# Lecture 3 --Review of Quantum Physics & Basic AMO Physics

Version #1 -- 2/9/2014

### I Some important model systems in QM

i) 2-state QM (d=2, simplest hilbert space)

spin-1/2 ( ↑ & ↓)

photon 2-polarization (⬄ & ⇳)

ii) Particle in box /1D Schrodinger

iii) Harmonic oscillator

iv) Hydrogen atom 🡪 AMO physics

v) Periodic potential 🡪 solid state physics

### II Foundations of QM: early milestones

i) Photon (Planck blackbody radiation)

E=hf=ℏω

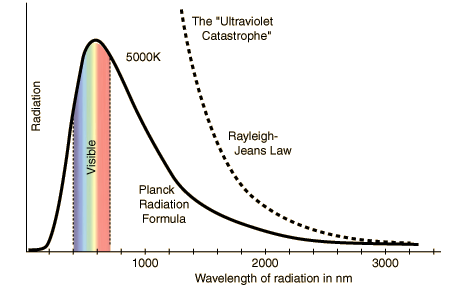


Fig 3.1

Total energy per unit volume in the cavity in ν and ν+dν

Rayleigh – Jeans formula:

Plank radiation formula:

ii) Photo-electric effect & Compton scattering (light matter interaction)

*… PE can measure Planck constant*

Setup of Photo-electric effect experiment: setup and Experiment Results

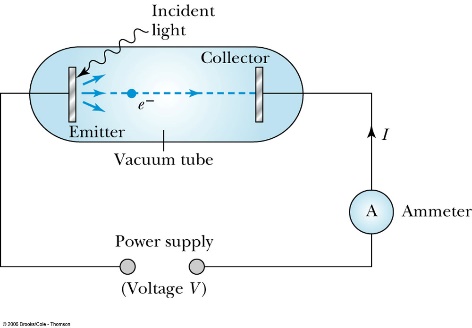
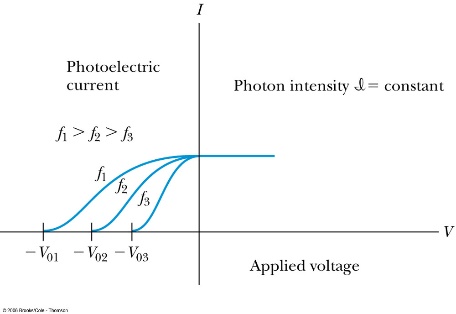
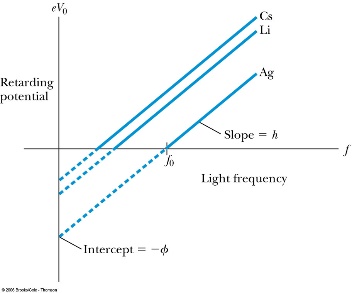
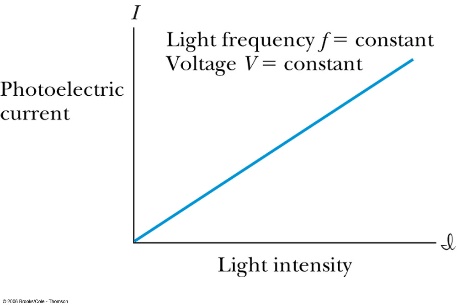


Fig. 3.2 experiment setup

1. (b) (c)

Fig. 3.3 Experiment results

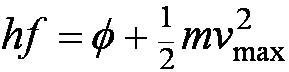
**Einstein’s Theory**

* Conservation of energy yields:

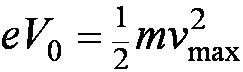
Energy before (photon) = energy after (electron)



where  is the work function of the metal.

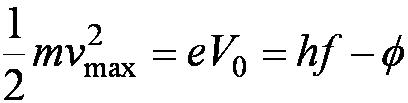
Explicitly the energy is 

* The retarding potentials measured in the photoelectric effect are the opposing potentials needed to stop the most energetic electrons.



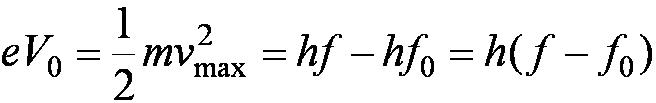
**Quantum Interpretation**

* The kinetic energy of the electron does not depend on the light intensity at all, but only on the light frequency and the work function of the material.

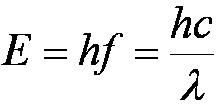


* Einstein in 1905 predicted that the stopping potential was linearly proportional to the light frequency, with a slope *h*, the same constant found by Planck.

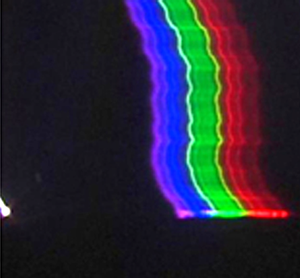
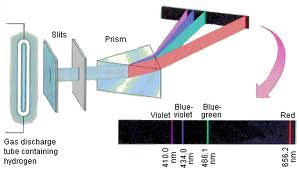
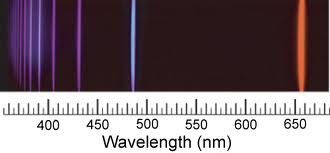
(fig. 3.3 (b))



* From this, Einstein concluded that light is a particle with energy:



iii) Spectroscopy (atomic physics/astronomy) --- start from hydrogen --- Bohr’s model (atom/matter quantized levels)



1. (b)

Fig. 3.4 (a) Spectrum of Ball Lightning (b) Hydrogen Spectrum

**External link:**

<http://physics.aps.org/articles/v7/5>

[Observation of the Optical and Spectral Characteristics of Ball Lightning](http://link.aps.org/doi/10.1103/PhysRevLett.112.035001)

Jianyong Cen, Ping Yuan, and Simin Xue

[Phys. Rev. Lett. **112**, 035001 (2014)](http://link.aps.org/doi/10.1103/PhysRevLett.112.035001)

### III Concepts & theory

i) Matter wave; wave-particle duality (De Broglie)

**Energy**: E = mc2 =

**Momentum**: = h/λ = h/(*mv*)

**Comparing to Photon (massless particle):** E=hf=pc => p=hf/c=h/λ

**P=h/λ is true for all particles**

Wave Optics: diffraction

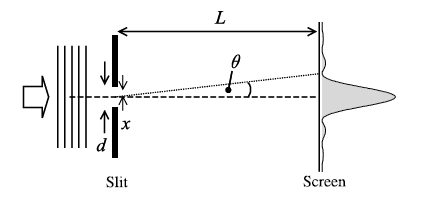


Fig. 3.5 When the distance *L* between the slit and screen is larger than the **Rayleigh Distance** *(d2/𝜆)* , the diffraction pattern is said to be in the **far-field (Fraunhofer) limit**. On the other hand, when *L≲ d2/𝜆*, we are in the **near-field (Fresnel) regime**. In what follows, we consider only Fraunhofer limit

Diffraction pattern:

Resolution: sinθmin = ±

resolution for circular aperture: sinθmin = 1.22

ii) Uncertainty principle (Heisenberg)

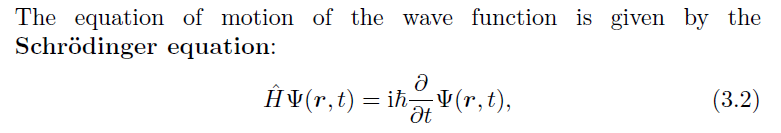
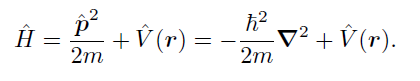
* + Fourier transform picture

**Heisenberg Uncertainty Principle:** Δ*x*Δ*Px ≥ ℏ/2*

### IV Theory & Formulation

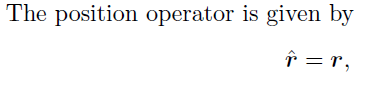
i) Schordinger equation/wavefuction

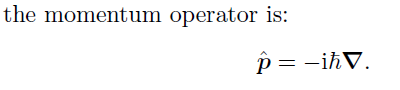
-- probability density



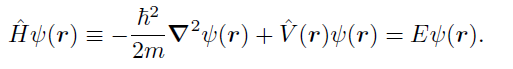
“Hamiltonian”

“Hamiltonian”

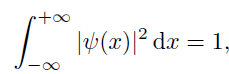
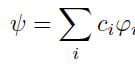
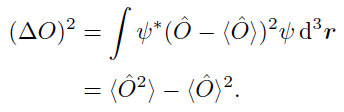
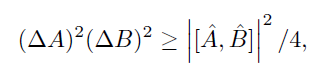






**Several Should Know Points**

* Example: free particle:
* Probability density:
* ****Normalizable (bound) vs unnormalizable (extended) state
* Superposition state
* Measurement(!..“weak”measure) & expectation value/ variance 
* Commutator/commutation & general uncertainty principle



E-t uncertainty

ii) Matrix formulation (Heisenberg)

iii) Dirac “bra-ket” … quantum state/Hilbert space



“Hamiltonian” [“*Abrahams example”*]

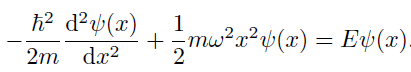
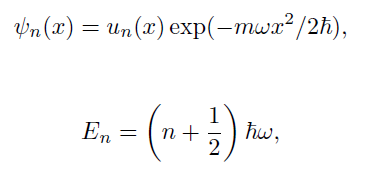
Wave function <-> vector in Hilbert space

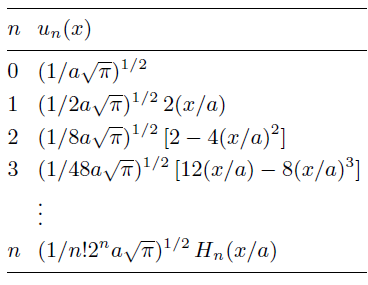
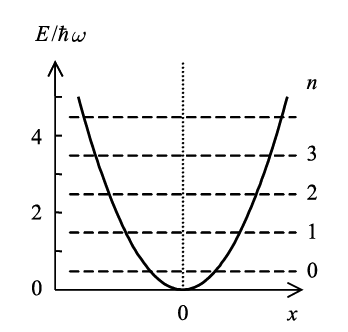
**Particle in a box/1D Schrodinger equation**

* Infinite square well (uncertainty)
* Finite square well
* 1D scattering state (refection & transmission --- “quantum reflection” & tunneling, even “resonant tunneling”)

**Harmonic oscillator**

* Harmonic trap
* Quantized EM fields…

****



Harmonic length



***Lecture3 notes are collected by Bohao Liu. Correction, supplement and suggestion are greatly welcomed. Bohao Liu’s email is liubohao@purdue.edu.***