L 33 Modern Physics [1]

- Introduction- quantum physics
- *Particles* of light → PHOTONS
- The photoelectric effect
  - Photocells & intrusion detection devices
- The Bohr atom
  - emission & absorption of radiation
  - LASERS

Sometimes light behaves like a particle and sometimes particles behave like waves!

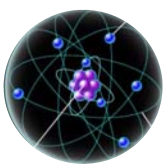
1

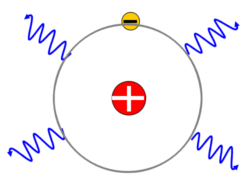
Modern Physics- Introduction

- "Modern" – 20^{th} Century
- By the end of the 19^{th} century it seemed that all the laws of physics were known
  - planetary motion was understood
  - the laws of electricity and magnetism were known
  - the conservation principles were established
- However, there were a few problems where classical physics didn't seem to work
- It became obvious that Newton's laws could not explain phenomena at the level of atoms

2

ATOMS and classical physics





- In the classical picture, the electrons in atoms orbit around the nucleus just as the planets orbit around the Sun.
- However, the laws of mechanics and electromagnetism predict that an orbiting electron should continually *radiate* electromagnetic waves, and very quickly the electron would loose all of its energy and collapse into the nucleus.
- *Classically, there could be no atoms!*

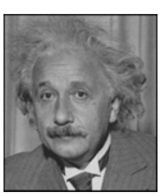
3

Problems with Newton's Laws

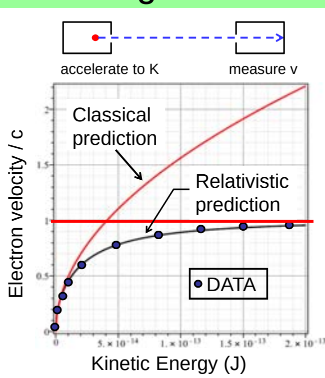
- Newton's laws, which were so successful in allowing us to understand the behavior of big objects such as the motions of the planets, could not explain phenomena at the atomic level
- This is not too surprising since Newton's laws were discovered by considering the behavior of macroscopic objects, like planets
- Physical "laws" have a limited range of applicability, and must continually be tested to find their limitations, and then modified

4

Newton's laws fail at high velocities



- Einstein showed that mass is not a constant, but depends on speed
- As speed increases, so does mass
- Speed can never exceed the speed of light, c



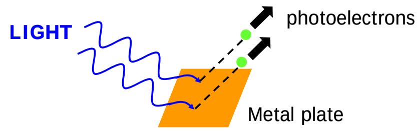
5

The failure of the "old" physics

- We will now discuss an example of an effect that could not be explained by the pre- 20^{th} century laws of physics.
- The discovery of the correct explanation led to a revolution in the way we think about light and matter, particles and waves
- The new concepts also led to a revolution in technology that has changed our lives, e.g., the semiconductor led to the introduction of the personal computes, cell phones, *etc.*

6

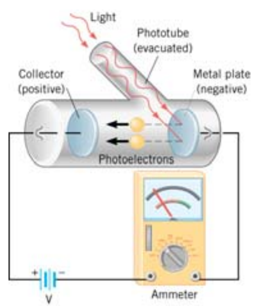
The photoelectric effect- *photons*



- When light shines on a metal surface, electrons may pop out
- Photoelectrons are only emitted if the wavelength of the light is *shorter* than some maximum value, *no matter how intense the light is*, so the color (wavelength) is critical
- blue light makes electrons pop out, red light does not

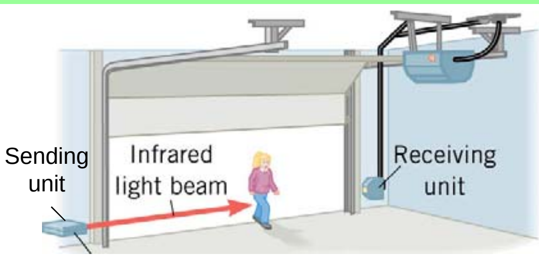
7

Details of a photocell



8

Photocells used as a safety device



The child interrupts the beam, stopping the current, which causes the motor to stop.

9

No classical explanation for the photoelectric effect

- According to electromagnetic wave theory, if the intensity of the light is sufficiently high, the electron should be able to absorb enough energy to escape
- The wavelength of the light should not make a difference.
- But the wavelength does matter!

10

Einstein received the 1921 Nobel Prize for explaining the photoelectric effect

- A radical idea was needed to explain the photoelectric effect.
- Light is an electromagnetic *wave*, but when it interacts with matter (the metal surface) it behaves like a *particle*
- Light is a particle called a ***photon*** → packets of energy moving at the speed of light!
- A beam of light is thought of as a beam of photons.

11

Photoelectric effect – *PHOTONS*

- The energy of a photon depends on the wavelength or frequency of the light
- Recall that speed of light
  = wavelength (λ) x frequency (f)
- Photon energy: $E = h f$
  E = Planck's constant (h) x frequency = $h f$
  $h = 6.626 \times 10^{-34}$ J s
- $f = c / \lambda$ → $E = h (c/\lambda) = (hc) / \lambda$
- Shorter wavelength (or higher f) photons have a higher energy

12

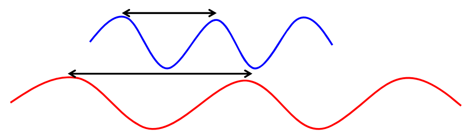
The photon concept explains the photoelectric effect

- A certain amount of energy is required to remove an electron from a metal
- A photoelectron is emitted if it absorbs a photon from the light beam that has enough energy (high enough frequency)
- No matter how many photons hit the electron, if they don't have the right energy the electron doesn't come out of the metal

13

Blue and red photons - example

- How much energy does a photon of wavelength = 350 nm (nanometers) have compared to a photon of wavelength = 700 nm?
- **Solution:** The shorter wavelength photon has the higher frequency. The 350 nm photon has twice the frequency as the 700 nm photon. Therefore, the 350 nm photon has twice the energy as the 700 nm photon.



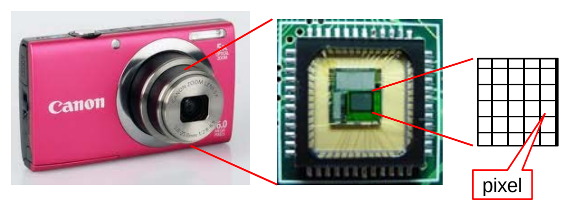
14

The quantum concept

- The photon concept is a radical departure from classical thinking.
- In classical physics, energy can come in any amounts
- In modern physics, energy is QUANTIZED → comes in definite packets → photons of energy $h\,f$.
- In the PE effect, energy is absorbed by the electrons only in discreet amounts

15

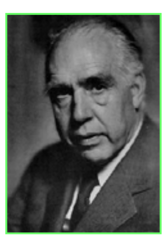
Video recorders and digital cameras



- Electronic cameras convert light into an electric charge using the photoelectric effect
- A two-dimensional megapixel array of sensors captures the charge and records its intensity on computer memory

16

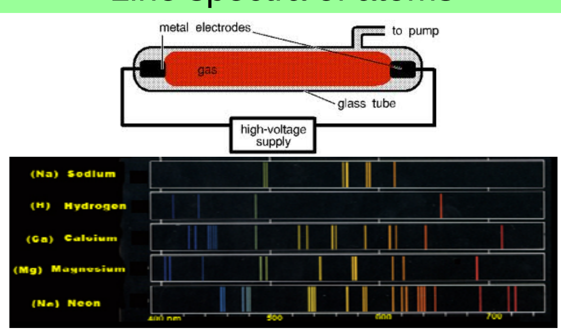
Niels Bohr explains atoms in 1913



- Niels Bohr, a Danish physicist, used the quantum concept to explain the nature of the atom
- Recall that the electron in a hydrogen atom should quickly radiate away all of its energy
- If this occurred, atoms would emit radiation over a *continuous* range of wavelengths
- But, atoms emit light in *discreet lines*

17

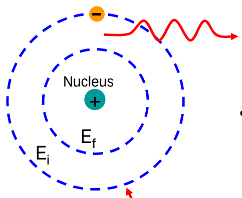
Line spectra of atoms



Line spectra are like fingerprints which uniquely identify the atom

18

The Bohr Atom

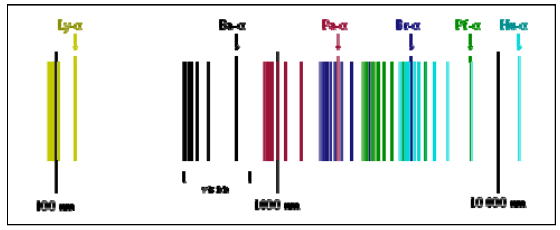


The orbits farther from the nucleus are higher energy states than the closer ones

- The electrons move in certain allowed, “stationary” orbits or states in which then *do not radiate.*
- The electron in a high energy state can make a transition to a lower energy state by emitting a photon whose energy was the difference in energies of the two states, $hf = E_i - E_f$

19

Line spectra of atomic hydrogen



The Bohr model was successful in predicting where all the spectral lines of H should be.

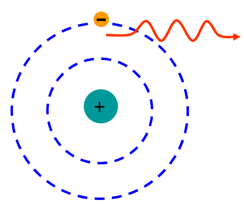
20

Emission and Absorption

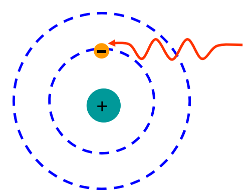
- When an electron jumps from a high energy state to a low energy state it emits a photon → *emission spectrum*
- An electron in a low energy state can absorb a photon and move up to a high energy state → *absorption spectrum*

21

Emission and Absorption



Electron spontaneously jumps to a lower energy state and *emits* a photon



Electron *absorbs* a photon and jumps to a higher energy state

22

Quantum Mechanics

- Niels Bohr was able to predict exactly where the spectral lines of hydrogen would be
- Bohr’s ideas were a radical departure in thinking
- His ideas led to the formulation of a new paradigm in physics – Quantum Mechanics (QM)
- Quantum Mechanics replaces Classical Mechanics as the correct theory to explain atomic level phenomena
- One of the consequences of QM is that certain quantities which can be known precisely in classical physics, are now subject to “uncertainty”

23