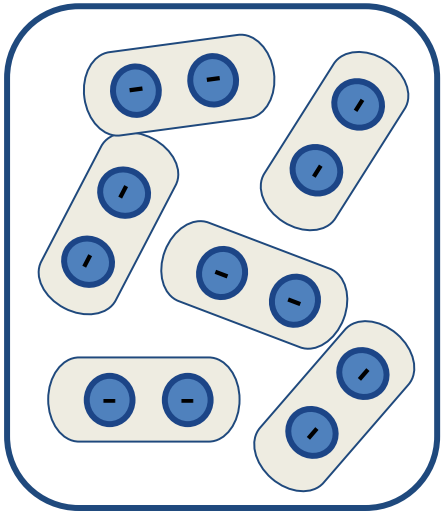


It exhibits interesting phenomena, such as magnetic levitation when placed on top of a magnet

Application: superconducting devices

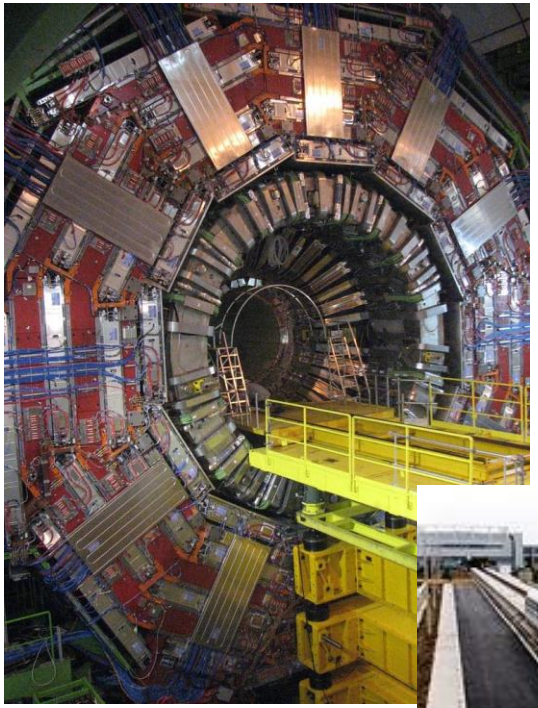


The solid makes the electrons feel attraction, forming a bound state.



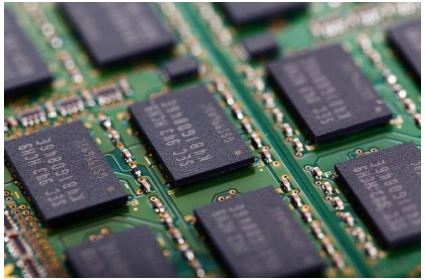
The collective state becomes rigid, and is not easily disturbed by culprits of resistance (such as dirt in the solid)

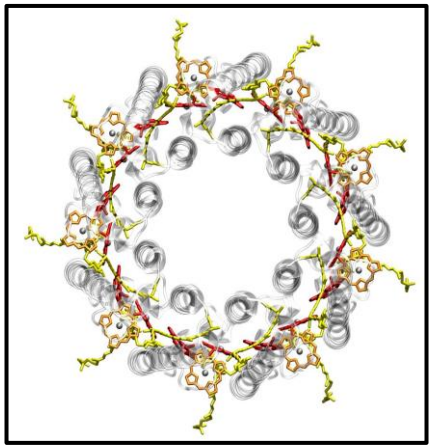
Application: superconducting devices



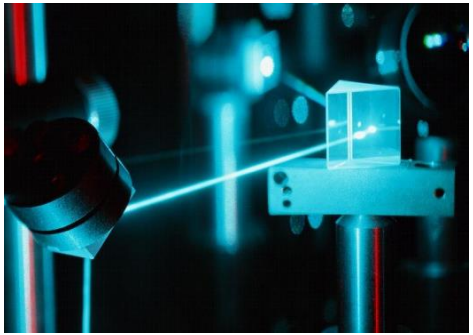
Superconductors arise in a wide range of technologies

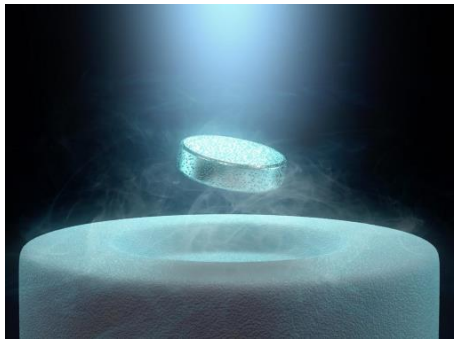
Conclusions



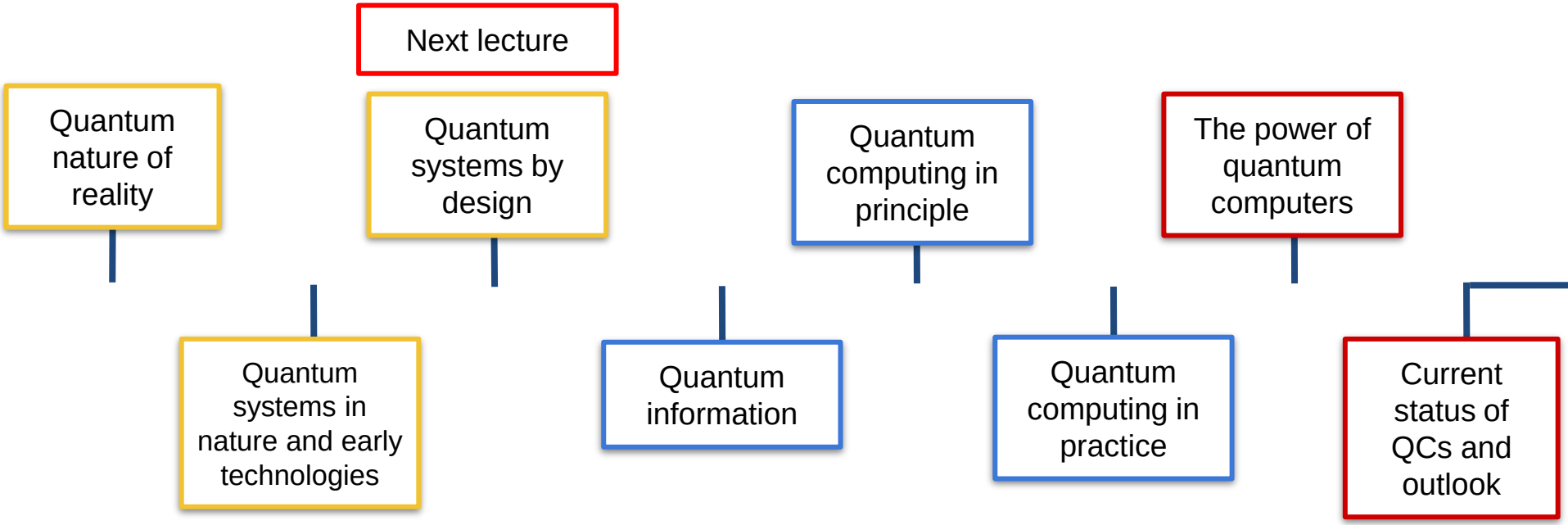


- Quantum behavior can be found in a wide range of systems in Nature.
- Many of the technologies that have been developed since the 1900s operate based on quantum effects.
- In all of these examples, we do not control directly these quantum effects.





Roadmap


Next lecture
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