NOTES

SECTIONS OF THESE NOTES AS REQUIRED FOR THE INDICATED CLASSES

UNIT 7: WAVES AND MODERN PHYSICS

Chapter 18 Early Quantum Theory

Classical Physics the laws, theories, and explanations about mechanics, thermodynamics, electricity and magnetism prior to 1900.
- explains most of the observations in our lives
- fails to explain 1) the photoelectric effect and 2) ultraviolet radiation by a blackbody

James Clerk MAXWELL – Electromagnetic Waves
- Changing electric fields induce changing magnetic fields.
- Changing magnetic fields induce changing electric fields.
- Together, the alternating electric and magnetic fields radiate from the source into space.
- The frequency of the waves is determined by the frequency of either the magnetic field or the electric field that produced the waves.

Electromagnetic Radiation Energy carried by electromagnetic waves through space
All electromagnetic radiation moves at the speed of light, ***c***
Types Radio waves, microwaves, infrared (heat), visible light, ultraviolet light, X-rays, gamma rays, cosmic rays

Universal Wave Equation
Wavelength (λ) and frequency (*f*) of the waves are related by the speed of light (c)
c = *f λ* Frequency varies inversely with wavelength.

18.1 The Particle Nature of Light

BLACKBODY RADIATION **840**

Blackbody An object that absorbs all frequencies of light (= black)
An object that emits a complete, continuous spectrum of electromagnetic radiation

When an object is heated a little and turns red, it emits infrared (IR) radiation.
When the object is heated until it glows white, it emits visible light (ROYGBIV).

Kirchhoff All objects absorb the same frequencies of radiation that they emit
- demonstrated that the power radiated by a blackbody varies with its temperature.

Boltzmann
- used Maxwell's idea of emission of radiation by vibrating charges on the surface to a blackbody
- predicted that the energy radiated from a blackbody increased as the frequency increased
  - true for low energy (infrared and visible) emissions

Ultraviolet Catastrophe the huge difference between the predicted energy and the actual energy emitted by higher frequencies of radiation
The experimental observations could not be explained by classical physics

EARLY QUANTUM THEORY 843

Electrons are believed to move about the nucleus of an atom on discrete energy levels (shells).
Electrons can absorb the energy of electromagnetic radiation. If enough energy is absorbed, they jump to a higher energy level (excited state).
Eventually, the electrons release energy and return to their starting (ground state) energy level. The energy is released as a packet electromagnetic radiation called a **photon**.

Max Planck German physicist who first realized that the energy released by excited electrons only comes in packets of specific sizes with certain frequencies.

$\boxed{E = n\,h\,f}$, where n = energy level → integer values only (0, 1, 2, 3,…)
h = Planck's constant 6.626×10^{-34} J / Hz
f = frequency (Hertz)

INTRODUCTION OF THE PHOTOELECTRIC EFFECT 844

Electrons (photoelectrons) escape from the surface of a metal when light is shone on the metal.
The photoelectrons are detected by an ammeter when they strike a metal plate that allows the circuit to be completed.

Photoelectric Effect – the emission of electrons from a metal when exposed to electromagnetic radiation.
Photoelectric cells use these photoelectrons in a closed circuit.
Plants use the photoelectrons in the process of photosynthesis
Garage door openers and solar panels operate using photoelectrons

Heinrich Hertz discovered the photoelectric effect by accident when sparks jumped between across a separate circuit when a nearby oscillating current
Led to development of radio, tv, microwave communication (Wii), and radar

THE EFFECTS OF LIGHT INTENSITY AND FREQUENCY 845

Light Intensity only affects the rate that photoelectrons are released (photoelectrons released per second) and does not affect the speed (maximum kinetic energy) of the photoelectrons.

Light Frequency determines the amount of energy that can be transferred to each electron (E=hf) which directly affects the kinetic energy (speed) of the photoelectron.

THE EXPERIMENTAL WORK OF LENARD AND THE CONCEPT OF STOPPING POTENTIAL 846

Philipp **Lenard** controlled the potential differences between the incident metal plate and the detector plate.

Stopping Potential is the potential difference that will stop all photoelectrons from reaching the detector plate.

EINSTEIN, MILLIKAN, WORK FUNCTION AND THRESHOLD FREQUENCY P 847-853

Einstein

- light behaves as packets of energy called photons
- the intensity of light affects the number of photons, not the energy of each photon
- the energy of one photon (E = hf) is transferred to one electron in one event
    - higher frequency photons (UV radiation) has more energy than IR photons
- some of the energy transferred is used to do work to overcome the attractive forces in the substance and the remainder was converted to kinetic energy
- more work is needed for electrons further beneath the surface than those on the surface

Work Function – minimum amount of energy required to remove an electron from the surface of a metal

(W) Each metal has a distinct work function

Maximum Kinetic Energy of a photoelectron is achieved when a surface electron is removed.

(E_{Kmax}) $\boxed{hf = E_{Kmax} + W}$

Millikan

- experimentally determined the charge of a single electron ($q_e = 1.6 \times 10^{19}$C)
- tried to prove Einstein wrong by precisely measuring the stopping potential for a variety of frequencies of several metals
- the maximum kinetic energy must be less than or equal to the electrical potential energy

$$\boxed{E_{Kmax} \leq E_P = q_e \cdot V_s}$$

- plotted maximum kinetic energy versus frequency

$$\boxed{E_{Kmax} = hf - W}$$

compare to **y = mx + b**

- slope = ***h*** = Planck's constant
- y-intercept (b) = ***−W*** = negative work function
- x-intercept (a) = f_0 = threshold (critical) frequency

- provided experimental support of Einstein's proposals of the quantum nature of the photoelectric effect

Threshold Frequency (f_0) the minimum frequency of the radiation (photon) required for a certain metal to emit a photoelectron.

Einstein's Photon Theory the excess energy of the incoming photon becomes the kinetic energy of the emitted electron.

$\boxed{E_k = h f - h f_0}$, where **h *f*** is the energy of the incoming photon and
h f_0 is the minimum energy required to escape
($h f_0 = W$)

The energy of the photoelectron is measured by balancing its kinetic energy with the repulsive force of a negatively charged anode.

The repulsive force depends on the voltage at the anode (stopping potential).

$\boxed{E_K = -q\,V_0}$, where E_K = the maximum kinetic energy of the electron
q = the charge on the electron
$q_{e-} = -1.60 \times 10^{-19}$ C
V_0 = the stopping potential of the anode

The kinetic energy of an electron is very small, so electron volts (eV) are used instead of joules.

One **electron volt** is the energy of one electron accelerated against a potential difference of one volt.

$$\mathbf{1\ eV = 1.60 \times 10^{-19}\ J}$$

Practice Problems (p. 561) 3, 4