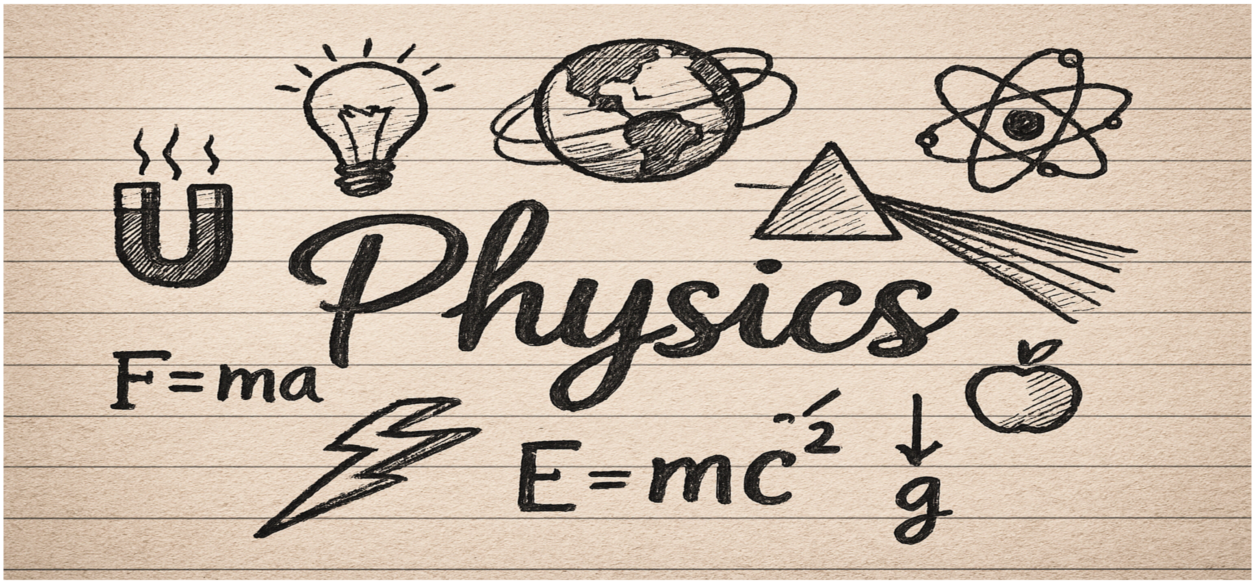


Class: 12th

Subject: physics

Chapter 19: DAWN OF MODERN PHYSICS

🩸 Important MCQs (From Summary)

1. When a positron meets an electron, the process is called:

(a) Pair production

(b) Photoelectric effect

(c) Annihilation ✅

(d) Compton effect

2. In annihilation of matter, the rest mass of particles is converted into:

(a) Mechanical energy

(b) Heat energy

(c) Electromagnetic energy ✅

(d) Potential energy

3. Each photon produced in electron–positron annihilation has energy:

(a) 0.25 MeV

(b) 0.51 MeV ✅

(c) 1.02 MeV

(d) 2.00 MeV

4. The wave nature of particles was proposed by:

(a) Einstein

(b) Bohr

(c) de Broglie ✅

(d) Heisenberg

5. The de Broglie wavelength of a particle depends upon its:

(a) Charge

(b) Density

(c) Momentum ✅

(d) Temperature

6. The experiment that confirmed wave nature of electrons is known as:

(a) Millikan experiment

(b) Rutherford experiment

(c) Davisson–Germer experiment ✅

(d) Compton experiment

7. Wave–particle duality means that matter and radiation behave as:

(a) Only waves

(b) Only particles

(c) Both waves and particles ✅

(d) Neither waves nor particles

8. Electron microscope works on the principle of:

(a) Photoelectric effect

(b) Pair production

(c) Wave nature of electrons ✅

(d) Compton effect

9. Heisenberg uncertainty principle states uncertainty between:

(a) Energy and mass

(b) Speed and distance

(c) Position and momentum ✅

(d) Charge and energy

10. The uncertainty relation is mathematically written as:

(a) $\Delta x + \Delta p = h$

(b) $\Delta x \cdot \Delta p \approx h$ ✅

(c) $p = h/\lambda$

(d) $E = mc^2$

🩸 **Important MCQs:**

1. Classical physics could not explain:

(a) Laws of motion

(b) Reflection of light

(c) Black body radiation ✅

(d) Simple harmonic motion

2. The explanation framework developed in the 20th century is called:

(a) Nuclear physics

(b) Classical physics

(c) Modern physics ✅

(d) Solid state physics

3. The two most important features of modern physics are:

(a) Mechanics and optics

(b) Electricity and magnetism

(c) Relativity and quantum theory ✅

(d) Thermodynamics and waves

4. The special theory of relativity explains:

(a) Slow moving objects

(b) Stationary objects

(c) Objects moving near the speed of light ✅

(d) Atomic structure

5. Quantum theory explains electromagnetic radiation as:

(a) Continuous waves

(b) Static fields

(c) Discrete packets of energy ✅

(d) Magnetic lines

6. Classical physics is applicable to:

(a) Atomic scale phenomena

(b) Subatomic particles

(c) Everyday life processes ✅

(d) High speed particles

7. Motion of an object depends upon:

(a) Mass

(b) Shape

(c) Observer ✅

(d) Size

8. The concept of direction is:

(a) Absolute

(b) Fixed

(c) Relative ✅

(d) Universal

9. The walls of a moving train are at rest with respect to:

(a) Ground observer

(b) Distant stars

(c) Passengers inside the train ✅

(d) Earth

10. A ball thrown vertically upward in a moving car appears to follow a ______ path to a ground observer:

(a) Straight

(b) Circular

(c) Parabolic ✅

(d) Elliptical

11. A frame of reference is defined as a:

(a) Measuring scale

(b) Coordinate system ✅

(c) Force system

(d) Energy system

12. An inertial frame of reference is one in which:

(a) Acceleration always exists

(b) Circular motion occurs

(c) Law of inertia is valid ✅

(d) Motion is impossible

13. A frame moving with uniform velocity relative to an inertial frame is:

(a) Non-inertial

(b) Accelerated

(c) Inertial ✅

(d) Rotating

14. A suddenly accelerated car represents a:

(a) Inertial frame

(b) Uniform frame

(c) Non-inertial frame ✅

(d) Absolute frame

15. Earth is treated as an inertial frame because:

(a) It is completely at rest

(b) It does not rotate

(c) Its acceleration is very small ✅

(d) No forces act on it

16. The special theory of relativity deals with frames of reference that are:

(a) Accelerating

(b) Rotating

(c) Inertial (non-accelerating) ✅

(d) Non-uniform

17. Problems involving accelerating frames are treated by:

(a) Classical mechanics

(b) Quantum theory

(c) Special theory of relativity

(d) General theory of relativity ✅

18. How many postulates form the basis of special theory of relativity?

(a) One

(b) Two ✅

(c) Three

(d) Four

19. The first postulate of relativity states that laws of physics are same in:

(a) All frames

(b) Accelerated frames

(c) All inertial frames ✅

(d) Rotating frames

20. The second postulate of relativity states that speed of light in free space is:

(a) Different for different observers

(b) Dependent on source motion

(c) A universal constant for all observers ✅

(d) Zero in vacuum

21. The value of speed of light in free space is approximately:

(a) 3×10^6 m/s

(b) 3×10^8 m/s ✅

(c) 3×10^{10} m/s

(d) 3×10^4 m/s

22. Time measured by an observer at rest in the frame of events is called:

(a) Dilated time

(b) Relative time

(c) Proper time ✅

(d) Contracted time

23. According to special theory of relativity, time is:

(a) Absolute

(b) Constant

(c) Independent of motion

(d) Dependent on motion of observer ✅

24. Length contraction occurs only in the direction:

(a) Perpendicular to motion

(b) At rest

(c) Of motion ✅

(d) Of force

25. According to relativity, as the speed of an object approaches the speed of light, its mass becomes:

(a) Zero

(b) Constant

(c) Decreases

(d) Infinite ✅

26. When a body is heated, it emits radiation that mainly depends upon its:

(a) Shape

(b) Colour

(c) Temperature ✅

(d) Volume

27. At low temperature, a heated body mainly emits radiation in the:

(a) Ultraviolet region

(b) Visible region

(c) Infrared region ✅

(d) X-ray region

28. As the temperature of a body increases, the emitted radiation becomes richer in:

(a) Longer wavelengths

(b) Invisible waves only

(c) Shorter wavelengths ✅

(d) Constant wavelengths

29. A black body is defined as a body which:

(a) Reflects all radiation

(b) Absorbs all incident radiation ✅

(c) Emits no radiation

(d) Transmits radiation

30. A black body is considered an ideal:

(a) Reflector

(b) Conductor

(c) Absorber and radiator ✅

(d) Insulator

31. According to Wien's displacement law, the product $\lambda_{max}T$ is:

(a) Variable

(b) Zero

(c) Constant ✅

(d) Infinite

32. Wien's constant is approximately equal to:

(a) 2.9×10^{-3} m K ✅

(b) 3.0×10^{8} m/s

(c) 6.63×10^{-34} Js

(d) 5.67×10^{-8} $Wm^{-2}K^{-4}$

33. According to Stefan–Boltzmann law, the total energy radiated per unit area is proportional to:

(a) T

(b) T^2

(c) T^3

(d) T^4 ✅

34. Planck proposed that radiation energy is emitted in:

(a) Continuous waves

(b) Electric pulses

(c) Discrete packets (quanta) ✅

(d) Magnetic fields

35. The energy of a photon is given by the relation:

(a) $E = mc^2$

(b) $E = pc$

(c) $E = hf$ ✅

(d) $E = h\lambda$

36. Electromagnetic radiation interacts with matter mainly depending upon its:

(a) Wavelength

(b) Intensity

(c) Energy ✅

(d) Speed

37. The three main interactions of radiation with matter are:

(a) Reflection, refraction, diffraction

(b) Absorption, emission, transmission

(c) Photoelectric effect, Compton effect, Pair production ✅

(d) Interference, polarization, scattering

38. The emission of electrons from a metal surface when light falls on it is called:

(a) Thermionic emission

(b) Field emission

(c) Photoelectric effect ✅

(d) Compton effect

39. The electrons emitted in photoelectric effect are known as:

(a) Free electrons

(b) Valence electrons

(c) Photoelectrons ✅

(d) Conduction electrons

40. In a photoelectric tube, the electrode connected to the positive terminal is called:

(a) Cathode

(b) Collector

(c) Anode ✅

(d) Emitter

41. Photoelectric current flows only when:

(a) Voltage is applied

(b) Light falls on cathode ✅

(c) Temperature is increased

(d) Pressure is reduced

42. The potential at which photoelectric current becomes zero is called:

(a) Breakdown potential

(b) Threshold potential

(c) Stopping potential ✅

(d) Operating potential

43. The maximum kinetic energy of photoelectrons depends upon the:

(a) Intensity of light

(b) Area of metal

(c) Frequency of light ✅

(d) Time of exposure

44. Increasing the intensity of incident light mainly increases the:

(a) Kinetic energy of electrons

(b) Speed of electrons

(c) Number of emitted electrons ✅

(d) Work function

45. The minimum frequency required to emit electrons from a metal surface is called:

(a) Cut-off frequency

(b) Natural frequency

(c) Threshold frequency ✅

(d) Resonant frequency

46. Photoelectric effect cannot be explained by:

(a) Quantum theory

(b) Photon concept

(c) Electromagnetic wave theory ✅

(d) Einstein's equation

47. Einstein's photoelectric equation is:

(a) $E = mc^2$

(b) $E = hf$

(c) $hf = \varphi + K.E_{max}$ ✅

(d) $p = h/\lambda$

48. The work function of a metal is equal to:

(a) hf

(b) hλ

(c) hf_0 ✅

(d) mc^2

49. A device based on photoelectric effect is called:

(a) Transformer

(b) Photocell ✅

(c) Capacitor

(d) Rectifier

50. Which cathode material is suitable for visible light in a photocell?

(a) Cesium

(b) Sodium or potassium ✅

(c) Iron

(d) Copper

51. The scattering of X-rays by electrons resulting in increased wavelength is called:

(a) Photoelectric effect

(b) Pair production

(c) Compton effect ✅

(d) Diffraction

52. The increase in wavelength during Compton scattering is known as:

(a) Doppler shift

(b) Red shift

(c) Compton shift ✅

(d) Blue shift

53. Compton wavelength depends upon the:

(a) Photon energy

(b) Electron rest mass ✅

(c) Intensity of radiation

(d) Frequency only

54. Pair production occurs when photon energy is greater than:

(a) 0.51 MeV

(b) 1.00 MeV

(c) 1.02 MeV ✅

(d) 2.00 MeV

55. Pair production usually takes place near a:

(a) Light nucleus

(b) Free electron

(c) Heavy nucleus ✅

(d) Proton

56. When an electron and a positron annihilate, they produce:

(a) One photon

(b) Two photons ✅

(c) Three photons

(d) One electron

57. In annihilation of matter, the produced photons move:

(a) In the same direction

(b) Randomly

(c) In opposite directions ✅

(d) Perpendicular to each other

58. The energy of each photon produced during annihilation is:

(a) 0.25 MeV

(b) 0.51 MeV ✅

(c) 1.02 MeV

(d) 2.00 MeV

59. The existence of positron was predicted by:

(a) Einstein

(b) Bohr

(c) Dirac ✅

(d) Compton

60. Positron was discovered in cosmic rays by:

(a) J. J. Thomson

(b) Werner Heisenberg

(c) Carl Anderson ✅

(d) Max Planck

61. According to de Broglie, wavelength associated with a particle is given by:

(a) $\lambda = mv/h$

(b) $\lambda = h/mv$ ✅

(c) $\lambda = hv$

(d) $\lambda = mc^2$

62. Wave nature of particles becomes noticeable when the particle has:

(a) Large mass

(b) High density

(c) Very small mass and high speed ✅

(d) Zero velocity

63. The experiment that confirmed the wave nature of electrons was performed by:

(a) Rutherford

(b) Bohr

(c) Davisson and Germer ✅

(d) Millikan

64. In Davisson–Germer experiment, electrons are diffracted by a:

(a) Glass plate

(b) Diffraction grating

(c) Nickel crystal ✅

(d) Magnetic field

65. Electron diffraction provides evidence for:

(a) Particle nature of electrons

(b) Charge of electron

(c) Wave nature of electrons ✅

(d) Mass of electron

66. The principle stating that matter and radiation show both wave and particle nature is called:

(a) Superposition principle

(b) Complementarity principle

(c) Wave–particle duality ✅

(d) Relativity principle

67. The practical device that uses wave nature of electrons is the:

(a) Optical microscope

(b) Photocell

(c) Electron microscope ✅

(d) Spectrometer

68. Compared to optical microscope, electron microscope has:

(a) Lower resolution

(b) Same resolution

(c) Much higher resolution ✅

(d) No magnification

69. According to Heisenberg uncertainty principle, it is impossible to measure simultaneously with perfect accuracy:

(a) Mass and energy

(b) Charge and mass

(c) Position and momentum ✅

(d) Energy and charge

70. The mathematical form of uncertainty principle is:

(a) $\Delta x + \Delta p = h$

(b) $\Delta x \cdot \Delta p \approx h$ ✅

(c) $\Delta E = mc^2$

(d) $p = h/\lambda$

🩸 Important Short Questions (From Summary)

1. What is an inertial frame of reference?

Answer:

👉 An inertial frame of reference is a coordinate system in which the law of inertia is valid.

2. What is a black body?

Answer:

👉 A black body is a solid object with a hollow cavity that absorbs all radiation entering it and emits radiation depending on its temperature.

3. What is the Stefan–Boltzmann law?

Answer:

👉 Stefan–Boltzmann law states that the total energy radiated per unit area of a black body is directly proportional to the fourth power of its absolute temperature.

4. What is the photoelectric effect?

Answer:

👉 The photoelectric effect is the emission of electrons from a metal surface when light of suitable frequency falls on it.

5. What are photoelectrons?

Answer:

👉 Photoelectrons are the electrons emitted from a metal surface due to the photoelectric effect.

6. What is the Compton effect?

Answer:

👉 Compton effect is the scattering of X-rays by loosely bound electrons, resulting in an increase in wavelength of scattered X-rays.

7. What is pair production?

Answer:

👉 Pair production is the conversion of a very high energy photon into an electron-positron pair.

8. What is annihilation of matter?

Answer:

👉 Annihilation of matter occurs when a positron meets an electron, and both are converted into two photons of gamma rays.

9. What is Heisenberg's uncertainty principle?

Answer:

👉 It states that the position and momentum of a particle cannot both be measured simultaneously with perfect accuracy.

10. What is the significance of $E = mc^2$?

Answer:

👉 **E = mc²** shows that mass and energy are interconvertible; a body's rest mass can be expressed as an equivalent energy.

🩸 Important Short Questions:

1. What is modern physics?

Answer:

👉 Modern physics is the branch of physics that explains phenomena which cannot be explained by classical physics, including relativity and quantum theory.

2. Name the two most significant features of modern physics.

Answer:

👉 The two most significant features are relativity and quantum theory.

3. Why could classical physics not explain black body radiation and the photoelectric effect?

Answer:

👉 Classical physics failed because it could not describe energy quantization and the behavior of very fast or very small particles.

4. What is relative motion?

Answer:

👉 Relative motion is the motion of an object as observed from a particular frame of reference; it is not absolute.

5. Give an example of relative motion.

Answer:

👉 A ball thrown straight up in a moving train falls straight down for passengers inside but appears to follow a parabolic path for a stationary observer outside.

6. What is a frame of reference?

Answer:

👉 A frame of reference is a coordinate system relative to which measurements of position and motion are taken.

7. Define an inertial frame of reference.

Answer:

👉 An inertial frame of reference is a system in which the law of inertia is valid; a body at rest remains at rest unless acted upon by an unbalanced force.

8. Give an example of an inertial frame of reference.

Answer:

👉 A car moving with uniform velocity relative to Earth is an inertial frame.

9. What is a non-inertial frame of reference?

Answer:

👉 A non-inertial frame is a frame that is accelerating or decelerating, where objects do not obey the law of inertia.

10. Why can Earth often be considered an inertial frame?

Answer:

👉 Because its acceleration due to rotation and revolution is very small, so treating it as inertial causes negligible error.

11. What is the special theory of relativity?

Answer:

👉 The special theory of relativity deals with physical phenomena observed in inertial (non-accelerating) frames of reference.

12. State the two postulates of the special theory of relativity.

Answer:

👉 1. The laws of physics are the same in all inertial frames.

👉 2. The speed of light in free space is constant for all observers, regardless of their motion.

13. What is time dilation?

Answer:

👉 Time dilation is the stretching of time due to relative motion; moving clocks run slower compared to stationary ones.

14. What is length contraction?

Answer:

👉 Length contraction is the shortening of distances measured along the direction of motion of an object relative to a stationary observer.

15. How does mass vary according to special relativity?

Answer:

👉 According to special relativity, the mass of a moving object increases with its speed.

Formula:

- $m = m0 \div \text{sqrt}(1 - v^2 / c^2)$

16. What is a black body?

Answer:

👉 A black body is an ideal absorber and emitter of radiation. It absorbs all radiation falling on it and emits radiation depending only on its temperature.

17. What is the significance of the intensity distribution curves of a black body?

Answer:

👉 The intensity distribution curves show how energy is distributed among different wavelengths at various temperatures.

Fact:

- Energy is not uniformly distributed.
- There is a wavelength lambda_max at which emitted energy is maximum.

The product of wavelength and temperature is constant:

Formula:

$\lambda_{max} \times T = \text{Constant}$

Where Wien's constant ≈ 2.9×10^{-3} m·K.

18. State Stefan-Boltzmann law.

Answer:

👉 The total energy radiated per second per square metre by a black body is proportional to the fourth power of its absolute temperature.

Formula:

$E = \text{sigma} \times T^4$

Where sigma = 5.67×10^{-8} $W \cdot m^{-2} \cdot K^{-4}$.

19. What is Planck's assumption about black body radiation?

Answer:

👉 Planck assumed that energy is radiated or absorbed in discrete packets called quanta.

Formula:

$E = h \times f$

Where h = 6.63×10^{-34} Js (Planck's constant), f = frequency of radiation.

20. What is a photon and how is its momentum related to energy?

Answer:

👉 A photon is an indivisible packet of electromagnetic energy traveling at the speed of light.

Formulas:

Energy of photon: $E = h \times f$

Momentum of photon: $p = E / c = h / \lambda$

Also: $E = p \times c$

21. What is the photoelectric effect?

Answer:

👉 The photoelectric effect is the emission of electrons from a metal surface when exposed to light of suitable frequency. The emitted electrons are called photoelectrons.

22. State Einstein's photoelectric equation.

Answer:

👉 The energy of an incident photon is partly used to overcome the work function of the metal and the rest appears as kinetic energy of the electron.

Formula:

$K.E._{max} = hf - \varphi$

Where h = Planck's constant, f = frequency of light, φ = work function of the metal.

23. What is threshold frequency?

Answer:

👉 Threshold frequency f_0 is the minimum frequency of incident light below which no electrons are emitted, regardless of light intensity.

Formula:

$\varphi = h \times f_0$

24. What is a photocell and its applications?

Answer:

👉 A photocell is a device based on the photoelectric effect that generates current when exposed to light.

Applications:

- Security systems
- Automatic doors
- Street lighting
- Exposure meters in photography
- Movie sound tracks

25. What is the Compton effect?

Answer:

👉 Compton effect is the scattering of X-rays by loosely bound electrons, in which the wavelength of scattered X-rays is larger than that of incident X-rays, showing particle-like behavior of light.

Formula (Compton shift):

$\Delta\lambda = (h / m_0 c) \times (1 - \cos\theta)$

Where m_0 = rest mass of electron, θ = scattering angle.

26. How is the Compton wavelength calculated?

Answer:

👉 Compton wavelength is the wavelength shift for $\theta = 90°$ in Compton scattering.

Formula:

$\lambda_C = h / (m_0 \times c)$

Numerical value: 2.43×10^{-12} m

27. What is pair production?

Answer:

👉 Pair production is the creation of an electron-positron pair when a high-energy photon interacts with matter, usually near a heavy nucleus.

28. What is the minimum photon energy required for pair production?

Answer:

👉 Energy required = 2×0.51 MeV = 1.02 MeV

Formula:

$E_{photon} = 2mc^2 + K.E.(electron) + K.E.(positron)$

29. How does photon energy convert to matter in pair production?

Answer:

👉 In pair production, photon energy is converted into rest mass energy of electron and positron along with their kinetic energy.

Formula:

$hf = 2mc^2 + K.E.(e^-) + K.E.(e^+)$

30. Why can the photoelectric and Compton effects not be explained by classical wave theory?

Answer:

👉 Classical wave theory predicts that increasing light intensity should increase electron energy, but experiments show:

Photoelectric effect: K.E. depends on frequency, not intensity.

Compton effect: X-rays behave like particles with momentum.

This proves light has particle-like properties (photons).

31. What is annihilation of matter?

Answer:

👉 Annihilation of matter is the process in which a positron and an electron meet and destroy each other, producing two photons in the γ-ray range, each with energy 0.51 MeV.

32. Who predicted the existence of positron and who discovered it?

Answer:

👉 Positron was predicted by Dirac in 1928 and discovered by Carl Anderson in 1932.

33. What is de Broglie hypothesis?

Answer:

👉 Louis de Broglie proposed that all particles possess wave-like properties, and the wavelength associated with a particle of mass m and velocity v is:

Formula:

$\lambda = h / (m \times v)$

34. Why are wave effects negligible for macroscopic objects?

Answer:

👉 Objects with large mass and ordinary speed have extremely small de Broglie wavelengths, making interference and diffraction effects negligible.

35. Explain Davisson and Germer experiment.

Answer:

👉 Electrons accelerated through a potential V are diffracted by a nickel crystal. The observed wavelength agrees with de Broglie's prediction, confirming the wave nature of electrons.

Formula:

$\lambda = h / \sqrt{2 m e V}$

36. What is wave-particle duality?

Answer:

👉 Wave-particle duality is the concept that all matter and radiation exhibit both wave-like and particle-like properties depending on the experiment.

37. How is the wave nature of electrons applied in electron microscopes?

Answer:

👉 Electron microscopes use the short de Broglie wavelength of high-energy electrons to achieve high resolution (0.5–1 nm), far better than optical microscopes. Electrons are focused using electric and magnetic fields instead of lenses.

38. State Heisenberg's uncertainty principle.

Answer:

👉 The position and momentum of a particle cannot be measured simultaneously with perfect accuracy.

Formula:

$\Delta x \times \Delta p \approx h$

39. How does the uncertainty principle relate energy and time?

Answer:

👉 The uncertainty in energy (ΔE) and the time interval (Δt) during which the particle has that energy are related as:

Formula:

$\Delta E \times \Delta t \approx h$

40. Why can an electron never be found inside the nucleus?

Answer:

👉 Confining an electron inside a nucleus would require it to have a speed greater than the speed of light, which is impossible according to relativity.

🩸 Important long questions:

🌟 Q.1: Explain the Special Theory of Relativity and its main postulates. How does it affect time, length, and mass?

❖ Answer:

The Special Theory of Relativity was proposed by Albert Einstein in 1905. It deals with the physics of objects moving at high speeds, especially those approaching the speed of light, and explains phenomena that classical physics could not, such as the behaviour of light, time, length, and mass in different frames of reference.

Main Postulates:

- The laws of physics are the same in all inertial frames of reference.
- The speed of light in free space is constant and has the same value ($c = 3 \times 10^8$ m/s) for all observers, regardless of their relative motion.

Consequences of Special Theory of Relativity:

1. Time Dilation:

Time is not absolute. The time measured by a moving observer (t') is longer than the proper time (t) measured by a stationary observer:

$$t' = t / \sqrt{1 - v^2 / c^2}$$

2. Length Contraction:

Length along the direction of motion appears shorter for a moving observer:

$$L' = L * \sqrt{1 - v^2 / c^2}$$

2. Relativistic Mass:

The mass of an object increases with speed:

$$m = m0 / \sqrt{1 - v^2 / c^2}$$

Where m0 is the rest mass and m is the relativistic mass.

3. Energy-Mass Relation:

Mass and energy are interconvertible:

$E = m * c^2$

4. Kinetic Energy of Moving Object:

The kinetic energy of a moving object can be expressed as:

$KE = (m - m_0) * c^2$

✦ **Summary:**

The Special Theory of Relativity shows that time, length, and mass are relative and depend on the motion of the observer. It replaces classical concepts when dealing with high-speed particles or atomic-scale phenomena, and introduces the famous equation $E = mc^2$, linking mass and energy.

🌟 **Q.2: What is black body radiation? Explain Wien's Law and Stefan-Boltzmann Law.**

❖ **Answer:**

Black Body Radiation:

A black body is an idealized object that absorbs all radiation incident on it and emits radiation at all wavelengths. The radiation emitted depends only on the temperature of the body. At low temperatures, the radiation is mainly in the infrared region, while at high temperatures, the radiation shifts toward shorter wavelengths. A perfect black body is both an ideal absorber and an ideal emitter of radiation.

Intensity Distribution:

The energy emitted by a black body is not uniform across all wavelengths. At a given temperature, the radiation has a maximum intensity at a particular wavelength.

Wien's Law:

Wien's Law states that the wavelength of maximum emission (λ_{max}) is inversely proportional to the temperature (T) of the black body:

$$\lambda_{max} \times T = \text{constant}$$

Where the constant (Wien's constant) is:

$b = 2.9 \times 10^{-3}$ m·K

This means that as the temperature increases, the peak wavelength shifts to shorter wavelengths.

Stefan-Boltzmann Law:

The total energy emitted per second per unit area (E) by a black body is proportional to the fourth power of its absolute temperature (T):

$$E = \sigma \times T^4$$

Where σ is Stefan-Boltzmann constant:

$\sigma = 5.67 \times 10^{-8}$ $W \cdot m^{-2} \cdot K^{-4}$

This law shows that the total radiated energy increases rapidly with temperature.

✦ **Summary:**

- A black body absorbs all radiation and emits energy depending only on its temperature.
- Wien's Law explains how the peak wavelength shifts with temperature.
- Stefan-Boltzmann Law gives the total energy emitted at a given temperature.
- These laws are fundamental to modern physics and help in understanding radiation, stars, and high-temperature objects.

🌟 **Q.3: Describe the Photoelectric Effect and its significance in modern physics.**

❖ **Answer:**

Photoelectric Effect:

The photoelectric effect is the phenomenon in which electrons are emitted from the surface of a metal when it is exposed to light of suitable frequency. The emitted electrons are called photoelectrons.

Experimental Setup:

- An evacuated tube contains a cathode (metal surface) and an anode.
- When monochromatic light falls on the cathode, electrons are emitted and attracted towards the anode, producing a photoelectric current.
- If the anode is made negative (stopping potential), the current reduces to zero.
- The maximum kinetic energy of photoelectrons is measured as:

$$\frac{1}{2} m v_{max}^2 = e V_s$$

Where m = mass of electron, v_{max} = maximum velocity, e = electron charge, V_s = stopping potential.

Key Observations:

- Electrons are emitted instantaneously when light hits the metal.
- There is a threshold frequency (f_0) below which no electrons are emitted, regardless of light intensity.
- The intensity of light affects the number of electrons, not their kinetic energy.

- The maximum kinetic energy of emitted electrons depends on the frequency of light and the metal:

Einstein's Photoelectric Equation:

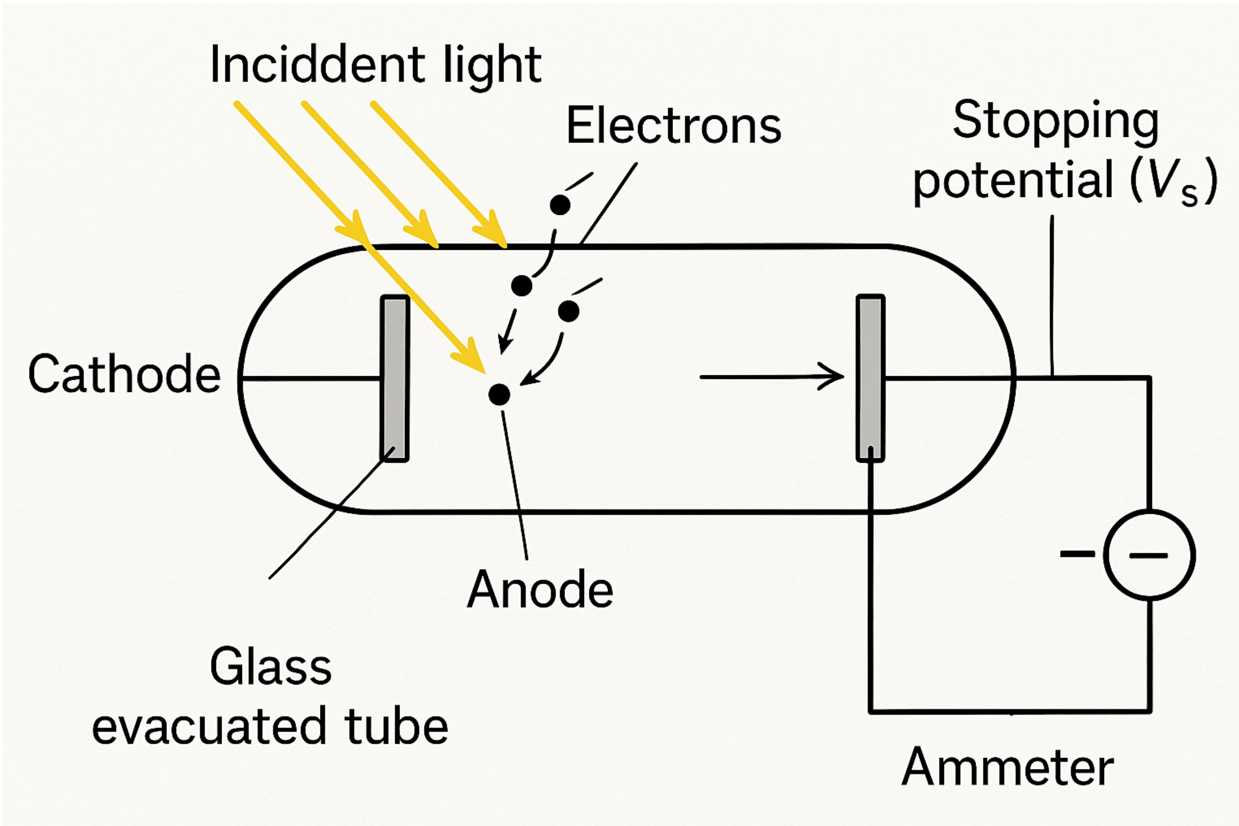
$K.E._{max} = hf - \varphi$

Where h = Planck's constant, f = frequency of light, φ = work function of the metal.

Significance in Modern Physics:

- Demonstrates the particle nature of light, supporting quantum theory.
- Contradicts classical wave theory, which cannot explain threshold frequency or instantaneous emission.
- Laid foundation for the concept of photons, where light consists of discrete energy quanta.
- Applications include photocells, solar panels, automatic doors, light sensors, and exposure meters.

✦ **Digram:**



✦ **Summary:**

The photoelectric effect proved that light behaves as particles (photons), not just waves. It was experimentally confirmed by Einstein, who received the Nobel Prize in 1921, and it forms a key principle of quantum mechanics, influencing modern electronics and photonics.

🌟 **Q.4: Explain the Compton Effect, Pair Production, and Annihilation of Matter.**

❖ **Answer:**

1. Compton Effect:

The Compton Effect is the phenomenon in which X-rays or gamma rays are scattered by loosely bound electrons in a material, resulting in an increase in wavelength of the scattered radiation.

Key Points:

- Discovered by Arthur Holly Compton in 1923.
- Classical wave theory cannot explain the increase in wavelength.
- Compton proposed that X-rays consist of photons with energy $E = hf$ and momentum $p = hf/c$.

When a photon collides with an electron:

- Part of the photon's energy is transferred to the electron.
- The scattered photon has lower energy ⟶ longer wavelength.

The Compton shift formula:

$\Delta\lambda = (h / m_e c)(1 - \cos\theta)$

Where:

h = Planck's constant

m_e = mass of electron

c = speed of light

θ = scattering angle

Significance:

- Confirms particle nature of light.
- Provides evidence for momentum transfer between photons and electrons.
- Awarded Nobel Prize in 1927.

2. Pair Production:

Pair production occurs when a high-energy photon ($E > 1.02$ MeV) interacts with the electric field of a nucleus and is converted into an electron-positron pair.

Key Points:

- **Positron:** particle with same mass as electron but positive charge.
- Conservation of energy and momentum is maintained.

Energy of photon:

$hf = 2\,m_e c^2 + K.E.(\text{electron}) + K.E.(\text{positron})$

- Minimum photon energy = 1.02 MeV (to create electron and positron).
- Any excess energy appears as kinetic energy of the particles.

Significance:

- Demonstrates conversion of energy into matter, supporting Einstein's $E = mc^2$.

- Important in high-energy physics and particle accelerators.

3. Annihilation of Matter:

- The annihilation of matter is the reverse process of pair production.

Key Points:

- When an electron and positron meet, they destroy each other.
- Their rest mass energy is converted into two photons:

Energy of each photon = 0.51 MeV

- The photons travel in opposite directions to conserve momentum.
- Discovered experimentally in cosmic rays by Carl Anderson in 1932.

Significance:

- Confirms existence of antiparticles.

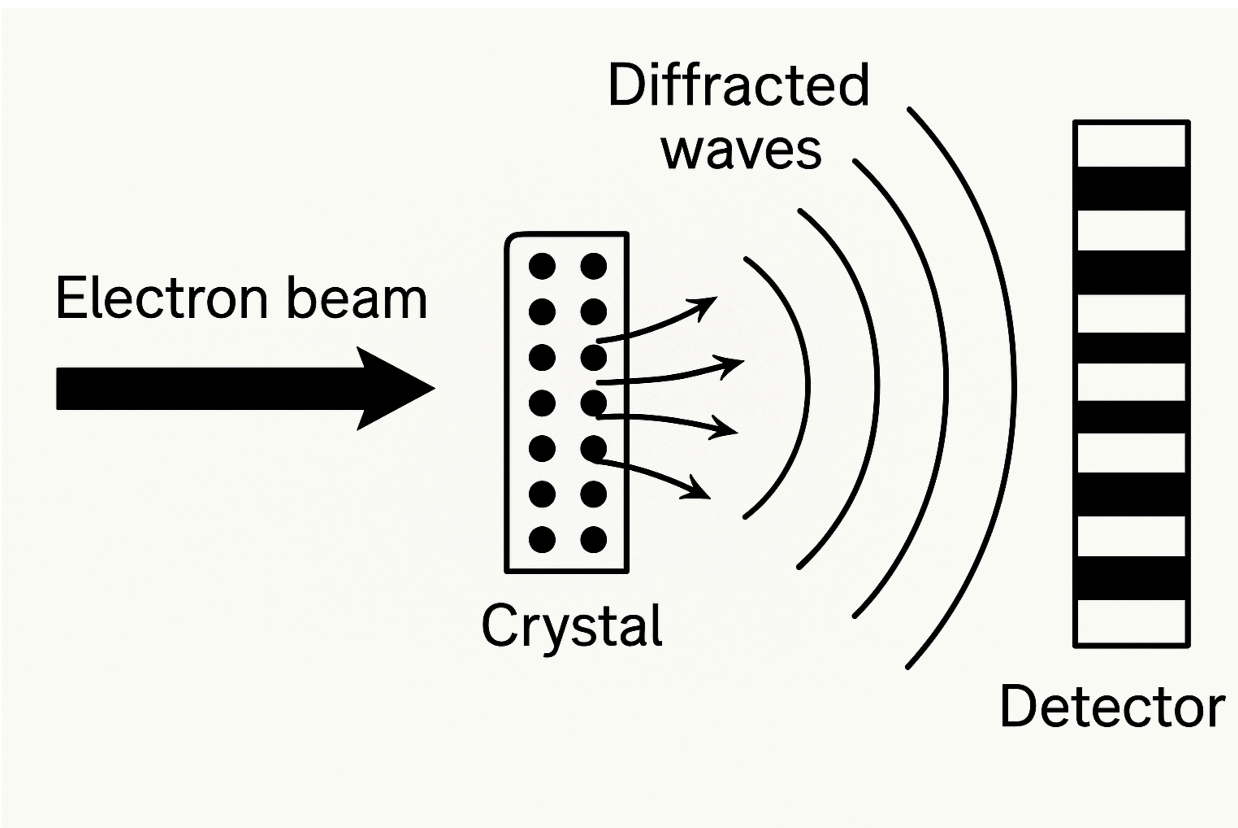
- Demonstrates mass-energy equivalence ($E = mc^2$).
- Basis for positron emission tomography (PET scans) in medical imaging.

🌟 Q.5: Discuss the Wave-Particle Duality of Matter and the Heisenberg Uncertainty Principle.

❖ **Answer:**

1. Wave-Particle Duality of Matter

Digram:



- Light and matter exhibit both wave-like and particle-like properties.
- Louis de Broglie (1924) proposed that every particle of matter has an associated wavelength, called the de Broglie wavelength.

De Broglie Relation:

lambda = h / p = h / (m * v)

Where:

lambda = wavelength of particle

h = Planck's constant

p = momentum of particle

m = mass of particle

v = velocity of particle

- Large objects (like bullets) have extremely small wavelengths $\longrightarrow$ wave effects are negligible.
- Electrons moving at high speeds have measurable wavelengths $\longrightarrow$ diffraction and interference effects can be observed.

Experimental Evidence:

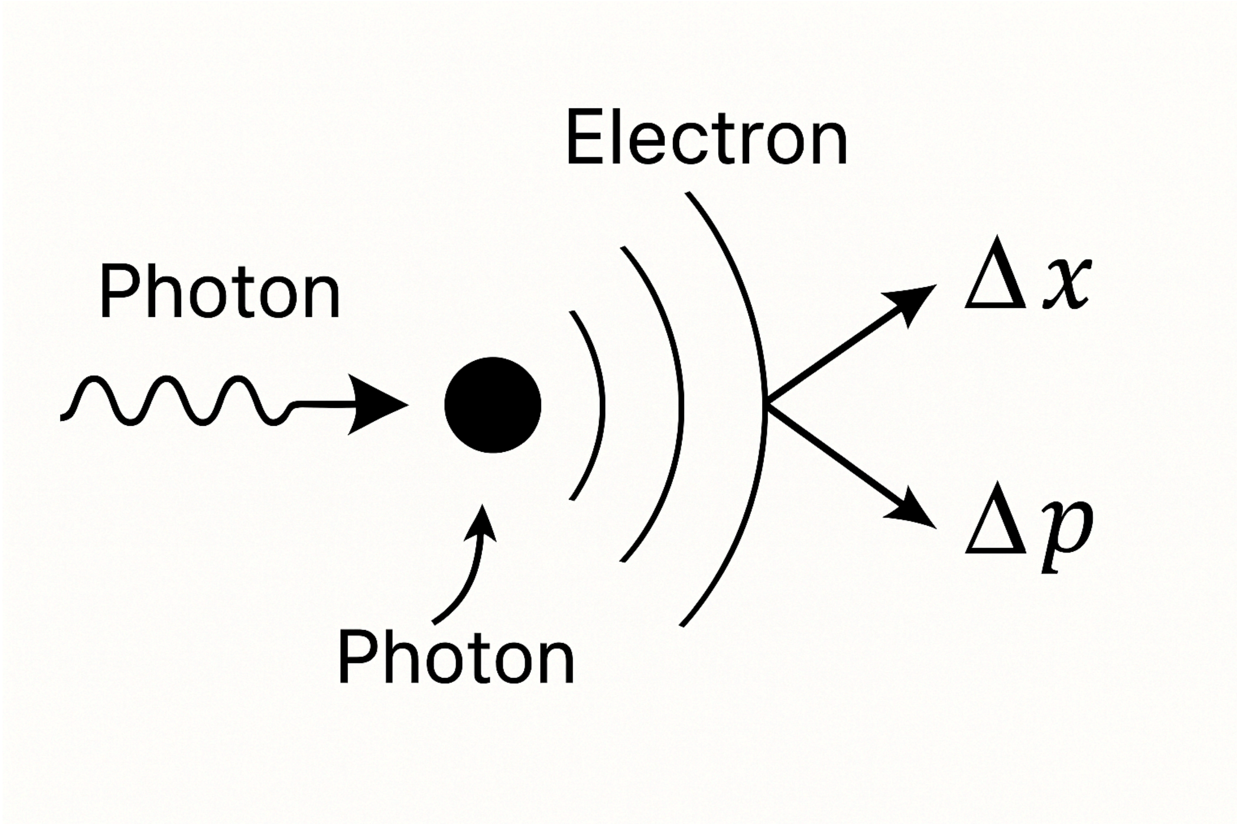
- **Davisson and Germer (1927):** Electron diffraction from nickel crystal confirmed wave nature of electrons.
- **G.P. Thomson** also observed electron diffraction, confirming de Broglie's hypothesis.

Applications – Electron Microscope:

- Uses electrons instead of light for imaging.
- Electric and magnetic fields focus electron beams like lenses.
- Provides resolution up to 0.5–1 nm, much better than optical microscopes (~0.2 micrometer).

2. Heisenberg Uncertainty Principle

Digram:



- Proposed by Werner Heisenberg (1927).
- States that position and momentum of a particle cannot be measured simultaneously with perfect accuracy.

Mathematical Form:

Delta x * Delta p_x approximately equal to h

Where:

Delta x = uncertainty in position

Delta p_x = uncertainty in momentum along x-axis

h = Planck’s constant

Energy-Time Form:

Delta E * Delta t approximately equal to h

- More precisely, h-bar = h / (2 * pi)
- The more accurately we measure position, the less accurately we can know momentum, and vice versa.
- This is important only for atomic and subatomic particles.

Physical Interpretation:

- A photon used to observe an electron disturbs its momentum, limiting simultaneous measurement.
- Explains why electrons cannot be localized exactly inside the nucleus.

Significance:

- Fundamental principle of quantum mechanics.
- Limits precision in microscopic measurements.
- Supports the wave-particle duality concept and quantum behavior of matter.

🩸 Exercise Questions:

🌟 19.1: What are the measurements on which two observers in relative motion will always agree upon?

❖ **Answer:**

- When two observers are in relative motion, not all measurements are the same for both. Some quantities appear different depending on the observer's frame of reference.
- **Measurements** that are the same for both observers (in relative motion) include:

1. Laws of physics – The fundamental laws (like Newton's laws, conservation laws) are valid in all inertial frames.

2. Speed of light in vacuum – The speed of light, c = 3 × 10^8 m/s, is constant for all observers, regardless of their motion.

3. Electric charge – The amount of charge on a particle is the same for all observers.

4. Mass at rest (rest mass) – The intrinsic mass of a particle when measured in its own rest frame remains the same.

5. Causality – The order of cause and effect remains unchanged; an event causing another is the same for all observers.

Other quantities like time intervals (time dilation), lengths (length contraction), and relative velocities can differ depending on the observer's motion.

✦ **Summary:**

Observers in relative motion agree on the laws of physics, speed of light, electric charge, rest mass, and causality, but may measure different times, lengths, and velocities.

🌟 **19.2: Does the dilation mean that time really passes more slowly in a moving system or that it only seems to pass more slowly?**

❖ **Answer:**

- **According to the Special Theory** of Relativity, time dilation occurs when an observer measures the time interval of a moving clock.
- **Proper time (t_0) is** measured in the rest frame of the clock.
- **Time measured by** a moving **observer** (t) is longer than t_0. That is, the moving clock appears to run slower from the perspective of a stationary observer.
- **For the person moving** with the **clock**, time passes normally in their own frame.

Conclusion: Time does not literally slow down for the moving person; it only appears dilated to an external observer.

✦ **Summary:**

Time dilation is relative, depending on the frame of reference. Moving observers experience normal time in their frame, while stationary observers see the moving clock running slower.

🌟 19.3: If you are moving in a spaceship at a very high speed relative to the Earth, would you notice a difference (a) in your pulse rate (b) in the pulse rate of people on Earth?

❖ **Answer:**

(a) Your pulse rate: In your own frame inside the spaceship, you would not notice any change. Your pulse and all biological processes occur normally because in your rest frame, time flows normally.

(b) Pulse rate of people on Earth: Observed from the spaceship, people on Earth would appear to have slower pulses. This is a direct effect of time dilation, as Earth is moving relative to you.

✦ **Summary:**

Time dilation affects relative observation. Moving observers see stationary clocks on Earth (or other frames) running slower, but experience normal time in their own frame.

🌟 19.4: If the speed of light were infinite, what would the equations of special theory of relativity reduce to?

❖ **Answer:**

- The Special Theory of Relativity is based on the finite speed of light, c. Relativistic effects such as time dilation, length contraction, and increase in mass occur because c is finite.

The Lorentz factor is given by:

- gamma = 1 / sqrt(1 - v^2 / c^2)

If the speed of light were infinite (c ⟶ ∞), then:

v^2 / c^2 ⟶ 0

=> gamma ⟶ 1

Consequences:

a. Time dilation disappears: moving clocks tick at the same rate as stationary clocks.

➢ t = gamma * t0 ⟶ t = t0

b. Length contraction disappears: objects in motion retain their proper lengths.

➢ $L = L0 / \gamma \rightarrow L = L0$

c. Relativistic mass increase disappears: mass remains constant regardless of speed.

➢ $m = \gamma * m0 \rightarrow m = m0$

Momentum and energy equations reduce to classical forms:

- Momentum: $p = m * v$
- Kinetic Energy: $KE = 1/2 * m * v^2$

✦ **Summary:**

If the speed of light were infinite, all relativistic effects vanish, and physics would follow classical Newtonian mechanics.

🌟 19.5: Since mass is a form of energy, can we conclude that a compressed spring has more mass than the same spring when it is not compressed?

❖ **Answer:**

According to Einstein's mass-energy equivalence:

$E = m * c^2$

- **Here**, E is the total energy of the object, m is its mass, and c is the speed of light.
- A **compressed spring** has elastic potential energy stored in it. This energy contributes to the total energy of the spring.
- **Therefore**, the total mass of the compressed spring is slightly more than its mass when it is uncompressed.

The increase in mass, Δm, can be calculated as:

$\Delta m = \Delta E / c^2$

Important note:

- In everyday life, this increase in mass is extremely small and not measurable, because c^2 is a very large number.
- For practical purposes, we treat the mass of the spring as constant.

✦ **Summary:**

Yes, a compressed spring has slightly more mass than the same spring when uncompressed, but the difference is negligible in everyday situations.

🌟 **19.6: As a solid is heated and begins to glow, why does it first appear red?**

❖ **Answer:**

- **When a solid is heated,** it emits thermal radiation. The color of the glow depends on the wavelength of the emitted light, which in turn depends on the temperature of the solid.
- **At low temperatures**, most of the radiation is in the infrared region, which is invisible to the human eye.
- **As the temperature increases slightly**, the solid starts emitting visible light, and the first visible color is red,

because red light has the longest wavelength among visible colors.

As the temperature rises further:

- The color shifts from red → orange → yellow → white.
- **This is because higher** temperature increases the proportion of shorter wavelength radiation emitted.

This phenomenon is explained by Black Body Radiation. According to Wien's Law:

$\lambda_{max} \times T = \text{constant}$

- Here, λ_{max} is the wavelength at which maximum radiation is emitted, and T is the absolute temperature.
- As T increases, λ_{max} decreases → radiation shifts to shorter wavelengths (toward blue).

✦ **Summary:**

A solid first appears red when heated because at lower temperatures, the peak of its emitted radiation is in the long-wavelength red region of visible light. As it gets hotter, the color shifts to higher energy (shorter wavelength) light.

🌟 19.7: What happens to total radiation from a blackbody if its absolute temperature is doubled?

❖ **Answer:**

The total energy radiated per second per unit area by a blackbody is given by Stefan-Boltzmann Law:

$E = \sigma \times T^4$

E = total energy radiated per unit area per second

T = absolute temperature of the blackbody (in Kelvin)

σ = Stefan-Boltzmann constant ≈ 5.67×10^{-8} $W/m^2 \cdot K^4$

If the absolute temperature is doubled:

$T \longrightarrow 2T$

Then, the total radiation becomes:

$E\_new = \sigma \times (2T)^4 = \sigma \times 16 \times T^4 = 16 \times E$

Conclusion:

Doubling the absolute temperature of a blackbody increases its total radiation by 16 times.

✦ **Summary:**

The total radiation emitted by a blackbody is very sensitive to temperature. A small increase in temperature leads to a large increase in emitted energy because it depends on the fourth power of absolute temperature.

🌟 **19.8: A beam of red light and a beam of blue light have exactly the same energy. Which beam contains the greater number of photons?**

❖ **Answer:**

The energy of a single photon is given by Planck's equation:

$E = h \times h$

Where

- **E** is the energy of the photon,
- **h** is Planck's constant (6.63×10^{-34} Js),
- **f** is the frequency of the light.

The frequency of light is related to its wavelength by:

$f = c / \lambda$

where

- **c** is the speed of light,
- **λ** is the wavelength of the light.

Combining these, the energy of a photon can also be expressed as:

$E = h \times c / \lambda$

Observation:

- Red light has a longer wavelength than blue light.

Therefore, the energy of a single red photon (E_red) is less than the energy of a single blue photon (E_blue).

If both beams have the same total energy, the number of photons in the beam is given by:

- Number of photons = Total energy / Energy per photon
- Since E_red < E_blue, the number of photons in the red beam is greater.

Conclusion:

- The red light beam contains more photons than the blue light beam when both have the same total energy.

✦ **Summary:**

- Photon energy is inversely proportional to wavelength: longer wavelength ⟶ lower energy.
- For equal total energy, beams with lower-energy photons must contain more photons.
- Hence, red light (longer wavelength) has more photons than blue light.

🌟 19.9: Which photon, red, green, or blue carries the most (a) energy and (b) momentum?

❖ **Answer:**

1. Energy of a Photon

The energy of a photon is given by:

$E = h * f = (h * c) / \lambda$

Where:

E = energy of photon

h = Planck's constant (6.63×10^{-34} Js)

f = frequency of light

c = speed of light (3×10^8 m/s)

λ = wavelength of light

Observation:

- Blue light has the shortest wavelength, so it has the highest energy.
- Green light has medium wavelength, so it has medium energy.
- Red light has the longest wavelength, so it has the lowest energy.

Conclusion:

$E_{blue} > E_{green} > E_{red}$

2. Momentum of a Photon

The momentum of a photon is given by:

$$p = E / c = h / \lambda$$

Observation:

- Momentum is inversely proportional to wavelength.
- Shorter wavelength → higher momentum.

Conclusion:

p_blue > p_green > p_red

Key Concept:

- Shorter wavelength photons carry more energy and momentum.
- Blue photon has the highest energy and momentum.

✦ **Summary:**

- Photon energy depends on frequency and wavelength: $E = h * f = (h * c) / \lambda$.
- Photon momentum depends on wavelength: $p = h / \lambda$.
- Shorter wavelength photons carry more energy and more momentum.

Among red, green, and blue photons:

  - Blue photon → highest energy and momentum
  - Green photon → medium energy and momentum
  - Red photon → lowest energy and momentum

🌟 19.10: Which has the lower energy quanta, radiowaves or X-rays?

❖ Explanation:

1. Photon Concept:

- Light and other electromagnetic radiation are made of tiny energy packets called photons.
- The energy of each photon depends on the frequency of the radiation.

2. Photon Energy Formula:

$E = h * f = (h * c) / \lambda$

Where:

E = energy of the photon

h = Planck's constant (6.63×10^{-34} Js)

f = frequency of the radiation

λ = wavelength of the radiation

c = speed of light

3. Comparison of Radiowaves and X-rays:

- **Radiowaves**: Very long wavelength (λ ~ meters to kilometers), very low frequency's (f ~ kHz to GHz)
- **X-rays:** Very short wavelength (λ ~ 10^-10 m), very high frequency (f ~ 10^18 Hz)

Effect on Photon Energy:

- Energy is directly proportional to frequency: $E \propto f$
- Energy is inversely proportional to wavelength: $E \propto 1/\lambda$

So: long wavelength → low frequency → low energy

- Short wavelength → high frequency → high energy

Conclusion:

- **Radiowaves** have much lower energy photons compared to X-rays.
- **X-rays** have high energy photons, capable of ionizing atoms and passing through materials.
- **Radiowaves** are non-ionizing and mostly used for communication, radio, and TV signals.

✦ **Summary:**

- **Radiowaves** ⟶ Long wavelength, low frequency ⟶ Low energy photons
- **X-rays** ⟶ Short wavelength, high frequency ⟶ High energy photons

Key Concept: Photon energy increases as the frequency of radiation increases.

🌟 19.11: Does the brightness of a beam of light primarily depend on the frequency of photons or on the number of photons?

❖ **Explanation:**

1. Concept of Brightness:

- Brightness (or intensity) of light refers to the energy delivered per second per unit area by the light beam.
- Light is made of photons, each carrying discrete energy.

2. Energy of Photons:

- Energy of a single photon is given by:

$E_{photon} = h * f$

where $h = 6.63 \times 10^{-34}$ Js (Planck's constant) and f is the frequency of light.

3. Total Energy of the Beam:

Total energy of the beam depends on both the number of photons (N) and the energy per photon:

$E_{total} = N * E_{photon}$

$E_{total} = N * h * f$

4. Dependence of Brightness:

- Increasing the frequency increases energy per photon but may not increase the number of photons.
- Increasing the number of photons (N) directly increases the total energy, making the beam brighter.
- **Therefore**, brightness mainly depends on the number of photons, while frequency affects the energy of individual photons.

Example:

A red light beam with many photons can be brighter than a blue light beam with fewer photons, even though blue photons have higher energy individually.

✦ **Summary:**

- Light consists of photons, each having energy $E_{photon} = h * f$.
- **Brightness** = total energy per unit area = $E_{total} = N * h * f$.
- **Brightness depends** primarily on the number of photons (N).
- **Frequency affects photon energy,** but more photons result in higher brightness.

🌟 19.12: When ultraviolet light falls on certain dyes, visible light is emitted. Why does this not happen when infrared light falls on these dyes?

1. Fluorescence Concept:

- Some dyes have the property of fluorescence, which means they can absorb energy from high-energy light and then emit light of lower energy in the visible range.
- When a photon of light hits a dye molecule, its energy can be absorbed if it is enough to excite the electrons of the molecule to a higher energy level.

2. Photon Energy and Frequency:

The energy of a photon depends on its frequency:

$E_{photon} = h * f$

where $h = 6.63 \times 10^{-34}$ Js is Planck's constant and f is the frequency of the light.

Higher frequency → higher energy, lower frequency → lower energy.

3. Effect of Ultraviolet Light:

- Ultraviolet (UV) light has a high frequency, therefore high-energy photons.
- These photons have enough energy to excite electrons in the dye molecules to higher energy levels.
- When electrons return to their original energy levels, they release the excess energy as visible light.

4. Effect of Infrared Light:

- Infrared (IR) light has a low frequency, therefore low-energy photons.
- These photons do not have enough energy to excite the electrons in the dye molecules.

Since no excitation occurs, no visible light is emitted.

Key Idea:

- **For fluorescence**, the photon energy must be equal to or greater than the energy gap of the dye molecules.
- UV photons satisfy this condition; IR photons do not.

✦ **Summary:**

Fluorescence: Emission of visible light after absorption of high-energy photons.

Photon energy formula: $E_{photon} = h * f$.

UV light: High frequency ⟶ high energy ⟶ excites electrons ⟶ visible light emitted.

IR light: Low frequency ⟶ low energy ⟶ electrons not excited ⟶ no visible light.

- **Conclusion:** Only photons with sufficient energy can cause fluorescence.

🌟 **19.13: Will bright light eject more electrons from a metal surface than dimmer light of the same colour?**

❖ **Explanation:**

1. Photoelectric Effect Concept:

- The photoelectric effect occurs when light of sufficient frequency strikes a metal surface and ejects electrons.
- The emitted electrons are called photoelectrons.

2. Dependence on Light Intensity:

- Brightness of light refers to the intensity, i.e., the number of photons striking the surface per second.

If the light has a frequency above the threshold frequency of the metal:

➢ More photons ⟶ more electrons ejected.

➢ Fewer photons ⟶ fewer electrons ejected.

3. Role of Photon Energy:

The energy of each photon depends on its frequency:

E_photon = h * f

- where h is Planck's constant and f is the frequency of the light.
- Increasing intensity does not increase the energy of individual electrons; it only increases the number of electrons emitted.

4. Threshold Frequency Importance:

- If the light is below the threshold frequency, no electrons are ejected, no matter how bright the light is.

Therefore, frequency is crucial; intensity only affects quantity of electrons, not their maximum kinetic energy.

✦ **Summary:**

- Brightness (intensity) increases the number of emitted electrons if frequency > threshold.
- Frequency determines whether electrons are ejected at all.
- **Photon energy formula:** E_photon = h * f.

- Maximum kinetic energy of electrons is independent of intensity, depends on frequency:

$K.E_{max} = h * f - \varphi$

where φ is the work function of the metal.

🌟 19.14: Will higher frequency light eject a greater number of electrons than low frequency light?

❖ Explanation:

1. Photoelectric Effect Concept:

- When light strikes a metal surface, electrons are emitted if the frequency of light is above the threshold frequency of the metal.

2. Role of Frequency:

Photon energy depends on frequency:

$E_{photon} = h * f$

- where h is Planck's constant and f is the frequency of light.
- Only photons with energy greater than or equal to the work function (φ) of the metal can eject electrons.

3. Higher vs. Lower Frequency:

- Higher frequency light: Each photon has more energy ⟶ electrons gain higher kinetic energy.
- **Lower frequency light:** Even if intensity is high, if frequency < threshold, no electrons are emitted.
- **Therefore**, higher frequency light does not necessarily eject more electrons; it increases the energy of emitted electrons. The number of electrons depends primarily on light intensity, not frequency.

4. Maximum Kinetic Energy:

The kinetic energy of emitted electrons is given by Einstein's photoelectric equation:

$$K.E_{max} = h * f - \varphi$$

- Here, increasing frequency increases K.E_max but does not increase the number of electrons.

✦ **Summary:**

- Frequency determines whether electrons are ejected and their kinetic energy.
- Intensity (brightness) determines the number of electrons emitted.
- High frequency light ⟶ higher energy electrons, not necessarily more electrons.
- Low frequency light below threshold ⟶ no electrons emitted, regardless of intensity.

🌟 **19.15: When light shines on a surface, is momentum transferred to the metal surface?**

❖ **Explanation:**

1. Photon Momentum Concept:

- Light consists of photons, which are particles of energy.
- Each photon carries energy E = h * f and momentum p = E / c = h * f / c,

where h is Planck's constant, f is frequency, and c is the speed of light.

2. Interaction with Metal Surface:

When photons strike a metal surface, they can:

- Be absorbed (transferring energy and momentum)
- Be reflected (changing direction, still transferring momentum)
- **In both cases**, momentum is transferred to the metal.

3. Magnitude of Transfer:

- The total momentum transferred depends on the number of photons and their individual momentum.
- Even though photon momentum is very small, for high-intensity light, the total momentum can produce measurable effects, like the radiation pressure on the surface.

4. Practical Example:

- In devices like solar sails in space, sunlight transfers momentum to large reflective surfaces, producing thrust.
- This is a direct consequence of the particle nature of light.

✦ Summary:

- Photons carry momentum p = h * f / c.
- When light hits a surface, photons transfer momentum to the metal.
- More photons or higher frequency → more momentum transfer.
- This effect is the basis for radiation pressure and applications like solar sails.

🌟 19.16: Why can red light be used in a photographic dark room when developing films, but a blue or white light cannot?

❖ Explanation:

1. Photographic Film Sensitivity:

- Photographic films are coated with light-sensitive chemicals (usually silver halides).
- These chemicals react to light and form a latent image which becomes visible after development.
- The film is most sensitive to shorter wavelengths (blue and green light) and less sensitive to longer wavelengths (red light).

2. Red Light in Dark Rooms:

- Red light has longer wavelength and lower energy photons compared to blue or white light.
- **Because of its low energy,** red light does not expose the film significantly, so the film remains safe while being handled in the dark room.

3. Blue or White Light Issue:

- Blue and white light contain higher energy photons.
- These photons can excite the silver halides, causing unintended exposure, which spoils the undeveloped film.

4. Practical Use:

- Photographers use red safelights in dark rooms to allow visibility without affecting the film.
- This principle is based on the energy of photons and the sensitivity of the chemical emulsion.

✦ **Summary:**

- Photographic films are sensitive to high-energy light (blue/white).
- Red light has low energy and does not affect the film significantly.

Therefore, red light is safe in a dark room, while blue or white light can ruin the film.

🌟 **19.17: Photon A has twice the energy of photon B. What is the ratio of the momentum of A to that of B?**

❖ **Explanation:**

1. Relationship Between Energy and Momentum of a Photon:

- A photon is a particle of light that has energy and momentum, even though it has no rest mass.
- Its energy E is related to its frequency f by Planck's relation:

$$E = h * f$$

where h is Planck's constant.

- The momentum p of a photon is related to its energy by:

$$p = E / c$$

where c is the speed of light in vacuum.

2. Given Condition:

- Energy of photon A: $E_A = 2 * E_B$
- Energy of photon B: E_B

3. Calculating Momentum:

- Momentum of photon A:

$p_A = E_A / c = (2 * E_B) / c = 2 * (E_B / c)$

- Momentum of photon B:

$p_B = E_B / c$

4. Finding the Ratio:

$p_A / p_B = [2 * (E_B / c)] / (E_B / c) = 2$

Conclusion:

- Photon A has twice the momentum of photon B.
- Ratio of momenta: $p_A : p_B = 2 : 1$

✦ **Summary:**

- The momentum of a photon depends directly on its energy.
- If the energy of a photon doubles, its momentum also doubles.

Key formulas:

➢ $E = h * f$ → Photon energy

➢ $p = E / c$ → Photon momentum

Practical Understanding: Higher energy photons (like blue or UV light) not only have more energy but also more momentum than lower energy photons (like red light).

🌟 **19.18: Why don't we observe a Compton effect with visible light?**

❖ **Explanation:**

1. Compton Effect Recap:

- The Compton effect occurs when high-energy photons (like X-rays or gamma rays) collide with loosely bound electrons in a material.
- **During this collision**, some energy and momentum of the photon are transferred to the electron, causing the photon to scatter with a longer wavelength.

The change in wavelength is called the Compton shift:

$\Delta\lambda = (h / m_e * c) * (1 - \cos\theta)$

where:

➢ h = Planck's constant

➢ m_e = electron rest mass

➢ c = speed of light

➢ θ = scattering angle

2. Visible Light Characteristics:

- Visible light photons have very low energy compared to X-rays or gamma rays.
- Their wavelengths are much larger than X-ray wavelengths.
- **As a result,** when visible light interacts with electrons, the momentum transfer is extremely small.

4. Why Compton Effect is Not Observed:

- The Compton wavelength shift $\Delta\lambda$ for visible light is negligible—far too small to measure experimentally.
- Visible light primarily interacts with electrons via other phenomena like absorption and scattering (Rayleigh scattering), not the Compton effect.
- Only high-energy photons with short wavelengths (X-rays, gamma rays) produce an observable Compton shift.

Conclusion:

- The Compton effect is not observed with visible light because the photon energy is too low to cause a measurable change in the electron's momentum.

✦ **Summary:**

- **Compton effect:** photon scatters from an electron $\longrightarrow$ wavelength increases.
- **Condition for observable effect:** photon energy must be high (X-rays, gamma rays).
- Visible light: too low energy $\longrightarrow$ Compton shift is negligible, hence no observable effect.

🌟 19.19: Can pair production take place in vacuum? Explain.

❖ Explanation:

1. What is Pair Production?

- Pair production is a process in which a high-energy photon is converted into a particle-antiparticle pair, typically an electron and a positron.
- The photon must have energy greater than or equal to 1.02 MeV, which is twice the rest mass energy of an electron (0.51 MeV each).

2. The basic energy condition is:

Energy of photon = Energy required for pair production + Kinetic energy of the particles

or in plain text:

hf = 2 * m_e * c^2 + K.E.

2. Requirement of a Nucleus or Particle:

- For momentum conservation, the photon cannot just produce the electron-positron pair in empty space.
- A nearby heavy nucleus is required to absorb recoil momentum.
- Without this third body, both energy and momentum cannot be simultaneously conserved.

3. Why Vacuum Alone Cannot Work:

- In a vacuum, there is no particle or nucleus to absorb the recoil.
- Therefore, a photon cannot spontaneously convert into matter in empty space.
- Pair production always occurs near a nucleus or particle to satisfy conservation laws.

Conclusion:

Pair production cannot take place in a vacuum because a photon alone cannot satisfy both energy and momentum conservation without a nearby particle to take up recoil.

✦ **Summary:**

Pair production: photon ⟶ electron + positron.

- Photon energy ≥ 1.02 MeV.
- Requires a nearby nucleus to conserve momentum.
- Cannot occur in vacuum because no particle is available to absorb recoil.

🌟 **19.20: Is it possible to create a single electron from energy? Explain.**

❖ **Explanation:**

1. Energy-Mass Equivalence:

According to Einstein's equation:

E = m * c^2

- energy and mass are equivalent. This allows energy to be converted into matter.

2. Electron Creation Requires Conservation Laws:

- A single electron has charge -e.
- If you try to create only one electron from energy, there is no particle with +e charge to balance the total charge.
- Charge conservation must be obeyed in all physical processes.

3. Practical Consequence:

- **Therefore**, creating a single electron from energy alone is impossible.
- **Instead**, energy can create an electron-positron pair (electron e- and positron e+) because:

➢ Total charge before = 0 (photon has no charge)

➢ Total charge after = (-e) + (+e) = 0 ⟶ charge is conserved.

4. The photon must have energy:

$E_{photon} \geq 2 * m_e * c^2 \approx 1.02$ MeV

- A nearby nucleus or particle is also required to absorb recoil momentum and conserve momentum.

Conclusion:

- A single electron cannot be created from energy alone because of charge conservation.
- Only electron-positron pairs can be created from high-energy photons.

✦ **Summary:**

- E = m * c^2 → energy can convert into mass.
- Single electron creation violates charge conservation.
- Electron-positron pair creation satisfies energy and charge conservation.
- Photon energy must be ≥ 1.02 MeV, and a nucleus is needed to absorb recoil.

🌟 **19.21: If electrons behaved only like particles, what pattern would you expect on the screen after the electrons pass through the double slit?**

❖ **Explanation:**

1. Electron as a Particle:

- If electrons were only particles, each electron would travel along a straight path.
- After passing through the double slit, each electron would hit the screen directly behind the slit it passes through.

2. Expected Pattern on Screen:

- The pattern would be two bright spots corresponding to the two slits.
- There would be no interference fringes (no series of alternating bright and dark bands).

3. Why Interference Requires Wave Nature:

- Interference patterns arise due to superposition of waves.
- Electrons show wave-particle duality, meaning each electron behaves like a wave while passing through both slits simultaneously.
- The wave nature causes constructive interference (bright bands) where waves reinforce each other, and destructive interference (dark bands) where waves cancel out.

4. Classical Particle Expectation:

If only particle behavior exists:

- No superposition ⟶ No interference
- Only direct hits behind slits ⟶ Simple pattern of two bands, similar to classical bullets passing through slits.

✦ **Summary:**

- Electrons are wave-particle dual.
- If electrons behaved only like particles, the double-slit experiment would show:
- Two bright bands on the screen (one for each slit).
- No interference pattern would appear.
- **Observation** of interference confirms the wave nature of electrons.

🌟 **19.22: If an electron and a proton have the same de Broglie wavelength, which particle has greater speed?**

❖ **Explanation:**

1. de Broglie Wavelength Formula:

The de Broglie wavelength of a particle is given by:

$\lambda = h / p$

Where:

- λ is the wavelength
- h is Planck's constant
- p is the momentum of the particle

2. Momentum in Terms of Mass and Velocity:

Momentum p is related to mass m and velocity v as:

$p = m * v$

Substituting in de Broglie formula:

$\lambda = h / (m * v)$

3. Comparing Electron and Proton:

Let $\lambda_e = \lambda_p$ (electron and proton have same wavelength)

Then:

$h / (m_e * v_e) = h / (m_p * v_p)$

Simplifying:

$m_e * v_e = m_p * v_p$

Therefore:

$v_e / v_p = m_p / m_e$

Mass Comparison:

Mass of proton m_p is much greater than mass of electron m_e

So:

$v_e >> v_p$

✅ **Conclusion**: The electron moves much faster than the proton if both have the same de Broglie wavelength.

✦ **Summary:**

- de Broglie wavelength is inversely proportional to momentum: λ = h / (m * v)
- **For same wavelength,** momentum of electron and proton is equal: m_e * v_e = m_p * v_p
- **Since** m_p >> m_e, electrons must have greater velocity.
- Electrons travel much faster than protons for the same de Broglie wavelength.

🌟 **19.23: We do not notice the de Broglie wavelength for a pitched cricket ball. Explain why?**

❖ **Explanation:**

1. de Broglie Wavelength Formula:

The de Broglie wavelength of a particle is:

λ = h / (m * v)

Where:

- λ is the wavelength
- h is Planck's constant (6.63×10^{-34} Js)
- m is mass of the object
- v is velocity of the object

2. Mass and Velocity of a Cricket Ball:

- Mass of cricket ball: $m \approx 0.15$ kg
- Velocity of ball: $v \approx 40$ m/s (typical pitch)

3. Calculate Approximate Wavelength:

$$\lambda = 6.63 \times 10^{-34} / (0.15 * 40)$$

$$= 6.63 \times 10^{-34} / 6$$

$$\approx 1.105 \times 10^{-34} \text{ m}$$

4. Comparison with Observable Scales:

- This wavelength ≈ 10^-34 m is extremely tiny, much smaller than atomic or nuclear scales.
- Human eyes or ordinary instruments cannot detect such tiny wavelengths.

5. Reason We Don't Notice Wave Nature:

- Wave effects like diffraction and interference can only be observed if the wavelength is comparable to the size of obstacles or openings.
- For a cricket ball, the wavelength is so tiny that its wave properties are completely negligible.

Therefore, we observe the cricket ball as a classical particle, not as a wave.

✦ Summary:

- The de Broglie wavelength decreases with increasing mass or speed: $\lambda = h / (m * v)$
- For macroscopic objects like a cricket ball, λ is extremely small ($\approx 10^{-34}$ m)
- Wave effects are not observable at this scale

Hence, the cricket ball behaves purely like a classical particle

🌟 **19.24: If the following particles have the same energy, which has the shortest wavelength? Electron, alpha particle, neutron, proton.**

❖ **Explanation:**

1. de Broglie Wavelength Formula:

The wavelength of a particle is given by:

$\lambda = h / p$

Where:

- λ = de Broglie wavelength
- h = Planck's constant (6.63×10^{-34} Js)
- p = momentum of the particle

2. Relation Between Momentum and Energy:

If all particles have the same kinetic energy E:

$E = p^2 / (2m) \Rightarrow p = \sqrt{2 * m * E}$

Substituting into de Broglie wavelength:

$\lambda = h / \sqrt{2 * m * E}$

3. Effect of Mass on Wavelength:

- From the formula, $\lambda \propto 1 / \sqrt{m}$
- Heavier particles have shorter wavelengths for the same energy.

4. Compare the Masses:

- Electron $m \approx 9.11 \times 10^{-31}$ kg
- Proton $m \approx 1.67 \times 10^{-27}$ kg
- Neutron $m \approx 1.675 \times 10^{-27}$ kg
- Alpha particle $m \approx 6.64 \times 10^{-27}$ kg (4 times proton mass)

The heaviest particle is the alpha particle, so it will have the shortest wavelength.

Answer:

Alpha particle has the shortest de Broglie wavelength.

✦ **Summary:**

- de Broglie wavelength: $\lambda = h / \sqrt{2 * m * E}$
- For same energy, wavelength decreases with increasing mass
- Order of wavelength (longest to shortest): Electron > Proton ≈ Neutron > Alpha particle
- Heavier particles behave more like classical particles with negligible wave effects

🌟 **19.25: When does light behave as a wave? When does it behave as a particle?**

❖ **Explanation:**

1. Wave Nature of Light:

- Light behaves as a wave when it exhibits phenomena such as interference, diffraction, and polarization.
- These effects arise because light can spread out, overlap, and combine, just like waves in water.

Example: Double-slit experiment: When light passes through two narrow slits, it produces a pattern of bright and dark fringes due to interference.

2. Particle Nature of Light:

- Light behaves as a particle when it interacts with matter in discrete quanta called photons.

Each photon carries energy:

$E = h * f$

Where:

- E = energy of photon
- h = Planck's constant (6.63×10^{-34} Js)
- f = frequency of light

Examples of particle behavior:

Photoelectric effect: Electrons are ejected from a metal surface only when incident light has frequency above a threshold, showing quantized energy transfer.

Compton effect: X-ray photons collide with electrons like tiny particles, transferring momentum.

3. Wave-Particle Duality:

- Light exhibits both wave and particle properties depending on the experiment.

The observed property depends on the type of interaction:

➤ Propagation through space ⟶ wave behavior

➤ Interaction with matter ⟶ particle behavior

✦ **Summary:**

- **Wave behavior:** Interference, diffraction, polarization ⟶ light spreads and overlaps like a wave

- **Particle behavior:** Photoelectric effect, Compton scattering → light interacts in discrete energy packets (photons)
- **Light is dual in nature,** and both aspects are complementary. The experiment determines which nature is observed.

🌟 **19.26:What advantages does an electron microscope have over an optical microscope?**

❖ **Explanation:**

1. Resolution:

- The resolving power of view a microscope depends on the wavelength of the waves used for imaging.
- Optical microscope uses visible light with wavelength $\lambda \approx 400–700$ nm.

Electron microscope uses accelerated electrons with de Broglie wavelength:

$\lambda = h / (m * v)$

Where:

➢ h = Planck's constant (6.63×10^{-34} Js)

➢ m = mass of electron

➢ v = velocity of electron

Electron wavelength is much shorter than visible light, giving much higher resolution (up to 0.5–1 nm vs. 0.2 µm for optical microscope).

2. Magnification:

- Electron microscopes can achieve magnifications up to 2 million times, whereas optical microscopes are limited to ~2000×.

3. Depth of Focus:

- Electron microscopes have greater depth of focus, meaning more of the specimen stays in focus at the same time.

4. Observation of Fine Details:

- Electron microscopes allow observation of sub-cellular structures, viruses, and even large molecules, which are impossible to see with optical microscopes.

5. Use of Electromagnetic Lenses:

- Unlike optical microscopes, electron microscopes use electric and magnetic fields to focus electron beams. This enables precise imaging of very tiny structures.

✦ Summary:

- Electron microscope provides much higher resolution and magnification than optical microscopes.
- It allows viewing of very small structures such as organelles, viruses, and molecules.
- Uses electrons instead of light, enabling detection of details not visible with optical microscopes.

Key equation:

$\lambda = h / (m * v)$

- Shorter λ ⟶ higher resolution

🌟 **19.27: If measurements show a precise position for an electron, can those measurements show precise momentum also? Explain.**

❖ **Explanation:**

According to Heisenberg Uncertainty Principle, it is impossible to measure both the position and momentum of a particle precisely at the same time.

Mathematically, the principle is expressed as:

$\Delta x * \Delta p \geq h / (4\pi)$

Where:

- Δx = uncertainty in position
- Δp = uncertainty in momentum
- h = Planck's constant (6.63×10^{-34} Js)

Reason:

- If we try to determine the electron's position very precisely (small Δx), the uncertainty in momentum Δp becomes very large.
- **Conversely**, if momentum is measured precisely (small Δp), the position becomes very uncertain (large Δx).
- This is not due to limitations of instruments but is a fundamental property of nature resulting from the wave-particle duality of matter.

Example:

Using light to locate an electron:

- Short wavelength light ⟶ precise position
- But photon transfers momentum to electron ⟶ momentum becomes uncertain
- Longer wavelength ⟶ momentum more certain, but position less certain

✦ **Summary:**

- Precise position ⟶ uncertain momentum; precise momentum ⟶ uncertain position.

- This principle is crucial in quantum mechanics and explains why atomic-scale phenomena cannot be described using classical physics.

Key equation:

$\Delta x * \Delta p \geq h / (4\pi)$

It emphasizes the inherent limitation in simultaneously knowing the position and momentum of microscopic particles like electrons.

Note:

This chapter is designed to provide a solid foundation of knowledge, with the goal of deepening understanding and encouraging further exploration of the subject. The content has been carefully selected to support effective learning and inspire students to engage with the topic more deeply.

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Purpose: To contribute to education by offering insightful, valuable content that enhances learning and understanding.