Overview: Basic concepts on Quantum Mechanics

Classical physics
Part I

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Objectives

In this course [General objective] participants will. . .

General Objective (chap. 1)

Appraise historical facts and experiments that started the revolutionary change to Quantum Mechanics such as postulates, entanglement, superposition and others, which are used in Quantum Computing

How do we do?

In this chapter, participants will. . .

Particular Objectives

- Recognize differences between Classical Mechanics and Quantum Mechanics
- Describe key basic concepts inside Modern Physics
- Analyze concepts on Physics and Mathematics
- Study some relevant experiments for the Quantum Mechanics.
- Do exercise with definitions (Kahoot, forms, and some other exercises)

What is Quantum Mechanics?

Quantum Mechanics

Concept

is a fundamental theory in physics that provides a description of the physical properties of nature at the scale of atoms and subatomic particles.

The scope of QM

Now it should not be thought that "quantum physics" is something which does not concern the macroscopic world. Actually *all* of physics is quantum physics; the laws of quantum physics as we know them today are our most general laws of nature.

Figure: Source [3]

Phenomenological theories

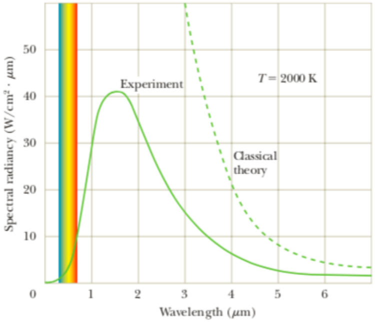
Phenomenological theories or Classical theories . . .

attempt to describe and summarize experimental facts within some limited domain of physics.

Today, every physical theory is ”phenomenological”

Why do we need QM?

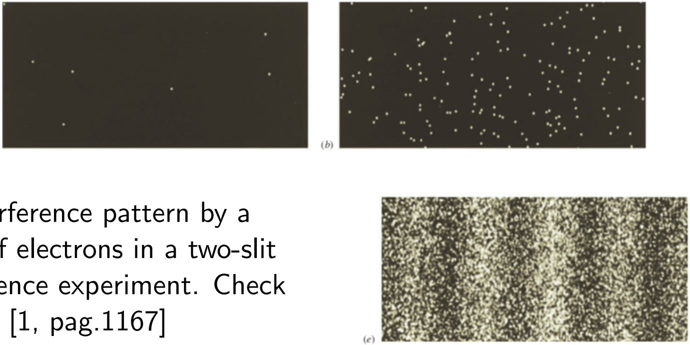
The solid curve shows the experimental spectral radiancy for a cavity at 2000 K. Note the failure of the classical theory, which is shown as a dashed curve. The range of visible wavelengths is indicated. (Source [1]).



$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/(\lambda k_B T)} - 1} \quad (1)$$

Eq.(1) represents energy per unit volume per unit wavelength

Double-slit

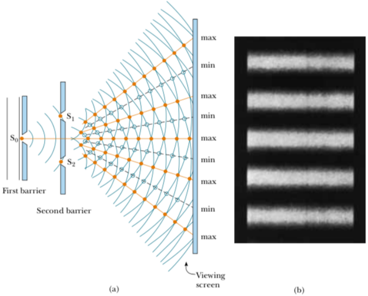


(a) (b) (c)

An interference pattern by a beam of electrons in a two-slit interference experiment. Check the ref. [1, pag.1167]

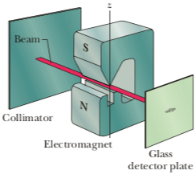
Double-slit

(a) Schematic diagram of Young's double-slit experiment. Slits S_1 and S_2 behave as coherent sources of light waves that produce an interference pattern on the viewing screen. (b) An enlargement of the center of a fringe pattern formed on the viewing screen with many slits could look like this (Check the ref. [1, pag.1054]).



Stern-Gerlach

When the electromagnet is off, the silver deposit is a narrow spot. However, when the electromagnet is turned on, the silver deposit should be spread vertically. See ref. [1, pag. 1226]



The reason is that silver atoms are magnetic dipoles, and so vertical magnetic forces act on them as they pass through the vertical magnetic field of the electromagnet; these forces deflect them slightly up or down.

Stern-Gerlach

We don't use Lorentz force, since $q = 0$. We use

$$\begin{aligned} U &= -\vec{\mu} \cdot \vec{B} \\ \frac{dU}{dz} &= -\mu_z \frac{dB}{dz} \end{aligned}$$

and $F_z = -\frac{\partial U}{\partial z}$. Where $\vec{\mu}$ is (dipole) magnetic moment vector in z-axis and Field vector component ($z-$axis). Therefore,

$$F_z = \mu_z \frac{dB}{dz}. \tag{2}$$

Eq. (2) represents the force experimented by an atom with a magnetic dipole moment experiences a force in a non-uniform magnetic field.

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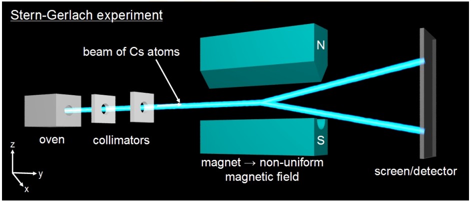
Stern-Gerlach

But the experiment showed



A silver atom consists of many electrons, each with a spin magnetic moment and an orbital magnetic moment. All those moments vectorially cancel out except for a single electron, and the orbital dipole moment of that electron is zero.

Stern-Gerlach

Combining the dipole moment $\vec{\mu}$ of a silver atom is the spin magnetic dipole moment of that single electron.
Therefore, we find

$$F_z^{\uparrow} = +\mu_z \frac{dB}{dz}. \tag{3}$$

$$F_z^{\downarrow} = -\mu_z \frac{dB}{dz}. \tag{4}$$

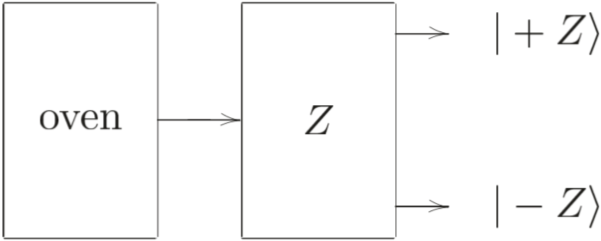
Reminder:

$$\vec{\mu}_s = -\frac{e}{m}\vec{S} \tag{5}$$

is the magnetic dipole moment, $\vec{S}$ is the spin angular momentum (or spin), e and m are the electric charge and the mass of electron.

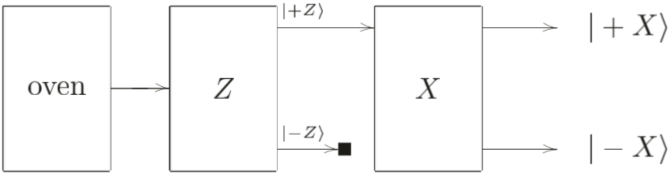
Extension of Stern-Gerlach aparatus (STA)

We use one STA [2, pag. 43]



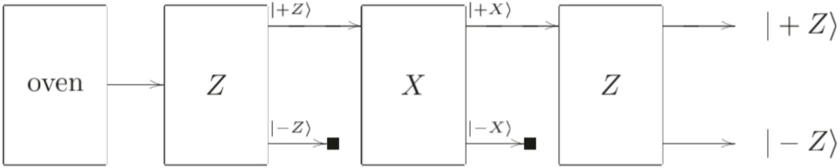
Extension of Stern-Gerlach aparatus (STA)

We use two STA



Extension of Stern-Gerlach aparatus (STA)

We use three STA



Analysis

We use next assignments

$$
\begin{aligned}
|+Z\rangle &\leftarrow |0\rangle \\
|-Z\rangle &\leftarrow |1\rangle \\
|+X\rangle &\leftarrow \frac{|0\rangle + |1\rangle}{\sqrt{2}} \\
|-X\rangle &\leftarrow \frac{|0\rangle - |1\rangle}{\sqrt{2}}
\end{aligned}
$$

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Analysis

The results of the cascaded SG experiment can be explained by assuming that the $\hat{z}$ SGA measures the spin (qubit) in the computational basis $|0\rangle, |1\rangle$, and the $\hat{x}$ SGA measures the spin with respect to the basis

$$\frac{|0\rangle + |1\rangle}{\sqrt{2}}, \frac{|0\rangle - |1\rangle}{\sqrt{2}}. \tag{6}$$

In the cascaded $\hat{z}$ $\hat{x}$ $\hat{z}$ experiment, if we assume that the spins are in the state $|+Z\rangle = |0\rangle = (|+X\rangle + |-X\rangle)/\sqrt{2}$ after exiting the first SG experiment, then the probability for obtaining $|+X\rangle$ out of the second apparatus is $\frac{1}{2}$, and the probability for $|-X\rangle$ is $\frac{1}{2}$ Similarly, the probability for obtaining $|+Z\rangle$ out of the third apparatus is $\frac{1}{2}$.

Conclusions

- We recognized differences between Classical Mechanics and Quantum Mechanics
- We described key basic concepts inside Modern Physics
- We analyze concepts on Physics and Mathematics.
- We studied some relevant experiments for the Quantum Mechanics.

Go to next lectures: Part II

References

[1] Halliday, David and Resnick, Robert and Walker, Jearl. *Fundamentals of physics*. John Wiley and Sons, 2013.

[2] Michael A Nielsen and Isaac Chuang. Quantum computation and quantum information, 2002.

[3] Wichmann, Eyvind Hugo. *Quantum Physics: Berkeley Physics Course Vol. 4*, volume 4. Tata McGraw-Hill Education, 2010.