Physics · Introduction to Modern Physics · Wave-Particle Duality

Wave Nature of Particles

thanawiya-archive.com

154	3	55
questions	sets	pages

Contents

Multiple choice questions (81 questions) — Questions · p. 2 — Answers · p. 36

Essay questions (21 questions) — Questions · p. 20 — Answers · p. 46

Past exam questions (52 questions) — Questions · p. 24 — Answers · p. 49

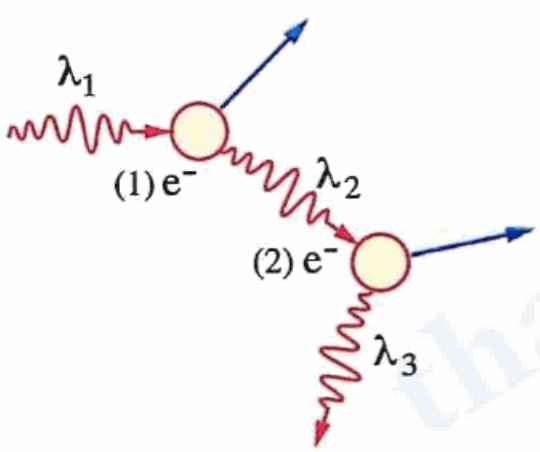
Click a question number to jump to its answer, and an answer number to go back to the question.

Multiple choice questions — 81 questions

1 In the Compton effect, the ratio of the electron's mass before the collision to its mass after the collision is .....

(A) greater than one
(B) less than one
(C) equal to one
(D) determined by the mass of the photon

2 The opposite figure shows an X-ray photon colliding with two free electrons: the photon collides with the first electron, then the scattered photon collides with the second electron. So .....



(A) $\lambda_1 > \lambda_2 > \lambda_3$ (B) $\lambda_1 < \lambda_2 > \lambda_3$ (C) $\lambda_1 > \lambda_2 < \lambda_3$ (D) $\lambda_1 < \lambda_2 < \lambda_3$

3 The Compton effect proves .....

(A) the wave nature of photons
(B) the particle nature of the electron
(C) the particle nature of photons
(D) the wave nature of the electron

4 In the Compton effect, when a high-frequency photon collides with a free electron, which of the following quantities increases for the photon after the collision?

(A) Energy (B) Frequency (C) Wavelength (D) Momentum

5 In the Compton effect, after the collision there is no decrease in .....

(A) the wavelength associated with the electron
(B) the energy of the photon
(C) the frequency of the photon
(D) the speed of the photon

6 In the Compton effect, when an X-ray photon collides with a free electron, which of the following has the lowest speed?

(A) The photon before the collision
(B) The electron before the collision
(C) The photon after the collision
(D) The electron after the collision

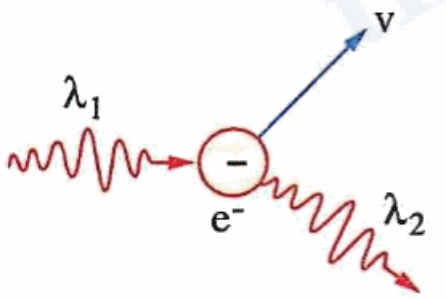
7 In the Compton effect, the ratio of the photon's energy after the collision to its energy before the collision is .....

(A) greater than one
(B) equal to one
(C) less than one
(D) cannot be determined

8 In the Compton effect, if the energy of the incident photon (before the collision) is (E_1), the energy of the scattered photon (after the collision) is (E_2), and the kinetic energy gained by the electron in the collision is (E_3), which of the following relations is correct?

(A) $E_3 = E_1 + E_2$ (B) $E_3 = E_1 - E_2$ (C) $E_3 < E_1 - E_2$ (D) $E_3 > E_1 - E_2$

9 The opposite figure shows the Compton effect, where the photon's energy changes by ΔE. If Planck's constant is h and the speed of light is c, the quantity $hc/(\Delta E)$ equals .....



(A) $(\lambda_2 - \lambda_1)/(\lambda_2 \lambda_1)$
(B) $(\lambda_2 + \lambda_1)/(\lambda_2 \lambda_1)$
(C) $(\lambda_2 \lambda_1)/(\lambda_2 - \lambda_1)$
(D) $(\lambda_2 \lambda_1)/(\lambda_2 + \lambda_1)$

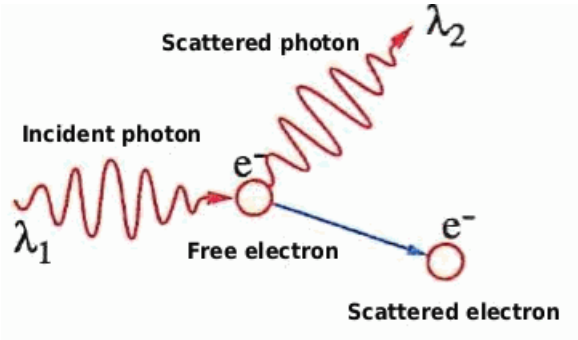
10 In the Compton effect, the greater the difference between the wavelength of the incident photon and that of the scattered photon (other factors constant), the energy gained by the electron .....

(A) increases
(B) decreases
(C) does not change
(D) cannot be determined

11 An X-ray photon of wavelength 7 Å collided with a free electron, and the kinetic energy of the electron increased by 1.853×10^{-18} J. The wavelength of the scattered X-ray photon equals .....

(A) 5.6 Å (B) 7.46 Å (C) 7.046 Å (D) 8.2 Å

12 The opposite figure shows the Compton effect. If the ratio of the wavelength of the incident photon to that of the scattered photon $((\lambda_1)/(\lambda_2))$ is $999/1000$, then after scattering the photon has lost ..... of its energy before the collision.



(A) $1/999$ (B) $1/1000$ (C) $999/1000$ (D) $1000/999$

13 In the Compton effect, if the photon loses x% of its energy in the collision, then .....

(A) the wavelength of the photon increases by x%
(B) the momentum of the photon decreases by x%
(C) the mass of the electron increases by x%
(D) the kinetic energy of the electron decreases by x%

14 The equivalent mass of a photon of electromagnetic radiation of wavelength 100 nm equals .....

(A) 4.42×10^{-31} kg (B) 4.42×10^{-32} kg (C) 2.2×10^{-34} kg (D) 2.21×10^{-35} kg

15 The energy produced when a mass of 1.6749×10^{-27} kg is converted equals .....

(A) 1.7×10^{-10} J (B) 1.5×10^{-10} J (C) 9.1×10^{-31} J (D) 3.4×10^{8} J

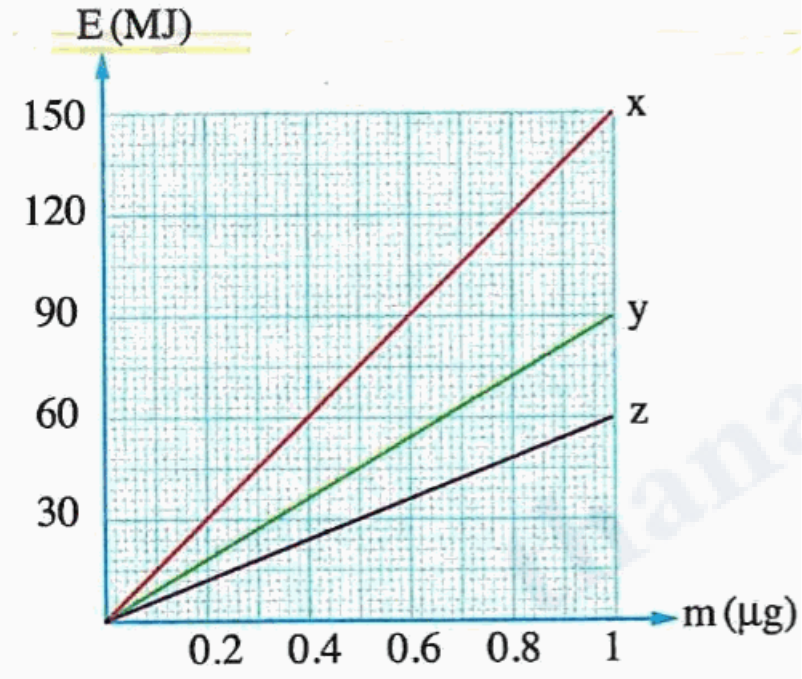
16 One of the properties of the photon is .....

(A) that its speed in vacuum is 3×10^{8} m/s (B) that it can be accelerated
(C) that it is deflected by an electric field (D) all of the above

17 Two photons whose frequencies are in the ratio 1 : 2. The ratio between their energies respectively is .....

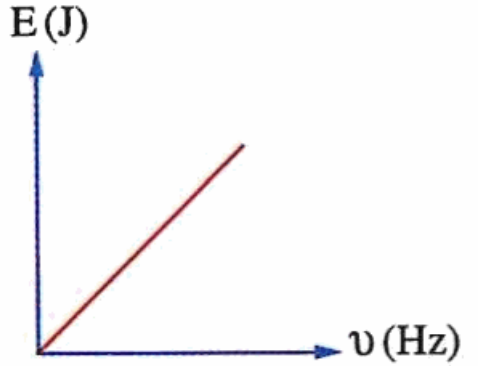
(A) 1 : 1 (B) 1 : 2 (C) 2 : 1 (D) 1 : 4

18 Assuming a mass of 1 μg is gradually converted into energy, which of the lines x, y, z in the opposite graph correctly represents the relation between the energy produced (E) and the mass converted (m)?



(A) Line x (B) Line y (C) Line z (D) All three lines

19 The opposite graph shows the relation between the energy of photons (E) and their frequency (ν). The slope of the straight line equals .....



(A) the wavelength (λ) (B) Planck's constant (h)
(C) the speed of light (c) (D) the momentum (P_L)

20 Assuming a small city uses 10^8 J of energy every second, the mass that must be completely converted into energy in a nuclear reactor to supply the city with energy for one year (365.25 days) equals .....

(A) 0.035 g (B) 0.58 g (C) 1.46 g (D) 35 g

21 A photon has momentum P_L. Its energy equals ..... (where (c) is the speed of light)

(A) $P_L\, c$ (B) $(P_L\, c)/2$ (C) $(P_L{}^2)/2c$ (D) $(P_L\, c)/4$

22 A photon of wavelength λ and frequency ν has a momentum of .....

(A) $h/(\lambda)$ (B) $(h\nu)/(\lambda)$ (C) $hc/(\lambda)$ (D) $(h\nu)/(c^2)$

23 n photons of a monochromatic light beam of wavelength λ fall on a surface. The total energy falling on the surface equals .....

(A) $hc/(n\lambda)$ (B) $(n\lambda)/hc$ (C) $nhc/(\lambda)$ (D) $nc/(\lambda)$

24 The ratio of a photon's momentum to its equivalent mass equals .....

(A) the speed of the photon (B) Planck's constant
(C) the energy of the photon (D) its wavelength

25 If the intensity of a beam of monochromatic light is doubled, the momentum of each photon of this light .....

(A) decreases to half (B) doubles
(C) becomes four times as large (D) does not change

26 A photon from a spectrum has a wavelength of 770 nm:

(1) Its energy equals .....

(A) 2.58×10^{-22} J (B) 2.58×10^{-21} J (C) 2.58×10^{-20} J (D) 2.58×10^{-19} J

27 A photon from a spectrum has a wavelength of 770 nm:

(2) Its equivalent mass while moving equals .....

(A) 2.87×10^{-37} kg (B) 2.87×10^{-36} kg (C) 2.58×10^{-38} kg (D) 2.58×10^{-35} kg

28 A photon from a spectrum has a wavelength of 770 nm:

(3) Its momentum equals .....

(A) 8.6×10^{-28} kg.m/s

(B) 8.6×10^{-29} kg.m/s

(C) 7.7×10^{-30} kg.m/s

(D) 7.7×10^{-29} kg.m/s

29 Two photons (x) and (y) travel in air. Photon (x) has momentum (P_L) and photon (y) has momentum $(2\ P_L)$, so .....

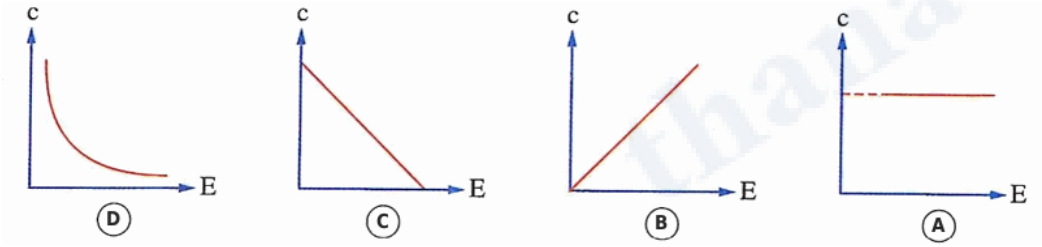
(A) the wavelength of photon (x) is twice that of photon (y)

(B) the wavelength of photon (x) is half that of photon (y)

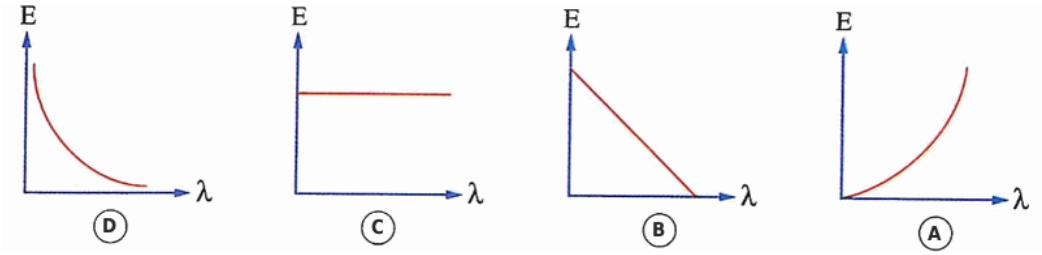
(C) the speed of photon (x) is twice that of photon (y)

(D) the speed of photon (x) is half that of photon (y)

30 Which of the following graphs shows the relation between the speed (c) of photons travelling in air and the energy (E) of each?



31 Which of the following graphs shows the relation between the energy of a photon (E) and its wavelength (λ)?



32 A monochromatic light beam falls on a certain area for a certain time. If the intensity of this beam is doubled so that it falls on the same area for the same time, then .....

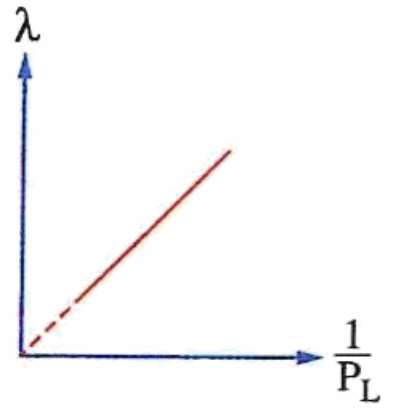
(A) the energy of one photon doubles

(B) the momentum of one photon doubles

(C) the equivalent mass of the photon decreases to half

(D) the number of photons doubles

33 The opposite graph shows the relation between the wavelength (λ) of several light beams and the reciprocal of the momentum $(1/P_L)$ of the photons in each beam. The slope of the straight line equals .....



(A) the speed of light
(B) Planck's constant
(C) the mass of the photon
(D) the frequency of the photon

34 A potential difference was applied to an electron, so its momentum increased by 25%. Its kinetic energy increases by about .....

(A) 65%
(B) 56%
(C) 38%
(D) 25%

35 A light beam whose photons have energy E falls perpendicularly on a reflecting surface. The change in the momentum of the photon when it is reflected equals ..... (where (c) is the speed of light)

(A) E/c
(B) $2E/c$
(C) $2E/(c^2)$
(D) $E/(c^2)$

36 Photons of radiation of wavelength λ fall on a surface. If the spacings between the particles of the surface are about 0.01 λ, most of these photons .....

(A) interfere at the surface
(B) pass straight through the surface
(C) are refracted inside the surface
(D) are reflected from the surface

37 A beam of monochromatic light of wavelength λ fell perpendicularly on a reflecting surface, and the number of photons reflected from the surface per second was φ_L. The force acting on the surface equals .....

(A) $2\ hc/(\lambda)\ \varphi_L$
(B) $2\ (h\lambda)/c\ \varphi_L$
(C) $2\ (\lambda\ c)/h\ \varphi_L$
(D) $2\ h/(\lambda)\ \varphi_L$

38 A monochromatic light beam is reflected perpendicularly from a reflecting surface at a rate of 10^{20} Photon/s, and the surface is acted on by a force of 2×10^{-7} N. The frequency of this light equals .....

(A) 7.2×10^{-16} Hz (B) 2.7×10^{16} Hz (C) 3.75×10^{14} Hz (D) 4.5×10^{14} Hz

39 A yellow light beam of total power 1 W and frequency 5.2×10^{14} Hz is reflected from a surface. The total number of photons reflected from the surface per second equals .....

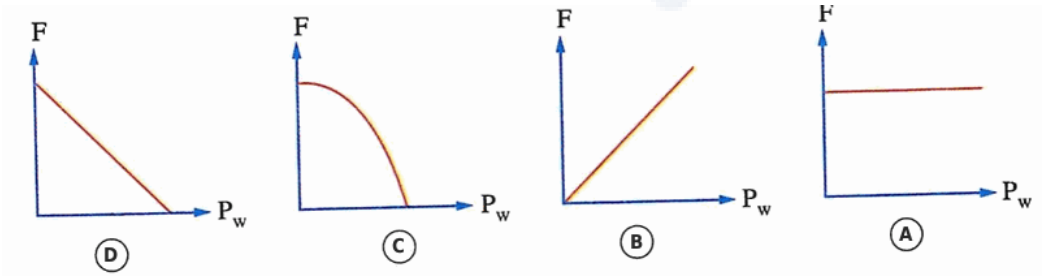
(A) 5.2×10^{20} photons (B) 3.4×10^{19} photons

(C) 2.9×10^{18} photons (D) 6.4×10^{17} photons

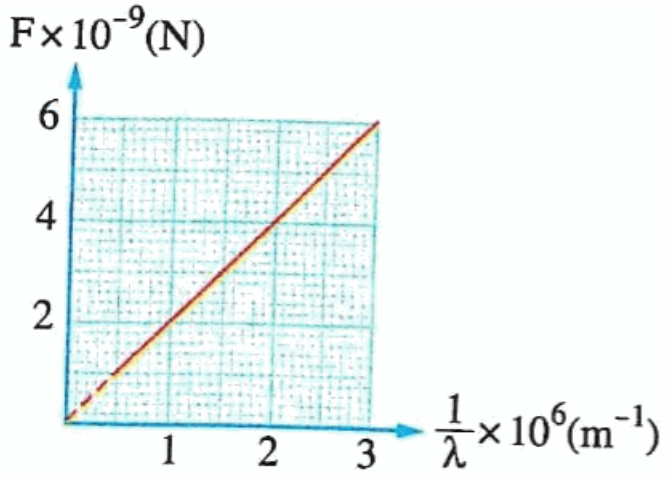
40 Two sources (a) and (b) of powers P_w and $2\ P_w$ emit two monochromatic electromagnetic beams of wavelengths λ and $4\ \lambda$ respectively. The ratio between the numbers of photons emitted by the two sources in the same time (N_a/N_b) equals .....

(A) 8/1 (B) 4/1 (C) 1/8 (D) 1/4

41 Several monochromatic light beams fall perpendicularly on a reflecting surface. Which of the following graphs shows the relation between the force (F) each beam exerts on the surface and the power (P_w) of each?

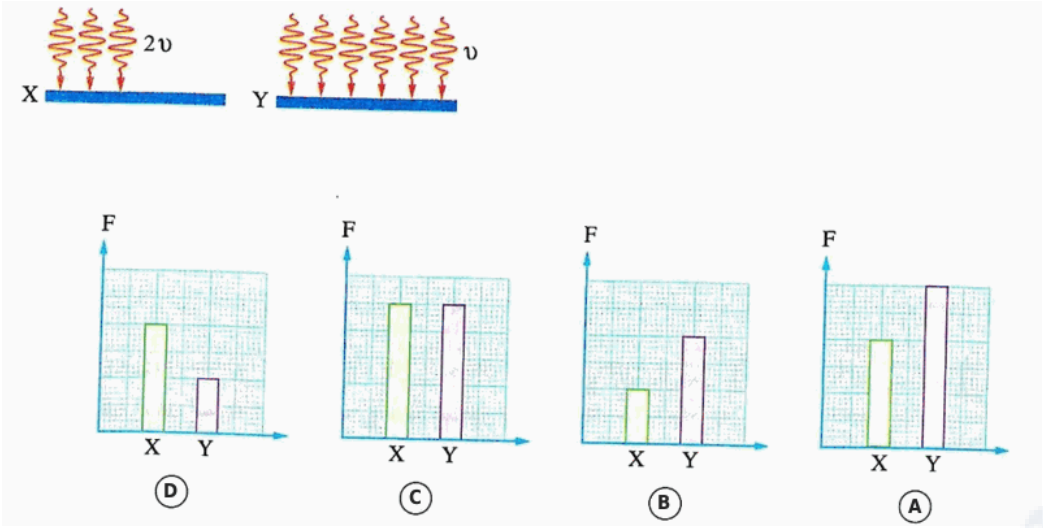


42 Several beams of monochromatic electromagnetic radiation fall perpendicularly at the same rate (φ_L) on a reflecting surface. The opposite graph shows the relation between the force (F) each beam exerts on the surface and the reciprocal of the wavelength $(1/(\lambda))$ of the photons of this beam. The rate at which the photons of any of these beams fall (φ_L) equals .....



(A) 7.5×10^{17} Photon/s
(B) 1.5×10^{18} Photon/s
(C) 3×10^{18} Photon/s
(D) 6×10^{18} Photon/s

43 The opposite figure shows two reflecting surfaces X and Y on which two beams of light of different frequencies but the same power fall. Which of the following figures shows the ratio of the two forces the beams exert on the surfaces when they are reflected?



44 A beam of electromagnetic radiation of power 10 W is reflected perpendicularly from the surface of a reflecting body of mass 10 kg. The force the beam exerts on the surface of the body equals .....

(A) 6.67×10^{-7} N (B) 3.3×10^{-4} N (C) 6.67×10^{-8} N (D) 6.67×10^{-3} N

45 A radio station broadcasts on a wave of frequency 92.4 MHz:

(1) The energy of one photon emitted by this station equals .....

(A) 6.12×10^{-27} J (B) 6.12×10^{-26} J (C) 8.16×10^{-27} J (D) 8.16×10^{-26} J

46 A radio station broadcasts on a wave of frequency 92.4 MHz:

(2) The number of photons emitted per second if the station's power is 100 kW is ..... photons/second.

(A) 1.63×10^{33} (B) 1.63×10^{32} (C) 1.63×10^{30} (D) 1.63×10^{28}

47 Light of wavelength 6000 Å fell on a metal surface, and the incident power was 39.6 W. If only 1% of the incident photons free electrons, the number of electrons freed from the metal surface per second equals .....

(A) 12×10^{16} electrons (B) 1.2×10^{18} electrons

(C) 12×10^{18} electrons (D) 1.2×10^{15} electrons

48 One of the following properties does not apply to the electron .....

(A) it has a wave nature while moving

(B) it has particle properties

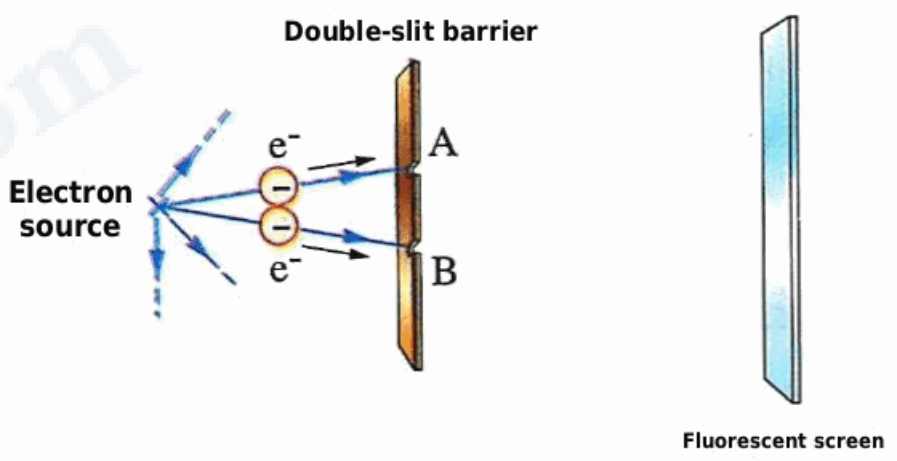
(C) its associated wavelength increases as its speed increases

(D) its kinetic energy increases as its speed increases

49 If the mass of a moving particle is m and the wavelength of the matter wave associated with its motion is λ, the speed of the particle is calculated from the relation .....

(A) $v = h/(m\lambda)$ (B) $v = hm/(\lambda)$ (C) $v = (\lambda)/hm$ (D) $v = 2h/(m\lambda)$

50 When an electron beam is directed at a double slit as in the figure, the fluorescent screen shows .....



(A) a single bright spot in the middle

(B) two bright spots with a dark space between them

(C) several bright spots and several dark ones

(D) a dark central spot surrounded by a bright circle

---

51 A proton and an electron move so that the waves associated with their motion have the same wavelength. Then ..... (given that: mass of proton > mass of electron)

(A) the kinetic energy of the electron is less than that of the proton

(B) the momentum of the proton is greater than that of the electron

(C) the speed of the electron is greater than that of the proton

(D) the speed of the proton is greater than that of the electron

---

52 An electron of mass m_e moves at speed v and the wavelength of the wave associated with its motion is λ. If the speed of the electron decreases to $v/2$, the wavelength of the wave associated with its motion becomes .....

(A) 4 λ (B) 2 λ (C) $(\lambda)/2$ (D) $(\lambda)/4$

---

53 If the de Broglie wavelength associated with the motion of a particle of mass m is λ, the kinetic energy of the particle equals ..... (where (h) is Planck's constant)

(A) $(2mh^2)/(\lambda^2)$ (B) $(\lambda^2)/(2mh^2)$ (C) $h/(2m\lambda)$ (D) $(h^2)/(2m\lambda^2)$

---

54 Light of wavelength 4500 Å fell on a metal surface whose work function is 3.36×10^{-19} J:

(1) The maximum speed of the emitted electrons equals .....

(A) 1.22×10^{5} m/s (B) 2.34×10^{5} m/s (C) 3.75×10^{5} m/s (D) 4.82×10^{5} m/s

---

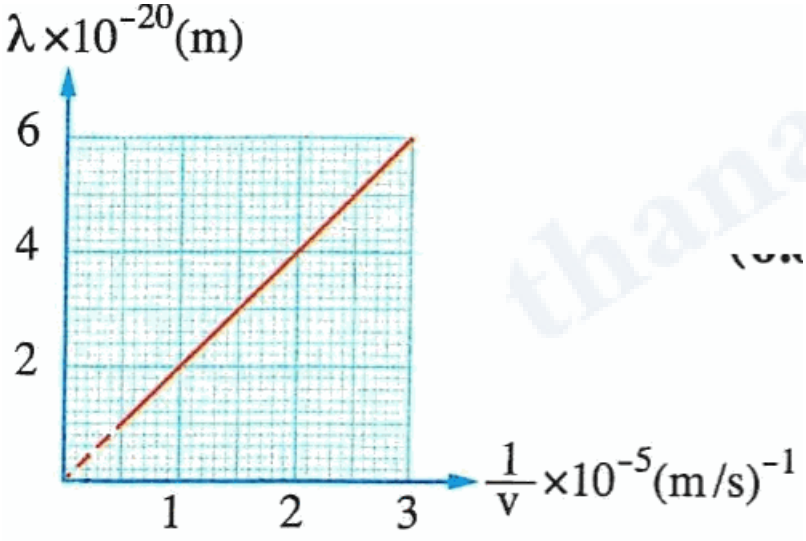
55 Light of wavelength 4500 Å fell on a metal surface whose work function is 3.36×10^{-19} J:

(2) The wavelength of the wave associated with the motion of the fastest photoelectrons emitted from the metal surface equals .....

(A) 1.5×10^{-9} m (B) 2.3×10^{-9} m (C) 5.8×10^{-9} m (D) 7.2×10^{-9} m

---

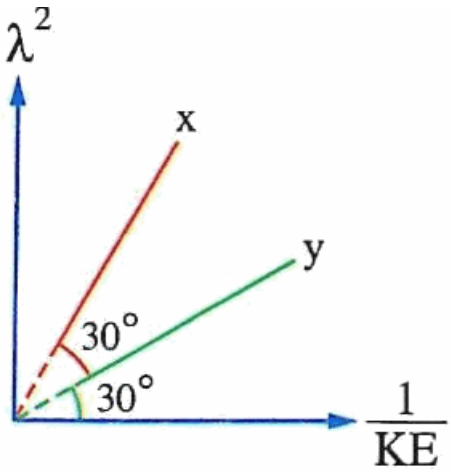
56 The opposite graph shows the relation between the de Broglie wavelength associated with the motion of a particle (λ) and the reciprocal of the particle's speed $(1/v)$. The mass of this particle equals ..... (given that: Planck's constant = 6.6×10^{-34} J.s)



(A) 1.3×10^{-19} kg (B) 2.3×10^{-19} kg (C) 3.3×10^{-19} kg (D) 4.3×10^{-19} kg

---

57 The opposite graph shows the relation between the square of the wavelength (λ^2) of the matter wave associated with the motion of two particles x and y and the reciprocal of their kinetic energy $(1/KE)$. The ratio between the masses of the two particles (m_x/m_y) equals .....



(A) $1/3$ (B) $1/(\sqrt{3})$ (C) $3/1$ (D) $(\sqrt{3})/1$

58 The speed at which an electron must move so that a wave of wavelength 1 Å is associated with its motion is .....

(A) 7.28×10^6 m/s (B) 2×10^7 m/s (C) 6.25×10^6 m/s (D) 1.37×10^7 m/s

59 An insect moves at 12 m/s. If the wavelength of the wave associated with the insect's motion is 5.5×10^{-30} m, the mass of this insect is .....

(A) 10^{-4} kg (B) 1.2×10^{-4} kg (C) 2×10^{-5} kg (D) 10^{-5} kg

60 A body of mass 10 kg moves at 5 m/s. The wavelength of the wave associated with its motion equals .....

(A) 1.325×10^{-30} m (B) 1.325×10^{-32} m
(C) 1.325×10^{-35} m (D) 1.325×10^{-36} m

61 Two bodies x and y have masses m and 2 m and speeds v and 4 v respectively. If the wavelength of the wave associated with the motion of body x is λ, the wavelength of the wave associated with the motion of body y equals .....

(A) 8 λ (B) 6 λ (C) $(\lambda)/6$ (D) $(\lambda)/8$

62 Two bodies have the same kinetic energy. If the wavelength of the wave associated with the motion of the first body is twice that of the second body, the relation between the masses of the two bodies m_1 and m_2 is .....

(A) $m_2 = m_1/4$ (B) $m_2 = m_1/2$ (C) $m_2 = 2\,m_1$ (D) $m_2 = 4\,m_1$

63 A proton $(_1{}^1H)$ and an alpha particle $(_2{}^4He)$ move at the same speed. Given that the mass of the alpha particle is four times the mass of the proton, the ratio between the wavelengths of the waves associated with their motion (proton to alpha) equals .....

(A) *1/2* (B) *2/1* (C) *1/4* (D) *4/1*

64 The opposite table gives the masses of three hypothetical particles A, B and C that have the same kind and amount of charge. Assuming the three particles were accelerated through the same potential difference:

(1) The ratio between the kinetic energies these particles gain respectively is .....

Mass (in kilograms)	Particle
m	A
9 m	B
27 m	C

(A) 27 : 9 : 1 (B) 1 : 9 : 27 (C) 1 : 1 : 1 (D) 9 : 3 : 1

65 The opposite table gives the masses of three hypothetical particles A, B and C that have the same kind and amount of charge. Assuming the three particles were accelerated through the same potential difference:

(2) The particle with the largest associated wavelength is .....

Mass (in kilograms)	Particle
m	A
9 m	B
27 m	C

(A) A (B) B

(C) C (D) cannot be determined

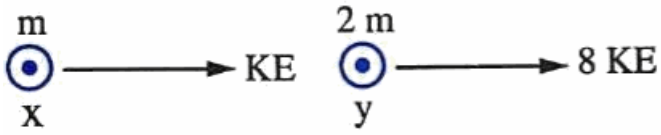
66 If an electron at rest is accelerated through a potential difference of 2500 V, what is its maximum speed?

(A) 3×10^7 m/s (B) 2.5×10^8 m/s (C) 2.5×10^6 m/s (D) 1.5×10^8 m/s

67 If the kinetic energy of a particle becomes 16 times as large, the percentage change in its de Broglie wavelength is .....

(A) 25% (B) 50% (C) 60% (D) 75%

68 The opposite figure shows two bodies x and y that differ in mass and kinetic energy. The ratio of the wavelengths of the matter waves associated with the motion of the two bodies $((\lambda_x)/(\lambda_y))$ is .....



(A) 4/1 (B) 1/4 (C) 1/1 (D) 1/3

69 In a cathode ray tube, when the potential difference between the anode and the cathode is 700 V, the wavelength of the wave associated with the fastest electrons when they reach the anode equals .....

(A) 1.2×10^{-11} m (B) 2.3×10^{-11} m (C) 4.6×10^{-11} m (D) 6.4×10^{-11} m

70 In the electron microscope, the component that focuses the electron beam is .....

(A) the anode (B) the cathode

(C) the filament (D) the magnetic lenses

---

71 In the electron microscope, which of the following choices gives the sequence of results that happen when the potential difference between the anode and the cathode is increased?

(A) Kinetic energy of the electrons: increases, wavelength associated with the electron: increases, resolving power of the microscope: increases

(B) Kinetic energy of the electrons: increases, wavelength associated with the electron: decreases, resolving power of the microscope: decreases

(C) Kinetic energy of the electrons: increases, wavelength associated with the electron: decreases, resolving power of the microscope: increases

(D) Kinetic energy of the electrons: decreases, wavelength associated with the electron: decreases, resolving power of the microscope: decreases

---

72 If the wavelength needed in an electron microscope to observe a particle is 1 Å:

(1) The maximum speed of the electrons used equals .....

(A) 7.28×10^6 m/s (B) 7.28×10^7 m/s (C) 3.28×10^5 m/s (D) 3.28×10^4 m/s

---

73 If the wavelength needed in an electron microscope to observe a particle is 1 Å:

(2) The potential difference between the anode and the cathode is about .....

(A) 662 V (B) 325 V (C) 442 V (D) 151 V

---

74 If a potential difference of 500 V is used between the anode and the cathode of an electron microscope, the de Broglie wavelength associated with the electron beam equals .....

(A) 1.1×10^{-10} m (B) 5.49×10^{-11} m (C) 7.76×10^{-11} m (D) 4.14×10^{-12} m

---

75 When an electron in an electron microscope is subjected to a potential difference of 20 kV:

(1) Its speed as it passes through the anode equals .....

(A) 59.3×10^6 m/s (B) 83.9×10^6 m/s (C) 2.7×10^7 m/s (D) 7×10^7 m/s

---

76 When an electron in an electron microscope is subjected to a potential difference of 20 kV:

(2) The wavelength associated with its motion equals .....

(A) 1.04×10^{-19} m (B) 1.04×10^{-16} m (C) 8.68×10^{-12} m (D) 2.7×10^{-10} m

77 An electron microscope was used to examine a particle twice: the first time with a potential difference of 16 kV and the second time with 25 kV. The ratio between the maximum speeds of the electrons in the two times $(((v_{max})_1)/((v_{max})_2))$ equals .....

(A) *3/4* (B) *2/3* (C) *4/5* (D) *5/7*

78 An electron microscope was used to examine a particle twice. The first time a potential difference (V_1) was used and the momentum of the fastest electrons was (P_L); the second time a potential difference (V_2) was used and the momentum of the fastest electrons was $(4\ P_L)$. The ratio between the potential differences (V_1/V_2) equals .....

(A) *1/2* (B) *1/4* (C) *1/16* (D) *16/1*

79 In the electron microscope, three different potential differences 9 V, 4 V and V were used. The ratio between:

(1) the maximum kinetic energies of the electrons in the three cases respectively equals .....

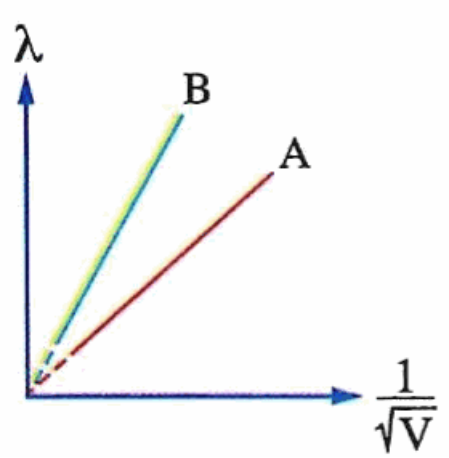
(A) 9 : 4 : 1 (B) 3 : 2 : 1 (C) √(3) : √(2) : 1 (D) 1 : 4 : 9

80 In the electron microscope, three different potential differences 9 V, 4 V and V were used. The ratio between:

(2) the wavelengths of the waves associated with the motion of the electrons in the three cases respectively equals .....

(A) 9 : 4 : 1 (B) 2 : 3 : 6 (C) √(3) : √(2) : 1 (D) 3 : 2 : 1

81 Two particles A and B with the same charge are accelerated through a potential difference V. The opposite graph shows the relation between the wavelength (λ) associated with the motion of the two particles and the reciprocal of the square root of the accelerating voltage $(1/(\sqrt{(V)}))$. The relation between the masses of the two particles is .....



(A) $m_A > m_B$

(B) $m_A < m_B$

(C) $m_A = m_B$

(D) cannot be determined

Essay questions — 21 questions

1 In the Compton effect, what happens to each of the following physical quantities after the collision compared with its value before the collision:

(1) the speed of the photon?

(2) the wavelength of the photon?

(3) the momentum of the photon?

(4) the energy of the photon?

(5) the equivalent mass of the photon?

(6) the energy of the electron?

(7) the momentum of the electron?

(8) the wavelength of the wave associated with the motion of the electron?

(9) the mass of the electron?

2 Explain how the Compton effect proves the particle nature of light (of photons).

3 Part of a mass of 10 g was converted in a nuclear reaction into energy of 9×10^{12} J. What is the remaining mass?

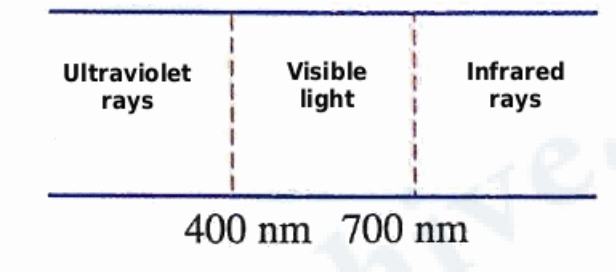
4 A star radiates energy into space at a rate of 4.5×10^{25} J/s. Calculate the mass the star loses in one minute.

5 The momentum of one photon of a monochromatic electromagnetic radiation equals the momentum of an electron moving at 2×10^{5} m/s. Calculate the wavelength of this radiation.

6 Use the opposite figure to find the region of the electromagnetic spectrum of the photon whose:

(1) frequency is 4×10^{15} Hz

(2) equivalent mass is 4×10^{-36} kg



7 Two bodies a and b: the kinetic energy of body a is four times that of body b, and the ratio of the wavelengths of the waves associated with their motion respectively is $2/1$. Find the ratio between the masses of the two bodies (m_a/m_b).

8 A photon of equivalent mass $3.2 \times 10^{-36}\ kg$ fell on a metal surface whose work function is 1.6 eV, as in the opposite figure:

(1) Show whether electrons are emitted from this surface, giving the reason.

(2) What is the equivalent mass of the photon falling on the surface so that an electron with a maximum kinetic energy of 1.6 eV is emitted from it?

9 What happens when photons fall on a surface whose interatomic spacings are smaller than the wavelength of the photons?

10 What happens when photons fall on a surface whose interatomic spacings are larger than the wavelength of the photons?

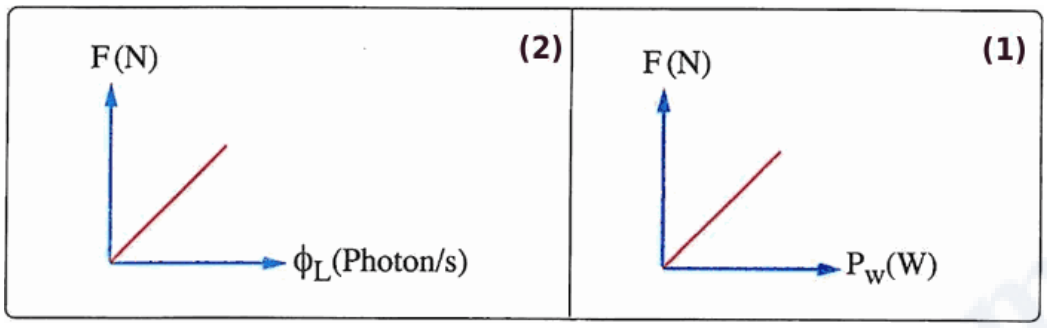
11 A beam of monochromatic electromagnetic radiation of power 200 W, whose photons have a wavelength of $8 \times 10^{-7}\ m$, fell perpendicularly on a reflecting surface. Calculate:

(1) the momentum of one photon of this beam.

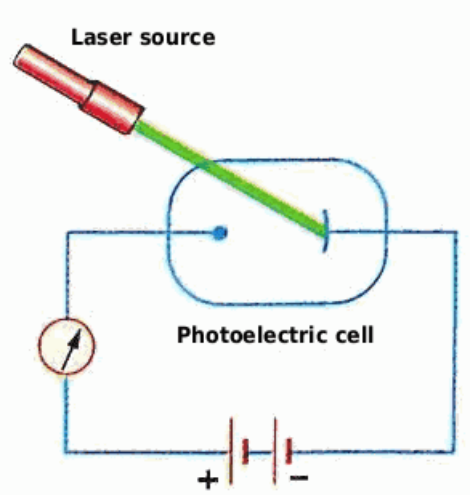
(2) the force the beam exerted on the surface when it was reflected.

12 Write the mathematical relation shown by each graph and what the slope of the straight line equals, for each of the following:

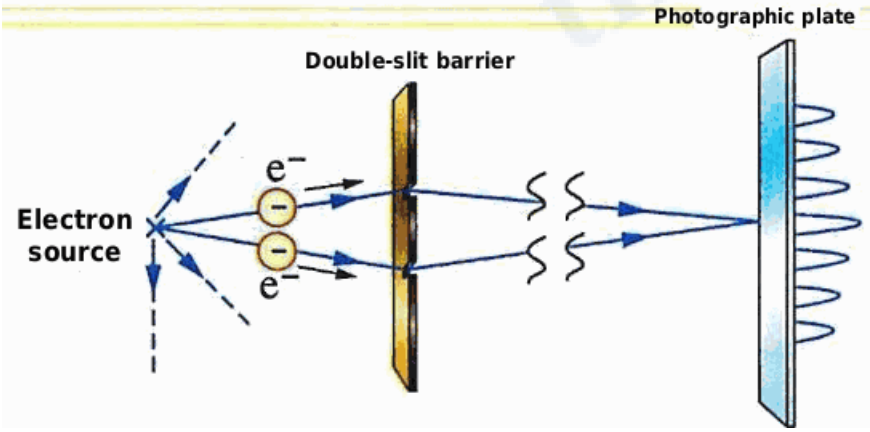
where: (F) is the force a light beam exerts on a reflecting surface, (P_w) the power of the light beam, (φ_L) the rate at which the photons fall.



13 The opposite figure shows a photocell whose cathode is hit by a laser beam of wavelength 550 nm and power 0.2 mW. If the longest wavelength needed to emit electrons from this cathode is greater than 550 nm, and assuming every incident photon emits an electron and all the freed electrons reach the anode, calculate the maximum photoelectric current in the circuit.



14 The opposite figure shows an electron beam falling on a photographic plate after passing through a double slit. Explain why what the electron beam forms on the photographic plate supports the wave theory of particles.



15 Monochromatic electromagnetic radiation whose photon energy is 4 eV falls on the cathode of a photocell whose work function is 2 eV. Calculate the shortest wavelength of the wave associated with the freed electron.

16 A free electron is accelerated from rest by a potential difference of 1000 V. Calculate the de Broglie wavelength associated with the motion of this electron when it reaches the anode.

17 Compare: the electron and the photon (in terms of: nature - rest mass - momentum - whether it can be accelerated).

18 What is the condition for seeing the details of the structure of a tiny object with a microscope?

19 Explain why the optical microscope cannot show the details of the corona virus.

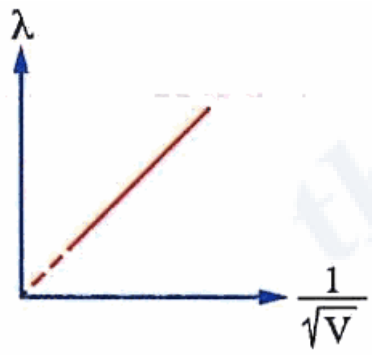
20 When the potential difference between the anode and the cathode of an electron microscope is increased, what happens, with explanation, to:

(1) the maximum kinetic energy of the electrons that reach the anode?

(2) the wavelength of the wave associated with the motion of the electrons?

(3) the resolving power of the microscope?

21 The opposite graph shows the relation between the wavelength (λ) associated with the electron beam in the electron microscope and the square root of the reciprocal of the potential difference between the anode and the cathode $(1/(\sqrt{V}))$. What quantity does the slope of the line represent?



Past exam questions — 52 questions

1 In the Compton effect, when a gamma-ray photon collides with an electron moving at speed v, ... (Trial exam / June 2021)

(A) momentum of the scattered photon: increases, momentum of the electron after the collision: increases

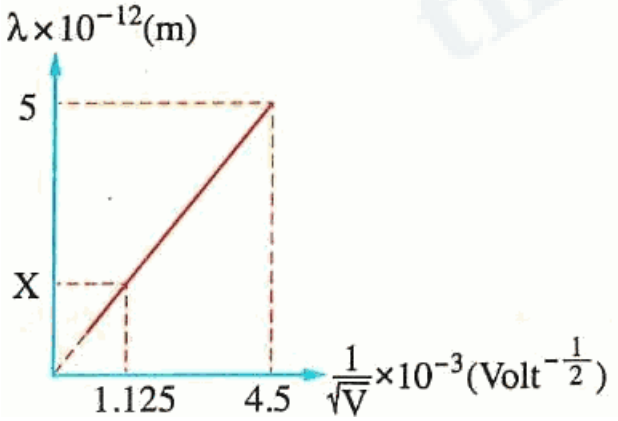
(B) momentum of the scattered photon: decreases, momentum of the electron after the collision: decreases

(C) momentum of the scattered photon: decreases, momentum of the electron after the collision: increases

(D) momentum of the scattered photon: increases, momentum of the electron after the collision: decreases

---

2 The opposite graph shows the relation between the wavelength of the wave associated with the motion of the electrons leaving the filament in a cathode ray tube at the moment they reach the anode, and the reciprocal of the square root of the potential difference used in the tube. The value of point (X) on the graph is ..... (Trial exam / June 2021)

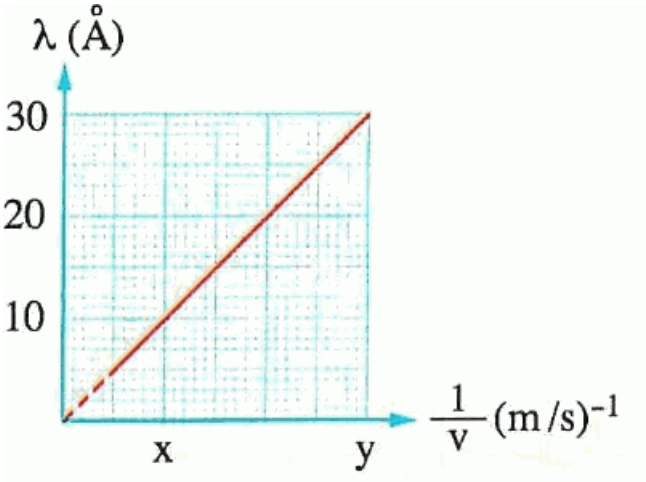


(A) $1.25 \times 10^{-12}\ m$ (B) $2.5 \times 10^{-12}\ m$ (C) $2 \times 10^{-11}\ m$ (D) $1.5 \times 10^{-11}\ m$

---

3 The opposite graph shows the relation between the wavelength (λ) of the matter wave associated with the motion of electrons emitted from a cathode and the reciprocal of their speed $(1/v)$. The ratio of the electron's speed at point x to its speed at point y equals ..... (Trial exam / June 2021)

$(h = 6.625 \times 10^{-34}\ J.s\ ,\ m_e = 9.1 \times 10^{-31}\ kg)$



(A) 9/1 (B) 1/9 (C) 3/1 (D) 1/3

---

4 An electron microscope is used to examine two different viruses (x) and (y). Given that the size of virus (x) is 1 nm and the size of virus (y) is 4 nm, the ratio of the potential difference between the anode and the cathode needed to see virus (x) to that needed to see virus (y) equals ..... (Trial exam / June 2021)

(A) 16 (B) 8 (C) 4 (D) 2

---

5 In the Compton effect, when a gamma-ray photon collides with an electron moving at speed (v), ... (1st session 2021)

(A) wavelength of the photon: decreases, mass of the electron: does not change

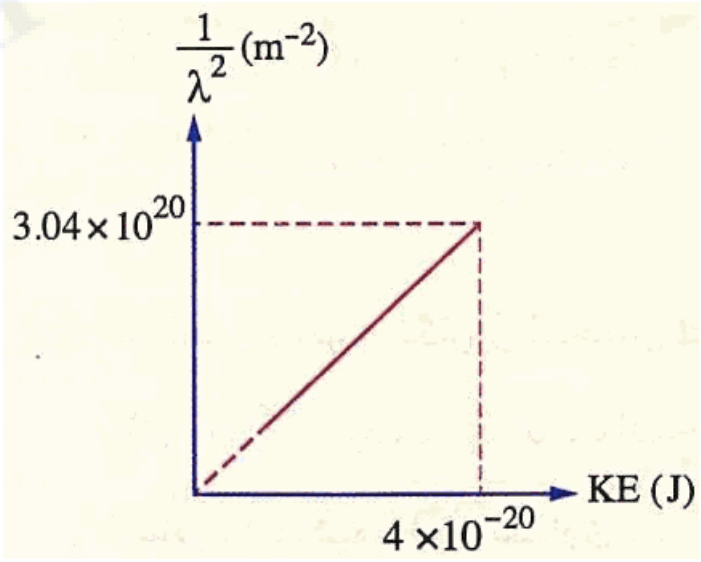
(B) wavelength of the photon: decreases, mass of the electron: decreases

(C) wavelength of the photon: increases, mass of the electron: does not change

(D) wavelength of the photon: decreases, mass of the electron: increases

---

6 The opposite graph shows the relation between the reciprocal of the square of the wavelength $(1/(\lambda^2))$ associated with the motion of a particle and the kinetic energy of this particle (KE). Using the graph, the mass of the moving particle equals ..... kg (1st session 2021)



(A) 1.67×10^{-27} (B) 3.33×10^{-27} (C) 7.6×10^{-39} (D) 3.8×10^{-39}

---

7 A body of mass 140 kg moves so that the wavelength of the wave associated with its motion is 1.8×10^{-34} m. Given that Planck's constant is 6.625×10^{-34} J.s, the speed of the body equals ..... (1st session 2021)

(A) 2.629×10^{-3} m/s (B) 2.269×10^{-3} m/s

(C) 0.26×10^{-3} m/s (D) 26.29×10^{-3} m/s

---

8 In the electron microscope, when the potential difference between the cathode and the anode is increased from 25 kV to 100 kV, the wavelength associated with the motion of the electron beam ..... (1st session 2021)

(A) decreases to half (B) doubles

(C) decreases to a quarter (D) becomes four times as large

---

9 In the Compton effect, when an X-ray photon collides with an electron moving at speed (v), ... (2nd session 2021)

(A) speed of the electron after the collision: increases, equivalent mass of the photon after the collision: increases

(B) speed of the electron after the collision: increases, equivalent mass of the photon after the collision: decreases

(C) speed of the electron after the collision: decreases, equivalent mass of the photon after the collision: decreases

(D) speed of the electron after the collision: decreases, equivalent mass of the photon after the collision: increases

---

10 Assuming the speed of an electron of mass $9.1 \times 10^{-31}\ kg$ equals the speed of a proton of mass $1.67 \times 10^{-27}\ kg$, the wavelength associated with the motion of the electron is about ..... the wavelength associated with the motion of the proton. (2nd session 2021)

(A) 545 times (B) 1545 times (C) 1835 times (D) 835 times

---

11 Given that the energy of the photon used in the optical microscope is $496.88 \times 10^{-21}\ J$ and the momentum of the electron in the electron beam used in the electron microscope is $7.626 \times 10^{-23}\ kg.m.s^{-1}$, a particle of size 400 nm can be seen with ..... (2nd session 2021)

(A) the optical microscope only (B) the optical and the electron microscope

(C) the electron microscope only (D) the eye only

---

12 An electron microscope is used to examine two different viruses (A) and (B), and the results were recorded as in the table:

Virus A: size (diameter) 10 nm, potential difference needed to see it 1.5 kV

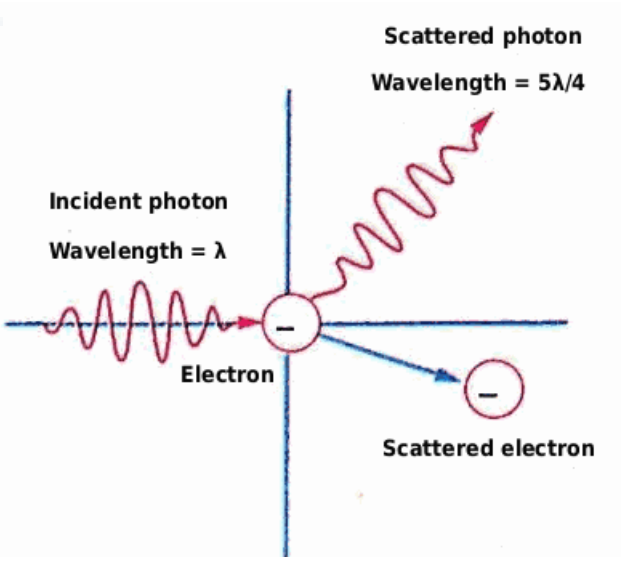
Virus B: size (diameter) X, potential difference needed to see it 37.5 kV

The value of (X) equals ..... (2nd session 2021)

(A) 1 nm (B) 0.4 nm (C) 0.8 nm (D) 2 nm

---

13 An X-ray photon collides with a free electron, and the data of the incident and scattered photons are shown in the figure. So the incident photon lost ..... of its original energy in the collision. (1st session 2022)



(A) $2/5$ (B) $3/5$ (C) $1/5$ (D) $4/5$

14 A moving photon has an equivalent mass of 3.68×10^{-38} kg. Its wavelength equals ..... (1st session 2022)

(A) $40\ \mu m$ (B) $50\ \mu m$ (C) $30\ \mu m$ (D) $60\ \mu m$

15 Photon x has a wavelength of 320 nm and photon y has a wavelength of 240 nm. The ratio of the momentum of photon x to that of photon y $((P_L)_x)/((P_L)_y)$ equals ..... (1st session 2022)

(A) $4/3$ (B) $3/4$ (C) $4/1$ (D) $3/1$

16 An electron microscope is used to see a virus of size X using a potential difference V. If the virus is replaced by another of size $1/10X$, the potential difference must be increased by ..... (1st session 2022)

(A) 100 V (B) 9 V (C) 99 V (D) 10 V

17 In the Compton effect, it was observed that when a gamma-ray photon of wavelength (λ) fell on a free electron, the photon lost $(1/4)$ of its energy. The wavelength of the scattered photon becomes ..... (2nd session 2022)

(A) 4λ (B) $4/3\lambda$ (C) $3/2\lambda$ (D) 2λ

18 Photon (x) has a frequency of 9.375×10^{14} Hz and photon (y) has a frequency of 1.25×10^{15} Hz. The ratio of the momentum of photon (x) to that of photon (y) $((P_L)_x)/((P_L)_y)$ equals ..... (2nd session 2022)

(A) 4/3 (B) 4/1 (C) 3/1 (D) 3/4

19 A moving photon has a frequency of 7.9×10^{11} kHz. Its equivalent mass = ... (2nd session 2022)

(A) 5.82×10^{-39} kg (B) 1.74×10^{-27} kg (C) 5.82×10^{-36} kg (D) 1.74×10^{-30} kg

20 In the electron microscope, the ratio of the maximum speed of the electrons when a potential difference of 60 kV is used to their maximum speed when 20 kV is used is ..... (2nd session 2022)

(A) $1/(\sqrt{3})$ (B) $\sqrt{3}$ (C) 3 (D) 1/3

21 In the Compton effect, when a gamma-ray photon collides with a free electron, which of the following choices is correct for the photon as a result of the collision? (Trial exam 2023)

(A) its momentum: decreases, its wavelength: constant

(B) its momentum: increases, its wavelength: decreases

(C) its momentum: decreases, its wavelength: increases

(D) its momentum: increases, its wavelength: increases

22 Two photons X and Y travel in vacuum. If the frequency of photon X is greater than that of photon Y, which of the following choices is correct? (Trial exam 2023)

(A) The speed of photon X is less than that of photon Y

(B) The energy of photon X is less than that of photon Y

(C) The wavelength of photon X is greater than that of photon Y

(D) The momentum of photon X is greater than that of photon Y

23 If red light has the longest wavelength in the visible spectrum, which of the following choices is correct for red light photons compared with the other photons of visible light? (Trial exam 2023)

(A) Their frequency has the largest value (B) Their energy has the largest value

(C) Their momentum has the smallest value (D) Their speed in air has the largest value

24 The resolving power of the electron microscope is high because the accelerated electrons have ..... (Trial exam 2023)

(A) a high kinetic energy and a short associated wavelength

(B) a high kinetic energy and a long associated wavelength

(C) a low kinetic energy and a short associated wavelength

(D) a low kinetic energy and a long associated wavelength

---

25 A photon from a spectrum has a frequency of 4.2×10^{14} Hz. The momentum of the photon equals ..... (1st session 2023)

(A) 9.275×10^{-26} kg.m/s (B) 9.275×10^{-28} kg.m/s

(C) 9.275×10^{-30} kg.m/s (D) 9.275×10^{-24} kg.m/s

---

26 Two cathode ray tubes work at potential differences of 2000 V and 8000 V, and the wavelengths of the waves associated with the electrons in them are λ_1 and λ_2 respectively. The ratio $(\lambda_1)/(\lambda_2)$ equals ..... (1st session 2023)

(A) 2/1 (B) 4/1 (C) 6/1 (D) 8/1

---

27 A potential difference (V) was used in an electron microscope to see a virus of size 20 nm. To see another virus of size 15 nm, the potential difference used must be ..... (1st session 2023)

(A) increased by 0.78 V (B) decreased by 0.78 V

(C) increased by 0.5 V (D) decreased by 0.5 V

---

28 If a proton moves at 3×10^6 m/s, the wavelength of the wave associated with its motion equals ..... (2nd session 2023)

(given that: $m_p = 1.67 \times 10^{-27}$ kg)

(A) 1.32×10^{-13} m (B) 7.5×10^{-14} m (C) 1.32×10^{-10} m (D) 7.5×10^{-10} m

---

29 An X-ray photon of wavelength 4×10^{-9} m collided with an electron at rest and lost 0.1% of its energy. The wavelength of the scattered photon after the collision equals ..... (2nd session 2023)

(A) 3.996×10^{-9} m (B) 4.002×10^{-9} m (C) 4.004×10^{-9} m (D) 4.008×10^{-9} m

---

30 In an electron microscope, a potential difference was used to give the electrons a speed of 1.8×10^{7} *m/s* in order to see a virus 300 Å long. Given that Planck's constant is 6.625×10^{-34} *J.s* and the mass of the electron is 9.1×10^{-31} *kg*, ... (2nd session 2023)

(A) seeing the virus with the microscope: not possible, wavelength associated with the electron beam: 0.4 Å

(B) seeing the virus with the microscope: possible, wavelength associated with the electron beam: 0.4 Å

(C) seeing the virus with the microscope: possible, wavelength associated with the electron beam: 4 Å

(D) seeing the virus with the microscope: not possible, wavelength associated with the electron beam: 4 Å

---

31 A photon has energy hυ. Its momentum and its wavelength are ..... (1st session 2024)
(given that: h is Planck's constant, υ is the frequency of the photon)

(A) momentum: *(hupsilon)/c*, wavelength: *(upsilon)/c*

(B) momentum: *(hupsilon)/c*, wavelength: *c/(upsilon)*

(C) momentum: *c/(hupsilon)*, wavelength: *(upsilon)/c*

(D) momentum: *c/(hupsilon)*, wavelength: *c/(upsilon)*

---

32 When an optical microscope is used to see an object of size X, the smallest momentum of a photon in the light beam used can be ..... (1st session 2024)

(A) *h/3X* (B) *h/X* (C) *3h/X* (D) *X/h*

---

33 Photons fall perpendicularly on a reflecting surface at a rate φ_L. If the energy of one photon is hυ, the change in the momentum of the photon when it is reflected equals ..... (2nd session 2024)

(A) *2h/(upsilon)* (B) *(hupsilon)/2c* (C) *(hupsilon)/c* (D) *(2hupsilon)/c*

---

34 A photon has an energy of 1.77×10^{3} *eV*. Its momentum is ..... (2nd session 2024)

(A) 9.44×10^{-25} *kg.m/s* (B) 9.44×10^{-15} *kg.m/s*

(C) 5.9×10^{-6} *kg.m/s* (D) 8.496×10^{-8} *kg.m/s*

---

35 A photon of frequency (υ) fell on a metal surface whose critical frequency is *((upsilon)/2)*, and an electron was freed with speed v. When another photon of frequency (2υ) falls on the same metal surface, the speed of the freed electron in the second case = ... (2nd session 2024)

(A) $\sqrt{(5)}\ v$ (B) $\sqrt{(3)}\ v$ (C) $2\ v$ (D) $\sqrt{(6)}\ v$

36 If a potential difference of 300 V is used between the anode and the cathode in the electron microscope, the values of ..... (2nd session 2024)

(A) maximum speed of the emitted electrons: $1.027 \times 10^7\ m/s$, associated wavelength: 7.09 Å

(B) maximum speed of the emitted electrons: $1.027 \times 10^7\ m/s$, associated wavelength: 0.07 nm

(C) maximum speed of the emitted electrons: $1 \times 10^8\ m/s$, associated wavelength: 0.07 Å

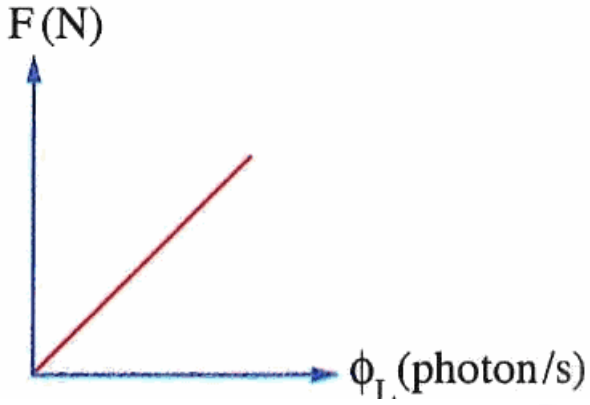
(D) maximum speed of the emitted electrons: $1 \times 10^8\ m/s$, associated wavelength: 7.09 nm

37 After a photon collides with a free electron in the Compton effect, the quantity that decreases is ..... (Sample exam 2025)

(A) the speed of the electron (B) the energy of the electron

(C) the speed of the photon (D) the frequency of the photon

38 A beam of monochromatic light falls perpendicularly on a reflecting surface. The opposite graph shows the relation between the force (F) the beam exerts on the surface when it is reflected and the rate at which the photons of the beam fall on the surface (φ_L). The slope of the line represents ..... (Sample exam 2025)



(A) the energy of the photon (B) the frequency of the photon

(C) twice the momentum of the photon (D) half the momentum of the photon

39 A photon has an energy of 4 eV. The equivalent mass of the photon equals ..... (Sample exam 2025)

(A) $9.22 \times 10^{-36}\ kg$ (B) $8.33 \times 10^{-36}\ kg$ (C) $7.11 \times 10^{-36}\ kg$ (D) $5.44 \times 10^{-36}\ kg$

40 A light beam falling on a shiny surface causes on the surface ..... (Sample exam 2025)

(A) a force only
(B) a pressure only
(C) a force and a pressure
(D) neither a force nor a pressure

41 If the kinetic energy of a particle becomes 16 times as large, the percentage change in its de Broglie wavelength is ..... (Sample exam 2025)

(A) 25 % (B) 50 % (C) 75 % (D) 100 %

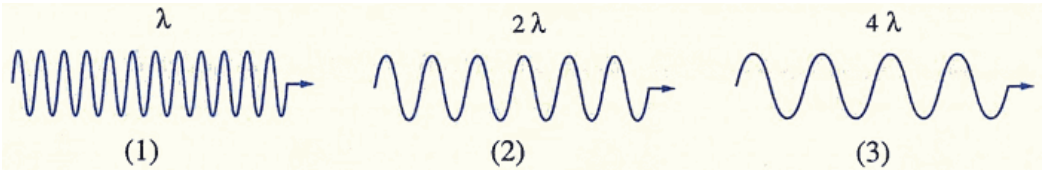
42 The idea of how the electron microscope works depends on ..... (Sample exam 2025)

(A) the wave nature of electrons
(B) the particle nature of electrons
(C) the wave nature of photons
(D) the particle nature of photons

43 When a beam of photons, each of momentum X, falls perpendicularly on a reflecting surface at a rate of Y photons / second, the force acting on the surface equals ..... (Sample exam 2025)

(A) XY (B) 4 XY (C) 2 XY (D) 0.5 XY

44 The figure shows three photons (1), (2) and (3), each labelled with its wavelength. If the energy of photon (3) is 3 eV, the energy of photon (1) is greater than that of photon (2) by ..... (Sample exam 2025)



(A) 6 eV (B) 4 eV (C) 8 eV (D) 9 eV

45 In the Compton effect, why does the wavelength associated with an X-ray photon increase when it collides with a free electron? (1st session 2025)

(A) The photon gains some of the electron's energy

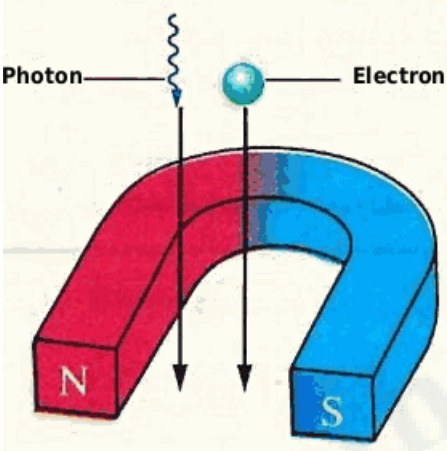
(B) The photon loses some of its energy to the electron

(C) The photon's speed decreases because of its collision with the electron

(D) The photon's momentum increases because of its collision with the electron

---

46 Assume that an electron and a photon move in a straight line into the region between the poles of a magnet as in the figure. What happens to the path of each? (1st session 2025)



(A) electron: is deflected from its straight path, photon: is deflected from its straight path

(B) electron: continues in its straight path, photon: is deflected from its straight path

(C) electron: is deflected from its straight path, photon: continues in its straight path

(D) electron: continues in its straight path, photon: continues in its straight path

---

47 If the electrons in an electron microscope are accelerated until their energy reaches $10^4\ eV$, what is the shortest wavelength of the wave associated with the electrons used? (1st session 2025)

(A) 12 Å (B) 0.012 Å (C) 1.2 Å (D) 0.12 Å

---

48 A gamma-ray photon of wavelength (λ_1) collided with a free electron whose motion is associated with a wave of wavelength (λ_2), and both were scattered. Then ..... (2nd session 2025)

(A) wavelength of the photon (λ_1): increases, wavelength associated with the electron (λ_2): increases

(B) wavelength of the photon (λ_1): decreases, wavelength associated with the electron (λ_2): decreases

(C) wavelength of the photon (λ_1): increases, wavelength associated with the electron (λ_2): decreases

(D) wavelength of the photon (λ_1): decreases, wavelength associated with the electron (λ_2): increases

---

49 Two photons A and B have wavelengths of 800 nm and 200 nm respectively. The ratio between the momenta of the two photons $((P_L)_A)/((P_L)_B)$ equals ..... (2nd session 2025)

(A) *1/4* (B) *4/1* (C) *1/2* (D) *1/1*

---

50 In the electron microscope, when the potential difference used to accelerate the electron beam is increased from (X) to (4X), the wavelength associated with the electron beam ..... (2nd session 2025)

(A) decreases to a quarter (B) becomes 4 times as large

(C) decreases to half (D) doubles

---

51 A light beam of power 10 W of monochromatic light of wavelength 4500 Å falls on a metal surface and photoelectrons are emitted from it. Assuming every photon falling on the surface emits an electron, calculate the rate of photoelectrons emitted from the metal surface. (2nd session 2023)

---

52 A radio station of power 100 kW broadcasts on a wave of frequency 92.4 MHz. If Planck's constant is 6.625×10^{-34} *J.s*, calculate: (Sample exam 2025)

(1) the energy of one photon it emits.

(2) the number of photons emitted per second.

Answer key and solutions

Multiple choice questions

1 C	2 D	3 C	4 C	5 D	6 B	7 C	8 B	9 C	10 A
11 C	12 B	13 B	14 D	15 B	16 A	17 B	18 B	19 B	20 D
21 A	22 A	23 C	24 A	25 D	26 D	27 B	28 A	29 A	30 A
31 D	32 D	33 B	34 B	35 B	36 D	37 D	38 D	39 C	40 C
41 B	42 B	43 C	44 C	45 B	46 C	47 B	48 C	49 A	50 C
51 C	52 B	53 D	54 D	55 A	56 C	57 A	58 A	59 D	60 C
61 D	62 D	63 D	64 C	65 A	66 A	67 D	68 A	69 C	70 D
71 C	72 A	73 D	74 B	75 B	76 C	77 C	78 C	79 A	80 B
81 A									

1 **Answer (C)**

The mass of the electron does not change in the collision,

so the ratio of its mass before the collision to its mass after it equals one.

2 **Answer (D)**

In each collision the photon loses part of its energy,

so its wavelength increases.

$\lambda_1 < \lambda_2 < \lambda_3$

3 **Answer (C)**

The Compton effect treats the photon as a particle with energy and momentum,

so it proves the particle nature of photons.

4 **Answer (C)**

The photon loses energy to the electron, so its energy, frequency and momentum decrease, and its wavelength increases.

5 **Answer (D)**

The speed of the photon in vacuum is constant (c),
so it does not decrease after the collision.

6 **Answer (B)**

The free electron is at rest before the collision, so its speed is zero,
and the photon's speed is always c,
so the electron before the collision has the lowest speed.

7 **Answer (C)**

The scattered photon loses part of its energy,
so the ratio of its energy after the collision to before it is less than one.

8 **Answer (B)**

Conservation of energy:

$E_1 = E_2 + E_3$

$E_3 = E_1 - E_2$

9 **Answer (C)**

$\Delta E = hc/(\lambda_1) - hc/(\lambda_2) = (hc(\lambda_2 - \lambda_1))/(\lambda_1\lambda_2)$

$hc/(\Delta E) = (\lambda_1\lambda_2)/(\lambda_2 - \lambda_1)$

10 **Answer (A)**

The energy gained by the electron:

$\Delta E = hc(1/(\lambda_1) - 1/(\lambda_2))$

The greater the difference between the two wavelengths, the greater the energy.

11 **Answer (C)**

$E_1 = hc/(\lambda_1) = (6.625 \times 10^{-34} \times 3 \times 10^8)/(7 \times 10^{-10}) = 2.84 \times 10^{-16}\ J$

$E_2 = E_1 - 1.853 \times 10^{-18} = 2.82 \times 10^{-16}\ J$

$\lambda_2 = hc/E_2 = 7.046\ mathringA$

12 **Answer (B)**

$E_2/E_1 = (\lambda_1)/(\lambda_2) = 999/1000$

The photon lost $1/1000$ of its energy.

13 **Answer (B)**

The momentum of the photon is proportional to its energy:

$p = E/c$

So if it loses $x\%$ of its energy, its momentum decreases by $x\%$.

14 **Answer (D)**

$m = E/(c^2) = h/(\lambda c)$

$m = (6.625 \times 10^{-34})/(10^{-7} \times 3 \times 10^8) = 2.2 \times 10^{-35}\ kg$

15 **Answer (B)**

$E = mc^2 = 1.6749 \times 10^{-27} \times 9 \times 10^{16}$

$E = 1.5 \times 10^{-10}\ J$

16 **Answer (A)**

The photon's speed in vacuum is $3 \times 10^8\ m/s$,

and it cannot be accelerated or deflected by an electric field because it is neutral.

17 **Answer (B)**

$E = h\nu$

so the ratio between the energies equals the ratio between the frequencies.

18 **Answer (B)**

$E = mc^2 = 10^{-9} \times 9 \times 10^{16} = 9 \times 10^7\ J = 90\ MJ$

which is line y.

19 **Answer (B)**

$E = h\nu$

The slope of the straight line (E against ν) equals Planck's constant h.

20 **Answer (D)**

$E = P \cdot t = 10^8 \times 365.25 \times 86400 = 3.156 \times 10^{15}\ J$

$m = E/(c^2) = (3.156 \times 10^{15})/(9 \times 10^{16}) = 0.035\ kg = 35\ g$

21 **Answer (A)**

$P_L = E/c$

$E = P_L\, c$

22 **Answer (A)**

$P_L = h/(\lambda)$

23 **Answer (C)**

The energy of one photon is $hc/(\lambda)$, and the total energy of n photons:

$E = nhc/(\lambda)$

24 **Answer (A)**

$P_L/m = (E/c)/(E/c^2) = c$

which is the speed of the photon.

25 **Answer (D)**

The intensity of the beam depends on the number of photons,

and the momentum of each photon $h/(\lambda)$ stays constant because λ is constant.

26 **Answer (D)**

$E = hc/(\lambda) = (6.625\times10^{-34}\times3\times10^{8})/(770\times10^{-9})$

$E = 2.58\times10^{-19}\ J$

27 **Answer (B)**

$m = E/(c^2) = (2.58\times10^{-19})/(9\times10^{16})$

$m = 2.87\times10^{-36}\ kg$

28 **Answer (A)**

$P_L = h/(\lambda) = (6.625\times10^{-34})/(770\times10^{-9})$

$P_L = 8.6\times10^{-28}\ kg\cdot m/s$

29 **Answer (A)**

$\lambda = h/P_L$

The momentum of y is twice that of x, so its wavelength is half that of x,

which means the wavelength of photon x is twice that of y.

30 **Answer (A)**

The speed of photons in air is constant (c),
so it does not depend on the energy.

31 **Answer (D)**

$E = hc/(\lambda)$
An inverse relation: the graph is a hyperbola.

32 **Answer (D)**

Doubling the intensity means doubling the number of photons per second,
while the energy and momentum of one photon stay constant.

33 **Answer (B)**

$\lambda = h \cdot 1/P_L$
The slope of the line equals Planck's constant h.

34 **Answer (B)**

$KE = (P^2)/2m$, so it is proportional to the square of the momentum.
$(KE')/KE = (1.25)^2 = 1.5625$
It increases by about 56%.

35 **Answer (B)**

The change in momentum on perpendicular reflection:
$\Delta P = P - (-P) = 2P = 2E/c$

36 **Answer (D)**

The wavelengths of the photons are much larger than the spacings between the particles,
so the photon sees the surface as one whole and is reflected from it.

37 **Answer (D)**

Force = rate of change of momentum:
$F = 2\,h/(\lambda)\,\varphi_L$

38 **Answer (D)**

$F = 2\,h/(\lambda)\,\varphi_L$
$\lambda = (2h\varphi_L)/F = (2 \times 6.625 \times 10^{-34} \times 10^{20})/(2 \times 10^{-7}) = 6.625 \times 10^{-7}\ m$
$\nu = c/(\lambda) = 4.5 \times 10^{14}\ Hz$

39 **Answer (C)**

The number of photons per second:

$n = P/(h\nu) = 1/(6.625\times10^{-34}\times5.2\times10^{14})$

$n = 2.9\times10^{18}$

40 **Answer (C)**

The number of photons:

$N = (P\lambda)/hc$

$N_a/N_b = (P\lambda)/(2P\times4\lambda) = 1/8$

41 **Answer (B)**

The force on the surface:

$F = 2P_w/c$

A direct linear relation through the origin.

42 **Answer (B)**

$F = 2\,\varphi_L\, h{\cdot}1/(\lambda)$

$slope = (6\times10^{-9})/(3\times10^{6}) = 2\times10^{-15}$

$\varphi_L = (2\times10^{-15})/(2\times6.625\times10^{-34}) = 1.5\times10^{18}\ Photon/s$

43 **Answer (C)**

For the same power and total reflection:

$F = 2P_w/c$

The force does not depend on the frequency,

so the two forces are equal.

44 **Answer (C)**

$F = 2P_w/c = (2\times10)/(3\times10^{8})$

$F = 6.67\times10^{-8}\ N$

45 **Answer (B)**

$E = h\nu = 6.625\times10^{-34}\times92.4\times10^{6}$

$E = 6.12\times10^{-26}\ J$

46 **Answer (C)**

$n = P/E = (10^{5})/(6.12\times10^{-26})$

$n = 1.63\times10^{30}\ photon/s$

47 **Answer (B)**

The number of photons of the beam per second:

$n = (P\lambda)/hc = (39.6 \times 6000 \times 10^{-10})/(6.625 \times 10^{-34} \times 3 \times 10^{8}) = 1.2 \times 10^{20}$

Only 1% of them freed electrons:

1.2×10^{18}

48 **Answer (C)**

The de Broglie wavelength $\lambda = h/mv$

decreases as the speed increases, it does not increase.

49 **Answer (A)**

$\lambda = h/mv$

$v = h/(m\lambda)$

50 **Answer (C)**

Electrons have a wave nature, so they interfere,

and bright and dark spots appear.

51 **Answer (C)**

The same wavelength means the same momentum p.

$v = p/m$, so the lighter one (the electron) is faster.

52 **Answer (B)**

$\lambda = h/mv$: an inverse relation.

At half the speed the wavelength doubles: 2λ

53 **Answer (D)**

$KE = (P^2)/2m$ and $P = h/(\lambda)$

$KE = (h^2)/(2m\lambda^2)$

54 **Answer (D)**

$E = hc/(\lambda) = (6.625 \times 10^{-34} \times 3 \times 10^{8})/(4500 \times 10^{-10}) = 4.417 \times 10^{-19}\ J$

$KE = 4.417 \times 10^{-19} - 3.36 \times 10^{-19} = 1.057 \times 10^{-19}\ J$

$v = \sqrt{(2KE/m)} = 4.82 \times 10^{5}\ m/s$

55 **Answer (A)**

$\lambda = h/mv = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 4.82 \times 10^{5})$

$\lambda = 1.5 \times 10^{-9}\ m$

56 **Answer (C)**

$\lambda = h/m \cdot 1/v$

$slope = (6\times10^{-20})/(3\times10^{-5}) = 2\times10^{-15} = h/m$

$m = (6.6\times10^{-34})/(2\times10^{-15}) = 3.3\times10^{-19}\ kg$

57 **Answer (A)**

$\lambda^2 = (h^2)/2m \cdot 1/KE$

The slope is inversely proportional to the mass:

$m_x/m_y = fractan30°tan60° = 1/3$

58 **Answer (A)**

$v = h/(m\lambda) = (6.625\times10^{-34})/(9.1\times10^{-31}\times10^{-10})$

$v = 7.28\times10^{6}\ m/s$

59 **Answer (D)**

$m = h/(v\lambda) = (6.625\times10^{-34})/(12\times5.5\times10^{-30})$

$m = 10^{-5}\ kg$

60 **Answer (C)**

$\lambda = h/mv = (6.625\times10^{-34})/(10\times5)$

$\lambda = 1.325\times10^{-35}\ m$

61 **Answer (D)**

$\lambda \propto 1/mv$

$(\lambda_y)/(\lambda_x) = mv/(2m\times4v) = 1/8$

$\lambda_y = (\lambda)/8$

62 **Answer (D)**

$KE = (h^2)/(2m\lambda^2)$, so the two energies are equal when $m\lambda^2$ is the same.

$\lambda_1 = 2\lambda_2 \Rightarrow m_2 = 4m_1$

63 **Answer (D)**

$\lambda = h/mv$ and the speed is the same.

The mass of the alpha particle is 4 times that of the proton.

$(\lambda_p)/(\lambda_\alpha) = 4/1$

64 **Answer (C)**

$KE = qV$, with the same charge and potential difference,
so the energy is the same for the three: $1 : 1 : 1$

65 **Answer (A)**

$\lambda = h/(\sqrt{(2mqV)})$
The smaller the mass, the larger the wavelength,
so A (the smallest mass) has the largest wavelength.

66 **Answer (A)**

$v = \sqrt{(2eV/m)} = \sqrt{((2 \times 1.6 \times 10^{-19} \times 2500)/(9.1 \times 10^{-31}))}$
$v = 3 \times 10^{7}\ m/s$

67 **Answer (D)**

$KE = (P^2)/2m$, so if it becomes 16 times as large, P becomes 4 times as large.
$\lambda = h/P$ becomes $1/4$, which means it decreases by 75%.

68 **Answer (A)**

$P = \sqrt{(2m\ KE)}$
$P_x = \sqrt{(2m\ KE)}$ and $P_y = \sqrt{(2(2m)(8KE))} = 4P_x$
$(\lambda_x)/(\lambda_y) = P_y/P_x = 4/1$

69 **Answer (C)**

$\lambda = h/(\sqrt{(2meV)})$
$\lambda = (12.27 \times 10^{-10})/(\sqrt{(700)}) = 4.6 \times 10^{-11}\ m$

70 **Answer (D)**

The magnetic lenses focus the electron beam in the electron microscope,
and they work like the lenses of the optical microscope.

71 **Answer (C)**

Increasing the potential difference increases the kinetic energy of the electrons,
so the wavelength $\lambda = h/(\sqrt{(2meV)})$ decreases,
and the resolving power increases.

72 **Answer (A)**

$v = h/(m\lambda) = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 10^{-10})$
$v = 7.28 \times 10^{6}\ m/s$

73 **Answer (D)**

$V = (h^2)/(2em\lambda^2)$

$V = (frac12.27\lambda(mathringA))^2 = 150.6\ V$

74 **Answer (B)**

$\lambda = (12.27\times10^{-10})/(\sqrt{(V)}) = (12.27\times10^{-10})/(\sqrt{(500)})$

$\lambda = 5.49\times10^{-11}\ m$

75 **Answer (B)**

$v = \sqrt{(2eV/m)} = \sqrt{((2\times1.6\times10^{-19}\times20000)/(9.1\times10^{-31}))}$

$v = 83.9\times10^{6}\ m/s$

76 **Answer (C)**

$\lambda = h/mv = (6.625\times10^{-34})/(9.1\times10^{-31}\times83.9\times10^{6})$

$\lambda = 8.68\times10^{-12}\ m$

77 **Answer (C)**

$v \propto \sqrt{(V)}$

$v_1/v_2 = \sqrt{(16/25)} = 4/5$

78 **Answer (C)**

$P = \sqrt{(2meV)}$, so $V \propto P^2$

$V_1/V_2 = (P_L/4P_L)^2 = 1/16$

79 **Answer (A)**

$KE = eV$: a direct relation.

$9V : 4V : V = 9 : 4 : 1$

80 **Answer (B)**

$\lambda \propto 1/(\sqrt{(V)})$

$1/3 : 1/2 : 1 = 2 : 3 : 6$

81 **Answer (A)**

$\lambda = h/(\sqrt{(2mqV)})$

The slope $= h/(\sqrt{(2mq)})$ increases as the mass decreases.

The slope of B is larger, so its mass is smaller: $m_A > m_B$

Essay questions

1 **Model answer**

(1) Stays constant.
(2) Increases.
(3) Decreases.
(4) Decreases.
(5) Decreases.
(6) Increases.
(7) Increases.
(8) Decreases.
(9) Stays constant.

2 **Model answer**

The Compton effect shows that when a photon collides with an electron it gives it momentum. According to the law of conservation of momentum, the photon must have momentum, speed and an equivalent mass, which are properties of particles. This proves the particle nature of light.

3 **Model answer**

$m = E/(c^2) = (9 \times 10^{12})/((3 \times 10^8)^2) = 10^{-4}\ kg = 0.1\ g$

Remaining mass = 10 − 0.1 = 9.9 g

4 **Model answer**

The mass converted into energy per second:

$m = E/(c^2) = (4.5 \times 10^{25})/((3 \times 10^8)^2) = 5 \times 10^8\ kg$

The mass converted into energy in one minute:

$M = 5 \times 10^8 \times 60 = 3 \times 10^{10}\ kg$

5 **Model answer**

$(P_L)_{ph} = (P_L)_e : h/(\lambda_{ph}) = m_e\ v_e$

$\lambda_{ph} = h/(m_e\ v_e) = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 2 \times 10^5) = 3.64 \times 10^{-9}\ m = 3.64\ nm$

6 **Model answer**

(1) $\lambda = c/(upsilon) = (3 \times 10^8)/(4 \times 10^{15}) = 7.5 \times 10^{-8}\ m = 75\ nm$

The photon belongs to the ultraviolet region.

(2) $E = mc^2 = 4 \times 10^{-36} \times (3 \times 10^8)^2 = 3.6 \times 10^{-19}\ J$

$\lambda = hc/E = (6.625 \times 10^{-34} \times 3 \times 10^8)/(3.6 \times 10^{-19}) = 5.52 \times 10^{-7}\ m = 552\ nm$

The photon belongs to the visible light region.

7 **Model answer**

$\lambda = h/mv : (\lambda_a)/(\lambda_b) = (m_b\ v_b)/(m_a\ v_a) = 2/1$, so $v_b/v_a = 2m_a/m_b$

$(KE)_a = 4(KE)_b : (m_b\ v_b^2)/(m_a\ v_a^2) = 1/4$

Substituting: $(m_b\ (2m_a)^2)/(m_a\ m_b^2) = 1/4$, so $m_a/m_b = 1/16$

8 **Model answer**

(1) $E_{ph} = mc^2 = 3.2 \times 10^{-36} \times (3 \times 10^8)^2 = 2.88 \times 10^{-19}\ J = 1.8\ eV$

Since $E_{ph} > E_w$, electrons are emitted from the surface.

(2) $E_{ph} = E_w + KE = (1.6 + 1.6) \times 1.6 \times 10^{-19} = 5.12 \times 10^{-19}\ J$

$m = E/(c^2) = (5.12 \times 10^{-19})/((3 \times 10^8)^2) = 5.69 \times 10^{-36}\ kg$

9 **Model answer**

The photons are reflected from the surface, because their wavelength is larger than the spacings between the atoms of the surface, so they treat it as a continuous surface and are reflected from it.

10 **Model answer**

The incident photons pass through the spacings, because their wavelength is smaller than the spacings between the atoms of the surface.

11 **Model answer**

(1) $P_L = h/(\lambda) = (6.625 \times 10^{-34})/(8 \times 10^{-7}) = 8.28 \times 10^{-28}\ kg.m/s$

(2) $F = 2P_w/c = (2 \times 200)/(3 \times 10^8) = 1.33 \times 10^{-6}\ N$

12 **Model answer**

(1) The relation: $F = 2P_w/c$, the slope: $(\Delta F)/(\Delta P_w) = 2/c$

(2) The relation: $F = (2hupsilon)/c\varphi_L$, the slope: $(\Delta F)/(\Delta \varphi_L) = (2hupsilon)/c = 2P_L$

13 **Model answer**

$\varphi_L = (P_w \lambda)/hc = (0.2 \times 10^{-3} \times 550 \times 10^{-9})/(6.625 \times 10^{-34} \times 3 \times 10^8) = 5.53 \times 10^{14}$ *photon/s*

Every photon emits an electron, so the rate at which electrons reach the anode is $\varphi_e = 5.53 \times 10^{14}$ *electron/s*

$I = \varphi_e e = 5.53 \times 10^{14} \times 1.6 \times 10^{-19} = 8.848 \times 10^{-5}$ *A*

14 **Model answer**

When an electron beam falls on a double slit, it is diffracted at each slit, then the two electron beams from the double slit interfere on the photographic plate and form interference fringes. These two properties (interference and diffraction) are properties of waves, which proves the wave nature of electrons and supports the wave theory of particles.

15 **Model answer**

$1/2 m_e v^2 = E - E_w$

$v = \sqrt{((2(E - E_w))/m_e)} = \sqrt{((2 \times (4 - 2) \times 1.6 \times 10^{-19})/(9.1 \times 10^{-31}))} = 8.39 \times 10^5$ *m/s*

$\lambda = h/(m_e v) = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 8.39 \times 10^5) = 8.68 \times 10^{-10}$ *m* = *8.68 AA*

16 **Model answer**

$v = \sqrt{(2eV/m_e)} = \sqrt{((2 \times 1.6 \times 10^{-19} \times 1000)/(9.1 \times 10^{-31}))} = 1.88 \times 10^7$ *m/s*

$\lambda = h/(m_e v) = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 1.88 \times 10^7) = 3.87 \times 10^{-11}$ *m* = *0.387 AA*

17 **Model answer**

Nature: the electron is a material particle that has a wave nature; the photon is a quantum of energy (a particle of light).

Rest mass: the electron has a rest mass; the photon has no rest mass.

Momentum: the electron $P = mv$; the photon $P_L = h/(\lambda)$

Acceleration: the electron can be accelerated by a potential difference; the photon cannot be accelerated (its speed is constant, c).

18 **Model answer**

The wavelength associated with the beam used in the microscope must be smaller than the dimensions of the tiny object.

19 **Model answer**

To see the details of a particle, the wavelength of the rays falling on it must be smaller than its dimensions, and the wavelength of visible light is larger than the dimensions of the virus.

20 **Model answer**

(1) The maximum kinetic energy of the electrons increases, according to the relation $KE = 1/2m_e v^2 = eV$

(2) The wavelength of the wave associated with the motion of the electrons decreases, according to de Broglie's relation $\lambda = h/(m_e v)$, because the speed of the electrons increases with the potential difference.

(3) The resolving power of the microscope increases, because the wavelength associated with the motion of the electrons is shorter.

21 **Model answer**

$eV = 1/2m_e v^2$, so $v = \sqrt{(2eV/m_e)}$

$\lambda = h/(m_e v) = h/(\sqrt{(2em_e)}) \times 1/(\sqrt{(V)})$

The slope $= (\Delta \lambda)/(\Delta (1/\sqrt{(V)})) = h/(\sqrt{(2em_e)})$

Past exam questions

1	2	3	4	5	6	7	8	9	10
C	A	C	A	C	A	D	A	B	C
11	12	13	14	15	16	17	18	19	20
B	D	C	D	B	C	B	D	C	B
21	22	23	24	25	26	27	28	29	30
C	D	C	A	B	A	A	A	C	B
31	32	33	34	35	36	37	38	39	40
B	B	D	A	B	B	D	C	C	C
41	42	43	44	45	46	47	48	49	50
C	A	C	A	B	C	D	C	A	C
51	52								
—	—								

1 **Answer (C)**

The photon loses part of its energy and momentum to the electron, so its momentum decreases and the electron's momentum increases.

2 **Answer (A)**

$\lambda \propto 1/(\sqrt{(V)})$

$X = 5 \times 10^{-12} \times 1.125/4.5 = 1.25 \times 10^{-12}\ m$

3 **Answer (C)**

$\lambda = h/mv$, so the wavelength is proportional to $1/v$

From the graph $\lambda_x = 10\ AA$ and $\lambda_y = 30\ AA$

$v_x/v_y = (\lambda_y)/(\lambda_x) = 3/1$

4 **Answer (A)**

The wavelength used is proportional to the size of the virus, and $\lambda \propto 1/(\sqrt{(V)})$

$V_x/V_y = ((\lambda_y)/(\lambda_x))^2 = (4/1)^2 = 16$

5 **Answer (C)**

The photon loses part of its energy, so its wavelength increases, and the mass of the electron does not change.

6 **Answer (A)**

$\lambda = h/(\sqrt{(2m\ KE)})$, so $1/(\lambda^2) = 2m/(h^2)\ KE$

The slope $= 2m/(h^2) = (3.04 \times 10^{20})/(4 \times 10^{-20}) = 7.6 \times 10^{39}$

$m = (7.6 \times 10^{39} \times (6.625 \times 10^{-34})^2)/2 = 1.67 \times 10^{-27}\ kg$

7 **Answer (D)**

$v = h/(m\lambda) = (6.625 \times 10^{-34})/(140 \times 1.8 \times 10^{-34}) = 26.29 \times 10^{-3}\ m/s$

8 **Answer (A)**

$\lambda \propto 1/(\sqrt{(V)})$

$(\lambda_2)/(\lambda_1) = \sqrt{(25/100)} = 1/2$

9 **Answer (B)**

The electron gains energy, so its speed increases, and the photon loses energy, so its equivalent mass $m = E/(c^2)$ decreases.

10 **Answer (C)**

$\lambda = h/mv$, and with equal speeds:

$(\lambda_e)/(\lambda_p) = m_p/m_e = (1.67 \times 10^{-27})/(9.1 \times 10^{-31}) \approx 1835$

11 **Answer (B)**

$\lambda_{ph} = hc/E = (6.625 \times 10^{-34} \times 3 \times 10^{8})/(496.88 \times 10^{-21}) = 400\ nm$

$\lambda_{e} = h/P = (6.625 \times 10^{-34})/(7.626 \times 10^{-23}) = 8.7 \times 10^{-12}\ m$

In both cases the wavelength is not larger than the size of the particle, so it can be seen with both microscopes.

12 **Answer (D)**

The size of the virus is proportional to the wavelength, and $\lambda \propto 1/(\sqrt{(V)})$

$X = 10 \times \sqrt{(1.5/37.5)} = 2\ nm$

13 **Answer (C)**

$E \propto 1/(\lambda)$, so the energy of the scattered photon $= 4/5E$

The energy lost $= 1/5E$

14 **Answer (D)**

$\lambda = h/mc = (6.625 \times 10^{-34})/(3.68 \times 10^{-38} \times 3 \times 10^{8}) = 6 \times 10^{-5}\ m = 60\ \mu\ m$

15 **Answer (B)**

$P_L = h/(\lambda)$

$((P_L)_x)/((P_L)_y) = 240/320 = 3/4$

16 **Answer (C)**

The wavelength must become $1/10$ of its value, and $\lambda \propto 1/(\sqrt{(V)})$

The potential difference becomes 100 V, which means it increases by 99 V.

17 **Answer (B)**

$E' = 3/4E$ and $E \propto 1/(\lambda)$

$\lambda' = 4/3\lambda$

18 **Answer (D)**

$P_L = (hupsilon)/c \propto upsilon$

$((P_L)_x)/((P_L)_y) = (9.375 \times 10^{14})/(1.25 \times 10^{15}) = 3/4$

19 **Answer (C)**

$m = (hupsilon)/(c^2) = (6.625 \times 10^{-34} \times 7.9 \times 10^{14})/((3 \times 10^{8})^2) = 5.82 \times 10^{-36}\ kg$

20 **Answer (B)**

$eV = 1/2mv^2$, so the speed $\propto \sqrt{(V)}$

$v_1/v_2 = \sqrt{(60/20)} = \sqrt{(3)}$

21 **Answer (C)**

The photon loses part of its energy, so its momentum decreases and its wavelength increases.

22 **Answer (D)**

$P_L = (hupsilon)/c$, so the higher frequency gives the larger momentum.

And all photons travel at the same speed.

23 **Answer (C)**

Red has the longest wavelength, so its frequency, energy and momentum $h/(\lambda)$ have the smallest values.

24 **Answer (A)**

The accelerated electrons have a high kinetic energy, so their associated wavelength is short $\lambda = h/mv$

25 **Answer (B)**

$P_L = (hupsilon)/c = (6.625 \times 10^{-34} \times 4.2 \times 10^{14})/(3 \times 10^8) = 9.275 \times 10^{-28}\ kg.m/s$

26 **Answer (A)**

$\lambda \propto 1/(\sqrt{(V)})$

$(\lambda_1)/(\lambda_2) = \sqrt{(8000/2000)} = 2/1$

27 **Answer (A)**

$(\lambda_2)/(\lambda_1) = 15/20 = 3/4$ and $\lambda \propto 1/(\sqrt{(V)})$

$V_2 = 16/9V = 1.78\ V$, which means it increases by 0.78 V

28 **Answer (A)**

$\lambda = h/mv = (6.625 \times 10^{-34})/(1.67 \times 10^{-27} \times 3 \times 10^6) = 1.32 \times 10^{-13}\ m$

29 **Answer (C)**

$E' = 0.999E$ and $E \propto 1/(\lambda)$

$\lambda' = (4 \times 10^{-9})/0.999 = 4.004 \times 10^{-9}\ m$

30 **Answer (B)**

$\lambda = h/mv = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 1.8 \times 10^{7}) = 4 \times 10^{-11}\ m = 0.4\ AA$

The wavelength is smaller than the size of the virus (300 Å), so it can be seen.

31 **Answer (B)**

$P_L = E/c = (hupsilon)/c$ and $\lambda = c/(upsilon)$

32 **Answer (B)**

The wavelength must not be larger than X, and $P_L = h/(\lambda)$

The smallest momentum $= h/X$

33 **Answer (D)**

The photon is reflected, so its momentum is reversed: $\Delta P = 2P_L = (2hupsilon)/c$

34 **Answer (A)**

$E = 1.77 \times 10^{3} \times 1.6 \times 10^{-19} = 2.832 \times 10^{-16}\ J$

$P_L = E/c = (2.832 \times 10^{-16})/(3 \times 10^{8}) = 9.44 \times 10^{-25}\ kg.m/s$

35 **Answer (B)**

$KE = hupsilon - hupsilon_c$

$KE_1 = hupsilon - (hupsilon)/2 = (hupsilon)/2$, $KE_2 = 2hupsilon - (hupsilon)/2 = (3hupsilon)/2$

$KE_2 = 3KE_1$, so the speed $= \sqrt{(3)}\ v$

36 **Answer (B)**

$v = \sqrt{(2eV/m)} = \sqrt{((2 \times 1.6 \times 10^{-19} \times 300)/(9.1 \times 10^{-31}))} = 1.027 \times 10^{7}\ m/s$

$\lambda = h/mv = (6.625 \times 10^{-34})/(9.1 \times 10^{-31} \times 1.027 \times 10^{7}) = 7.09 \times 10^{-11}\ m = 0.07\ nm$

37 **Answer (D)**

The photon loses part of its energy, so its frequency decreases, while its speed stays constant (c).

38 **Answer (C)**

$F = 2P_L\varphi_L$

The slope $= (\Delta F)/(\Delta \varphi_L) = 2P_L$ (twice the momentum of the photon)

39 **Answer (C)**

$m = E/(c^2) = (4 \times 1.6 \times 10^{-19})/((3 \times 10^{8})^2) = 7.11 \times 10^{-36}\ kg$

40 **Answer (C)**

The photons are reflected from the shiny surface, so they exert a force on it, and the force on the area causes a pressure.

41 **Answer (C)**

$\lambda = h/(\sqrt{(2m\,KE)})$, so the wavelength becomes $(\lambda)/4$

The percentage change $= (\lambda - (\lambda)/4)/(\lambda) = 75\ \%$

42 **Answer (A)**

The electron microscope depends on the wave nature of electrons (de Broglie waves).

43 **Answer (C)**

$F = 2P_L\varphi_L = 2XY$

44 **Answer (A)**

$E \propto 1/(\lambda)$: photon (3) has wavelength 4λ and energy 3 eV

Photon (2): 6 eV, photon (1): 12 eV

The difference = 12 − 6 = 6 eV

45 **Answer (B)**

The photon loses part of its energy to the electron, so its wavelength $\lambda = hc/E$ increases.

46 **Answer (C)**

The electron is charged, so it is deflected in the magnetic field, and the photon is not charged, so it continues in its straight path.

47 **Answer (D)**

$\lambda = h/(\sqrt{(2mKE)}) = (6.625 \times 10^{-34})/(\sqrt{(2 \times 9.1 \times 10^{-31} \times 10^4 \times 1.6 \times 10^{-19})}) = 1.2 \times 10^{-11}\ m = 0.12\ AA$

48 **Answer (C)**

The photon loses energy, so its wavelength increases, and the electron gains energy, so its speed increases and its associated wavelength decreases.

49 **Answer (A)**

$P_L = h/(\lambda)$

$((P_L)_A)/((P_L)_B) = 200/800 = 1/4$

50 **Answer (C)**

$\lambda \propto 1/(\sqrt{(V)})$, and when the potential difference becomes 4 times as large, the wavelength decreases to half.

51 **Model answer**

$P_w = hc/(\lambda)\varphi_L$

$\varphi_L = (P_w \lambda)/hc = (10 \times 4500 \times 10^{-10})/(6.625 \times 10^{-34} \times 3 \times 10^8) = 2.26 \times 10^{19}$ *photon/s*

The rate of emitted photoelectrons = the rate of photons falling on the surface = 2.26×10^{19} electrons/second.

52 **Model answer**

(1) $E = hupsilon = 6.625 \times 10^{-34} \times 92.4 \times 10^6 = 6.12 \times 10^{-26}\ J$

(2) $\varphi_L = P_w/E = (100 \times 10^3)/(6.12 \times 10^{-26}) = 1.63 \times 10^{30}$ *photon/s*