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Elective 2 Atomic World

2.1 Rutherford's atomic model

Use the following data wherever necessary :

Charge of electron	$e = 1.60 \times 10^{-19}$ C
Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Permittivity of free space	$\varepsilon_o = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}

Part A :

The following question marked with {SP} is the Sample Paper question of the new DSE Examination.

M1. Which of these conclusions could NOT be deduced from Rutherford's scattering experiment ?

{SP}
(1) Alpha particles are helium nuclei.
(2) There are discrete energy levels in an atom.
(3) The positive charge in an atom is confined to a very small region.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

Part B :

The following question marked with {PP} is the Practice Paper question of the new DSE Examination.

M2. Which of the following can be concluded from the Rutherford scattering experiment ?

{PP}
(1) The nucleus of an atom consists of protons and neutrons.
(2) The nucleus of an atom is very small compared to the size of the atom.
(3) Electromagnetic waves emitted from atoms of gases are of specific frequencies.

A. (2) only
B. (3) only
C. (1) & (2) only
D. (1) & (3) only

Part C :

The following question marked with { } is the past DSE question. The number inside the bracket represents the year of the examination.

M3. From the classical point of view what are the limitations of Rutherford's model of the atom ?

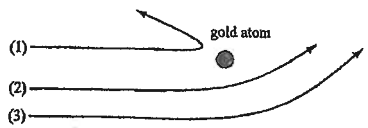
{12}
(1) Atoms would continuously emit electromagnetic radiation.
(2) Atoms would be unstable and they would collapse eventually.
(3) The atomic emission spectrum would be continuous instead of discrete.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

Part D :

The following questions marked with ( ) are the past HKCE questions. The number inside the brackets represents the year of the examination.

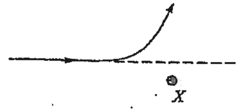
M4. α-particles are scattered by the heavy nucleus of a gold atom.
(82) Which of the paths shown in the diagram is/are the possible path for the scattered α-particles ?



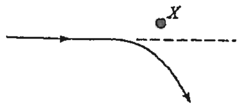
A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M5. An alpha particle is scattered by a heavy nucleus X. Which of the following paths of the alpha particle is IMPOSSIBLE ?
(91)

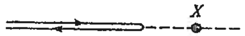
A.



B.



C.



D.

M6. Which of the following is/are correct deduction(s) from the Geiger-Marsden's α particle scattering experiment ?
(93)
(1) α particles have a strong penetrating power.
(2) Most of the space in an atom is empty.
(3) All the charged particles of an atom are concentrated in a tiny nucleus.

A. (2) only
B. (3) only
C. (1) & (2) only
D. (1) & (3) only

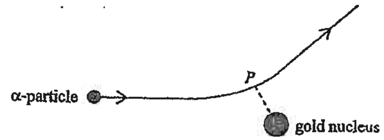
Part E :

The following questions marked with [ ] are the past HKAL questions. The number inside the brackets represents the year of the examination.

M7. Since the beginning of the 20th century, α-particles had been used as energetic projectiles to bombard various substances to
[08] trigger reactions. Many great discoveries came from this kind of experiments. Which of the following discoveries is NOT a nuclear reaction ?

A. In the discovery of protons, α-particles were used to bombard nitrogen gas.
B. In the discovery of neutrons, α-particles were used to bombard beryllium.
C. In the discovery of artificial radioactivity, α-particles were used to transmute aluminium into phosphorus.
D. In the discovery of large angle deflection, α-particles were used to bombard gold foil.

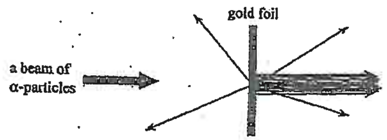
M8.
[10]



An α-particle ($^4_2$He) of initial kinetic energy 7.7 MeV approaches a gold nucleus ($^{197}_{79}$Au) from far away. The α-particle is deflected as shown. Estimate the kinetic energy of the α-particle at point P where it is 6.5×10^{-14} m from the gold nucleus which is assumed to be stationary throughout.

A. 3.5 MeV
B. 4.2 MeV
C. 7.3 MeV
D. 11.2 MeV

M9.
[12]



A thin gold foil is bombarded by a beam of α-particles and they are scattered as shown. This experimental result provides information about

A. the energy level of electrons in a gold atom.
B. the binding energy of the nucleus of a gold atom.
C. the size of the nucleus of a gold atom relative to that of a gold atom.
D. the existence of neutrons in the nucleus of a gold atom.

Part F :

The following questions are designed to give supplemental exercise for this chapter.

M10. Which of the following statements correctly describe the limitation of the Rutherford's atomic model ?
(1) The model cannot explain why the atom does not collapse according to classical electromagnetic theory.
(2) The model cannot explain why the spectral lines emitted by gas atoms in a discharge tube are discrete.
(3) The model cannot explain why the electrons orbit around the nucleus.

A. (1) only
B. (1) & (2) only
C. (2) & (3) only
D. (1), (2) & (3)

M11. From the result of the alpha-scattering experiment, Rutherford proposed his nuclear model of atom. Which of the following statements concerning the model is NOT correct ?

(1) All the positive charges are concentrated inside a very tiny nucleus.

(2) There exist discrete energy levels for electrons to stay in the atom.

(3) Radiations of discrete wavelength would be emitted when the electrons revolve around the nucleus.

A. (1) only
B. (3) only
C. (1) and (2) only
D. (2) and (3) only

M12. The deflection of alpha particles by a thin gold foil through angles that range from 0° to 180° can be explained by

A. scattering from free electrons.
B. diffraction from the nucleus.
C. scattering from small but heavy regions of positive charge.
D. reflection from the nucleus.

Answers

1. C	6. A	11. D
2. A	7. D	12. C
3. D	8. B	
4. A	9. C	
5. D	10. B	

Solution

1. C

✓ (1) Alpha particles are helium nuclei, but this is not deduced from Rutherford's scattering experiment.

✓ (2) The existence of discrete energy levels cannot be deduced from Rutherford's scattering experiment.

✗ (3) The positive charge confining to a very small region, the nucleus, could be deduced from the experiment.

2. A

✗ (1) Rutherford scattering experiment concluded that there is a tiny nucleus, but the particles inside the nucleus are not known by this experiment..

✓ (2) The large angle of deflection confirmed that there is very tiny nucleus inside the atom.

✗ (3) Rutherford scattering experiment cannot give any conclusion about the emitted electromagnetic waves.

3. D

✓ (1) Since the orbital electrons have centripetal acceleration, by classical electromagnetic theory, they would emit electromagnetic radiation continuously.

✓ (2) As the atoms loses energy continuously, the electrons would spiral towards the centre and the atoms would collapse eventually.

✓ (3) The emission spectrum would be continuous radiation of every wavelength may be emitted..

4. A

✓ (1) α particle is deflected away from the gold nucleus by the electrostatic repulsive force.

✗ (2) α particle cannot be attracted towards the gold nucleus as both carry positive charges.

✗ (3) The path shows that α is attracted towards the nucleus, thus it is impossible.

5. D

Since the dotted path passes through the nucleus *X*, it is a head-on collision.

Thus, the deflection is 180° and the alpha particle should be rebounded back along the original path.

6. A

× (1) α-particles have in fact weak penetrating power.

✓ (2) As most of the space in an atom is empty, thus most α-particles pass through the foil without deflection

× (3) Only the positive charged particles are concentrated in a tiny nucleus, but not the negative charges.

7. D

× A. During the bombardment, the α particle knocks out a proton from the nucleus, so it is a nuclear reaction.

× B. During the bombardment, the α particle knocks out a neutron from the nucleus, thus it is a nuclear reaction.

× C. When aluminium is transmuted into phosphorus, the nucleus is changed, thus it is a nuclear reaction.

✓ D. During the collision, alpha particles are rebounded by the gold nucleus, alpha particles do not make contact with the nucleus, thus it is not a nuclear reaction.

8. B

By conservation of energy :

$\therefore$ KE at far distance $=$ KE at P $+$ PE at P where $PE = \dfrac{Qq}{4\pi\varepsilon_o r}$

$$\therefore\ 7.7\times10^{6}\times1.6\times10^{-19} = KE_P + \frac{(79\times1.6\times10^{-19})(2\times1.6\times10^{-19})}{4\pi\varepsilon_o(6.5\times10^{-14})}$$

$$\therefore\ KE_P = 6.72\times10^{-13}\ \text{J} = \frac{6.72\times10^{-13}}{1.6\times10^{-19}} = 4.2\times10^{6}\ \text{eV} = 4.2\ \text{MeV}$$

9. C

× A. α particles are scattered by the nucleus of the atoms, thus no relation with the energy level of electrons.

× B. Binding energy is the energy to split the nucleus, but α cannot reach the nucleus of the atoms.

✓ C. The closest approach of the α particles can give an estimate of the size of the nucleus.

× D. This experiment can only tell the structure of atom, but not the structure of the nucleus.

10. B

✓ (1) Apply the classical electromagnetic theory onto the Rutherford's atomic model, the electrons orbiting the nucleus have centripetal acceleration, thus electromagnetic waves would be emitted continuously, and the atom would gradually lose energy and collapse. Actually, an atom would not emit electromagnetic waves and would not collapse.

✓ (2) When a high voltage is applied to the gas in a discharge tube, the gas would emit light consisting of discrete spectral lines. Rutherford's model cannot explain why only the waves of certain frequency or wavelength are emitted, but not the continuous range of wavelengths.

× (3) The orbiting motion of electrons is a circular motion, centripetal force is provided by the electrostatic attraction force between the nucleus and the electrons.

11. D

✓ (1) All the positive charges are concentrated inside the tiny nucleus that can deflect the alpha particles.

× (2) The discrete energy levels are proposed by Bohr, not by Rutherford.

× (3) Rutherford model cannot explain the emission of radiation of discrete wavelength.

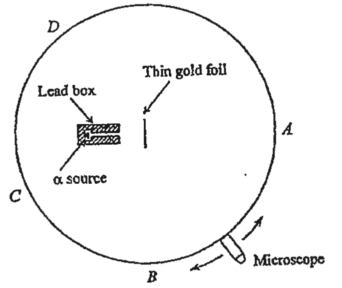
< Note that the question asks for incorrect statements. >

12. C

The process of changing the direction of the alpha particles by the positive charged nucleus is called scattering.

The following question marked with ( ) is the past HKCE questions. The number inside the bracket represents the year of the examination.

Q1. (92) The figure shows a simplified set-up of the α particle scattering experiment, which was carried out in a vacuum. α particles were emitted through a narrow slit to strike on a thin gold foil. The detector was a microscope with a fluorescent screen in the front.



(a) Explain briefly (4 marks)

(i) why a lead box with a narrow slit was used.

(ii) why the experiment was performed in a vacuum.

(b) In the above experiment, most of the α particles emitted were detected at *A*, and a small number were detected in various positions around the foil, such as *B*, *C* and *D*.

This experiment led to Rutherford's atomic model. Describe this model. (4 marks)

(c) How would the number of α particles detected at *A* be affected if the thickness of the gold foil were increased to 1 mm? (1 mark)

(d) State another type of detector which can detect α particles. (1 mark)

Q1. (a) (i) To obtain a fine beam of α particles. [2]

OR

To enable the α particles travel in a straight line.

(ii) α particles have very short ranges in air. [2]

OR

The range of α particles in air is only a few centimetres. [2]

(b) There exists a tiny nucleus in the atom. [1]

Most of the space in an atom is empty. [1]

All the positive charge and most of the mass were concentrated in the nucleus. [1]

The negative electrons move around the nucleus. [1]

(c) The number of α particles detected at *A* becomes zero. [1]

(d) GM tube [1]

OR

photographic film [1]

2.2 Photoelectric effect

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3 \times 10^8 \text{ m s}^{-1}$
Charge of electron	$e = 1.6 \times 10^{-19} \text{ C}$
Electron rest mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$

The following list of formulae may be found useful :

Einstein's photoelectric equation	$\frac{1}{2} m_e v_{max}^2 = hf - \phi$

Part A :

The following questions marked with {SP} are the Sample Paper questions of the new DSE Examination.

M1. The equivalent wavelength of a photon of energy 10 eV is
{SP} A. 213 nm
B. 124 nm
C. 25.6 nm
D. 19.7 nm

M2. In an experiment on the photoelectric effect, a beam of monochromatic light is directed onto a metal plate to liberate
{SP} electrons. The velocity of the fastest photoelectrons emitted is
A. directly proportional to the frequency of the incident light.
B. directly proportional to the intensity of the incident light.
C. independent of the nature of metal.
D. independent of the intensity of the incident light.

M3. The work function W of five metals are tabulated below.
{SP}

Metal	Caesium	Barium	Calcium	Magnesium	Beryllium
$W / 10^{-19}$ J	3.4	4.0	4.6	5.9	8.0

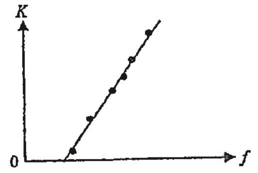
When monochromatic light of wavelength 400 nm is incident on each of the metals, how many of them would exhibit photoelectric emission ?
A. 1
B. 2
C. 3
D. 4

Part B :

The following questions marked with { } are the past DSE questions. The number inside the brackets represents the year of the examination.

M4. Photons with energy 7 eV are incident on the cathode of a photocell. The maximum kinetic energy of the photoelectrons
{12} emitted is 4 eV. When photons of energy 4 eV are incident on the cathode, the stopping potential will be
A. 0 V.
B. 1 V.
C. 2 V.
D. 3 V.

M5. In studying the photoelectric effect, a certain metal is illuminated by ultraviolet radiation of different frequency f and the
[12] maximum kinetic energy K of the photoelectrons emitted is measured. The graph is plotted as shown.



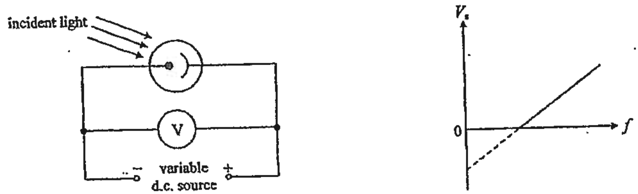
What would happen to the graph if ultraviolet radiation of higher intensity is shone on the same metal ?

	slope of the graph	intercept of the graph on the horizontal axis
A.	smaller	unchanged
B.	larger	unchanged
C.	unchanged	unchanged
D.	unchanged	smaller

Part C :

The following questions marked with [ ] are the past HKAL questions. The number inside the brackets represents the year of the examination.

M6.
[80]



In an experiment with a photocell, readings were taken of the stopping potential V_S for a series of frequencies f of the incident light, and the results plotted as a graph of V_S against f are shown in the diagram above. If the emitting electrode is now changed to one of a different metal, which also gives photoelectrons, the new graph

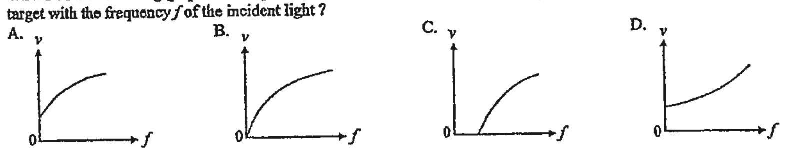
(1) cuts the V_S axis at the same point
(2) cuts the f axis at the same point
(3) has the same slope

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

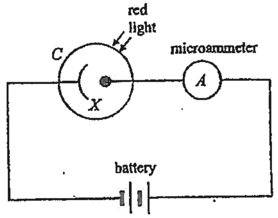
M7. For the photoelectric effect, which of the following is the correct relationship between the energy E of a photon, the work
[81] function W of the surface which it strikes, and the maximum kinetic energy K of the emitted photoelectrons ?

A. $E = W + K$
B. $E = W - K$
C. $E = K - W$
D. $K = 2(W + E)$

M8. Which of the following graphs best represents the variation of the maximum velocity v of the photoelectrons emitted from a
[82] target with the frequency f of the incident light ?



M9.
[85]



Red light shines on the photoelectric cell C as shown. If the reading of the microammeter is zero, this may be explained by the fact that

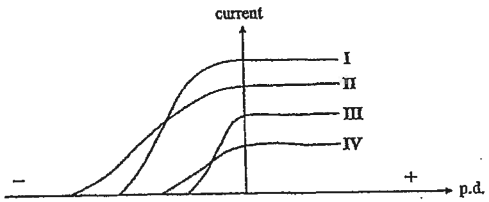
(1) the e.m.f. of the battery is too small.
(2) the intensity of the light is too low.
(3) electrode X is made of a material with too great a work function.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M10. When a beam of light of intensity I and frequency f is shone on the surface of a metal connected to earth, 200 electrons are
[86] ejected from the surface per second. If a light beam of intensity $2I$ and frequency $2f$ is used, the number of electrons ejected from the metal per second will be

A. 50.
B. 100.
C. 200.
D. 400.

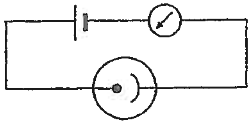
M11.
[87]



The figure above shows the currents observed in a photocell circuit as a function of the p.d. between the plates of the photocell when light beams I, II, III and IV were each directed in turn at the cathode. Which of the beams has the highest frequency ?

A. I
B. II
C. III
D. IV

M12.
[88]



Light falls on the photo-sensitive metal surface of a photocell. A battery and a sensitive meter are connected to the photocell as shown. Which of the following statements is correct ?

A. No current is observed in the meter until after a considerable time, when the metal surface has heated up.
B. The maximum energy of the electrons emitted is proportional to the intensity of light.
C. The maximum kinetic energy of the electrons emitted is independent of the particular metal used.
D. No current is observed in the meter unless the frequency of light is above a minimum value.

M13. When light of wavelength 4.0×10^{-7} m is incident on the surface of a metal, the kinetic energy of the electrons emitted has a
[89] maximum value of 3.0×10^{-19} J. What is the longest wavelength of light which would cause electrons to be emitted from the metal ?

A. 6.6×10^{-7} m
B. 1.0×10^{-6} m
C. 2.5×10^{-6} m
D. 9.8×10^{-5} m

M14. The photoelectric effect occurs when monochromatic light falls upon a metal surface in a photocell. What happens when the
[90] light intensity increases ?

A. More electrons are emitted with unchanged speed.
B. More electrons are emitted with increased speed.
C. The same number of electrons is emitted with increased speed.
D. More photons are emitted from the surface.

M15. A beam of monochromatic light falls on a metal surface. If the frequency of the light is doubled but the intensity remains
[91] unchanged, which of the following statements is/are correct ?

(1) The photon energy is doubled.
(2) The number of photons falling on the surface per second is halved.
(3) The maximum kinetic energy of photoelectrons ejected is doubled.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M16. In an experiment on the photoelectric effect, a beam of monochromatic light is directed onto a metal plate to liberate
[91] electrons. Which of the following statements is true ?

A. The velocity of the fastest electrons is directly proportional to the frequency of the incident light.
B. The velocity of the fastest electrons is directly proportional to the intensity of the incident light.
C. The kinetic energy of the fastest electrons is directly proportional to the frequency of the incident light.
D. The velocity of the fastest electrons is independent of the intensity of the incident light.

M17. The work function of a metal is the least energy required to
[92] A. release one mole of electrons from the surface of the metal.
B. bring one mole of electrons from the interior of the metal to the surface.
C. release one electron from the surface of the metal.
D. bring one electron from the interior of the metal to the surface.

M18. When light of frequency f_1 is shone on to a metal surface, the maximum energy of the electrons emitted is E_1. If the same
[95] surface is illuminated with light of frequency f_2, the maximum energy of the electrons emitted is E_2. The Planck constant is given by

A. $\dfrac{f_2E_1 - f_1E_2}{f_1f_2}$

B. $\dfrac{E_1+E_2}{f_1+f_2}$

C. $\dfrac{E_1-E_2}{f_1+f_2}$

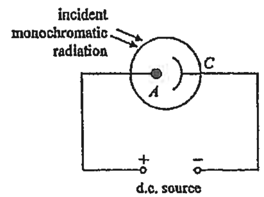
D. $\dfrac{E_1-E_2}{f_1-f_2}$

M19. A metal surface is illuminated with monochromatic light so that it emits photoelectrons. The maximum kinetic energy of the
[96] emitted photoelectrons depends on

(1) the distance of the metal surface from the light source.
(2) the work function of the metal surface.
(3) the wavelength of the incident monochromatic light.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M20.
[97]

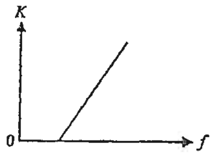


A d.c. source is applied to a photocell as shown. Monochromatic radiation is incident on cathode C so that photoelectrons are emitted from the cathode surface. The maximum kinetic energy of the photoelectrons reaching anode A can be increased by using

(1) a d.c. source of higher voltage.
(2) monochromatic radiation of longer wavelength.
(3) the same monochromatic radiation but of higher intensity.

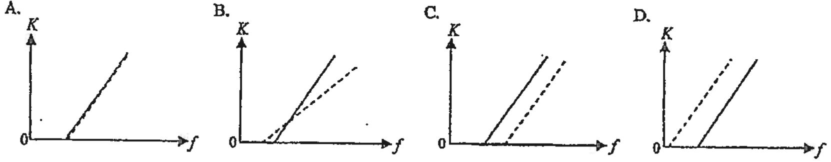
A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M21.
[99]



The above graph shows the variation in maximum kinetic energy K of photoelectrons with the frequency f of the incident radiation on a metallic surface. If radiation of twice the intensity is used, which of the following graphs (dotted line) shows the variation of K with f?

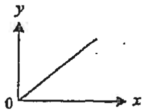
A. B. C. D.



M22. In a series of photoelectric emission experiments on a certain metal surface, relationships between the following physical
[00] quantities were investigated.

f = frequency of incident light
I = intensity of incident light
i = photoelectric current
K = maximum kinetic energy of photoelectrons

Two of these quantities, when plotted on a graph of y against x, would give a straight line through the origin as shown.



Which of the following correctly identifies x and y?

(Assume the frequencies used are greater than the threshold frequency.)

	x	y
A.	f	K
B.	f	i
C.	I	K
D.	I	i

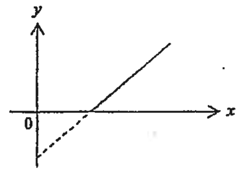
M23. A certain photocell emits electrons when illuminated with yellow light. This photocell will probably NOT emit electrons
[01] when illuminated with

A. blue light.
B. green light.
C. red light.
D. ultra-violet radiation.

M24. A beam of red light falls on one electrode of a photocell and electrons are emitted. The red beam is then replaced by a blue
[02] one that has the same intensity. Which of the following physical quantities would decrease as a result of this change?

A. The maximum kinetic energy of the photoelectrons emitted
B. The energy of each photon striking the electrode
C. The number of photons striking the electrode per second
D. The magnitude of the potential difference across the photocell required to reduce the photo-electric current to zero

M25.
[03]



In an experiment on the photoelectric effect, a student measured the potential V_S required to prevent photoemission when a metal was illuminated with radiations of varying wavelength λ. His observations led him to plot the graph as shown, but he omitted the axes labels. The correct labels for the axes are

	x	y
A.	$1/\lambda$	V_S
B.	V_S	λ
C.	λ	V_S
D.	V_S	$1/\lambda$

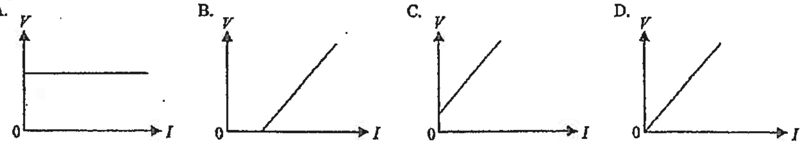
M26. A beam of blue light falls on the cathode of a photocell so that electrons are emitted. The blue beam is then replaced by a
[04] yellow one with the same intensity and electrons are also emitted. What would happen to each of the following physical quantities when the blue beam is replaced by the yellow beam?

K : the maximum kinetic energy of the electrons emitted
I : the magnitude of the photoelectric current

	K	I
A.	increase	remain unchanged
B.	decrease	remain unchanged
C.	decrease	increase
D.	decrease	decrease

M27. In a photoelectric emission experiment using light of a certain wavelength, the potential difference V required to stop any
[06] electrons from reaching the anode is measured for different light intensity I. Which of the following graphs shows how V depends on I?

A. B. C. D.



M28. The work function W of five metals are tabulated below.
[07]

Metal	Caesium	Barium	Calcium	Magnesium	Beryllium
$W/10^{-19}$ J	3.4	4.0	4.6	5.9	8.0

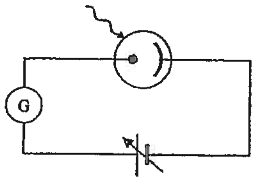
If monochromatic light of wavelength 400 nm is incident on each of the metals, how many of them would exhibit photoelectric effect?

A. 1
B. 2
C. 3
D. 4

M29. The human eye is most sensitive to green light of wavelength 520 nm. Our eyes can detect light of minimum intensity
[08] 2.0×10^{-13} W m^{-2}. Estimate the minimum number of photons entering an eye in one second in order to cause sensation, assuming that the average diameter of the pupil is 5 mm.

A. 10000
B. 1000
C. 100
D. 10

M30.
[10]



Monochromatic light is incident on a photo-emissive cell connected to a variable d.c. supply as shown. The galvanometer shows no deflection. Which of the following can be a possible reason ?

(1) The temperature of the photo-emissive cell is too low.
(2) The wavelength of the incident light is too long.
(3) The d.c. voltage applied has been reduced to zero.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M31. In photoelectric emission experiments, when a monochromatic light of wavelength λ is incident on metals X and Y, the
[10] maximum kinetic energy of the photoelectrons emitted are 1.0 eV and 0.5 eV respectively. If the incident light is replaced by that of wavelength $\lambda/2$, the maximum kinetic energy of the photoelectrons emitted from metal X becomes 3.0 eV. What is the maximum kinetic energy of the photoelectrons emitted from metal Y ?

A. 1.0 eV
B. 1.5 eV
C. 2.0 eV
D. 2.5 eV

M32. When a metal surface is illuminated by light of wavelength 400 nm, the emission of photoelectrons can be stopped by a
[12] potential of 0.9 V. Find the work function of the metal.

A. 0.9 eV
B. 2.2 eV
C. 2.9 eV
D. 3.1 eV

Answers

1. B	11. B	21. A	31. D
2. D	12. D	22. D	32. B
3. C	13. B	23. C	
4. B	14. A	24. C	
5. C	15. C	25. A	
6. B	16. D	26. C	
7. A	17. C	27. A	
8. C	18. D	28. C	
9. B	19. D	29. D	
10. C	20. A	30. B	

Solution

1. B

By $E = hf = \dfrac{hc}{\lambda}$

$\therefore\ (10 \times 1.6 \times 10^{-19}) = \dfrac{(6.63\times10^{-34})(3\times10^{8})}{\lambda}$

$\therefore\ \lambda = 1.24 \times 10^{-7}\text{ m} = 124\text{ nm}$

2. D

The intensity of the incident light affects the number of photons, but not the energy of photons.

Thus, the maximum KE and maximum speed are not affected by the intensity of light.

3. C

Energy of the photon with wavelength 400 nm :

$$E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{(400\times10^{-9})} = 4.97\times10^{-19}\text{ J}$$

To eject photoelectrons from a metal, the energy of this photon has to exceed the work function W of the metal.

Only Caesium, Barium and Calcium can exhibit photoelectric effect, thus the number is 3.

4. B

Photoelectric equation : $E = W + K_{max}$

For $E = 7$ eV and $K_{max} = 4$ eV :

$\therefore\ (7) = W + (4) \qquad \therefore\ W = 3$ eV

For $E = 4$ eV :

$\therefore\ (4) = (3) + K_{max} \qquad \therefore\ K_{max} = 1$ eV $\qquad \therefore\ V_S = 1$ V

5. C

The slope of the graph is equal to h, which is a Universal constant, thus it should be unchanged.

The intercept on the horizontal axis is the threshold frequency, which depends on the metal, thus it should be unchanged.

6. B

$K_{max} = hf - \phi$ $\therefore eV_S = hf - hf_o$ $\therefore V_S = \frac{h}{e}\cdot f - \frac{h}{e}\cdot f_o$

× (1) y-intercept $= -\frac{h}{e}\cdot f_o$ which depends on materials.

× (2) x-intercept $= f_o$, which depends on materials.

✓ (3) Slope $= \frac{h}{e}$, which is a constant for different materials.

7. A

By Einstein's Photoelectric Equation, $E = W + K$

8. C

$E = \phi + K_{max}$ $\therefore hf = \phi + \frac{1}{2}mv^2$ $\therefore v = \sqrt{\frac{2h}{m}\cdot f - \frac{2\phi}{m}}$

$\therefore$ The graph is a quadratic graph of shape $y \propto \sqrt{x}$ with positive x-intercept

9. B

× (1) If electrons are ejected, they are accelerated by the battery, no matter how large is the e.m.f.

× (2) Energy of photon is independent of intensity of incident light.

✓ (3) By $E = \phi + K_{max}$, if ϕ is too large and $E < \phi$,

i.e. the energy of the photons shining onto C is too small, then no photoelectrons would be emitted.

10. C

$P = \frac{N}{t}\cdot hf$ $\therefore \frac{N}{t} = \frac{P}{hf} \propto \frac{P}{f} \propto \frac{I}{f}$

$\therefore \frac{N/t}{200} = \frac{2I}{I}\cdot\frac{f}{2f}$

$\therefore \frac{N}{t} = 200\ s^{-1}$

11. B

Highest frequency of light $\Rightarrow$ greatest energy of photons

$\Rightarrow$ greatest KE_{max} of photoelectrons

$\Rightarrow$ greatest stopping potential

$\therefore$ II has the greatest magnitude of potential

12. D

× A. Photoelectrons are ejected without any time lag.

× B. Energy of photoelectrons is independent of the intensity of light.

× C. By $K_{max} = E - \phi$ $\therefore K_{max}$ is affected by the work function ϕ that depends on the type of metal.

✓ D. Frequency of light below threshold frequency $\Rightarrow$ no photoelectrons can be ejected $\Rightarrow$ no current

13. B

$E = \phi + K_{max}$ $\therefore h\cdot\frac{c}{\lambda} = h\cdot\frac{c}{\lambda_o} + K_{max}$

$\therefore (6.63\times10^{-34})\cdot\frac{(3\times10^8)}{(4.0\times10^{-7})} = (6.63\times10^{-34})\cdot\frac{(3\times10^8)}{\lambda_o} + (3\times10^{-19})$ $\therefore \lambda_o = 1.0\times10^{-6}$ m

14. A

(1) $I\uparrow \Rightarrow P\uparrow \Rightarrow \frac{N}{t}\uparrow$ (by $P = \frac{N}{t}\cdot h\cdot\frac{c}{\lambda}$)

(2) Same frequency of light $\Rightarrow$ same energy of photoelectrons $\Rightarrow$ same speed

15. C

✓ (1) $f \to 2f \Rightarrow E \to 2E$ (by $E = hf$)

✓ (2) $f \to 2f \Rightarrow \frac{n}{t} \to \frac{1}{2}\cdot\frac{n}{t}$ (by $P = \frac{n}{t}\cdot hf$)

× (3) By $hf = hf_o + K_{max}$ $\therefore f \to 2f$ does not imply $K_{max} \to 2K_{max}$

16. D

× A. As $hf = hf_o + \frac{1}{2}mv_{max}^2$ $\therefore f$ is not directly proportional to v_{max}.

× B. Velocity of photoelectron is independent of intensity of light, provided that the frequency is unchanged.

× C. $hf = hf_o + K_{max}$ $\therefore K_{max}$ is not directly proportional to f.

✓ D. Energy, and hence velocity of photoelectron, is independent of the intensity of light.

Intensity of light only affects the number of photons, thus affects the number of photoelectrons emitted.

17. C

Work function of a metal is the minimum energy required to remove an electron from the surface of the metal.

It depends on the particular metal.

18. D

By $hf = \phi + K_{max}$

$hf_1 = \phi + E_1$ ... (1)

$hf_2 = \phi + E_2$ ... (2)

(1)−(2): $hf_1 - hf_2 = E_1 - E_2$ $\therefore h = \frac{E_1 - E_2}{f_1 - f_2}$

19. D

$E = W + K_{max}$

$\therefore K_{max} = h \cdot \frac{c}{\lambda} - W$

$\therefore$ (2) and (3) are correct.

20. A

✓ (1) Higher voltage $\Rightarrow$ photoelectrons gain more KE

× (2) $\lambda \uparrow \Rightarrow K_{max} \downarrow$ (by $K_{max} = h \cdot \frac{c}{\lambda} - W$)

× (3) Energy of photoelectrons is independent of the intensity of incident light.

21. A

KE of photoelectrons is independent of intensity of radiation

$\therefore$ no change in the graph

22. D

By $i = \frac{n}{t}e$ $\therefore$ $i \propto \frac{n}{t}$.

By $P = \frac{N}{t}E$ $\therefore$ $P \propto \frac{N}{t}$

As $i \propto \frac{n}{t} \propto \frac{N}{t} \propto P \propto I$ $\therefore$ $i \sim I$ graph is a straight line graph. $\therefore$ D is correct.

23. C

Since red light has a frequency lower than yellow light

thus the energy of a red light photon is less than that of yellow light

therefore the energy of the red light photon may not be greater than the work function of the metal

so photoelectrons may not be ejected.

24. C

× A. Since blue light photon has a greater energy, by $E = W + K_{max}$,
the maximum kinetic energy of the photoelectrons emitted is greater for blue light.

× B. As blue light has a higher frequency than that of the red light, by $E = hf$,
energy of a blue light photon is greater than the energy of a red light photon.

✓ C. Since the two beams of light have the same intensity,
the power P incident onto the electrode are the same.
By $P = \frac{N}{t}hf$, as blue light has higher frequency f, the number of photons per second N/t is smaller.

× D. Since blue light ejects photoelectrons of greater maximum kinetic energy,
By $K_{max} = eV_S$, the stopping potential V_S for blue light is greater.

25. A

As $hf = hf_o + eV_S$

$\therefore V_S = \frac{hc}{e} \cdot \frac{1}{\lambda} - \frac{hf_o}{e}$

A graph of V_S against $\frac{1}{\lambda}$ gives a straight line with negative y-intercept, thus, x is $\frac{1}{\lambda}$ and y is V_S

26. C

① Yellow light has a smaller frequency f than blue light.
By $hf = W + K$ $\therefore f\downarrow \Rightarrow K\downarrow$

② Intensity of light $\propto P = \frac{N}{t}hf$ and Current $I = \frac{n}{t}e$

$\therefore f\downarrow \Rightarrow \frac{N}{t}\uparrow \Rightarrow \frac{n}{t}\uparrow \Rightarrow I\uparrow$

27. A

V is the stopping potential, which is related to the maximum kinetic energy K_{max} of the photoelectrons by $K_{max} = eV$

The maximum kinetic energy is related to the frequency f of the light by $hf = W + K_{max}$

It can be found that the stopping potential is not affected by the light intensity I.

Thus, the graph should be a horizontal line, indicating that V is independent of I.

28. C

Energy of the photon with wavelength 400 nm :

$$E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{(400\times10^{-9})} = 4.97\times10^{-19}\ \text{J}$$

To eject photoelectrons from a metal, the energy of this photon has to exceed the work function W of the metal.

Only Caesium, Barium and Calcium can exhibit photoelectric effect, thus the number is 3.

29. D

$$E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{(520\times10^{-9})} = 3.825\times10^{-19}\ \text{J}$$

$$P = IA = (2.0\times10^{-13})\times\frac{\pi}{4}(5\times10^{-3})^2 = 3.93\times10^{-18}\ \text{W}$$

$$P = \frac{N}{t}E$$

$$\therefore (3.93\times10^{-18}) = \frac{N}{t}\times(3.825\times10^{-19})$$

$$\therefore \frac{N}{t} = 10\ \text{s}^{-1}$$

30. B

× (1) The temperature of the photo-emissive cell would not affect the photoelectric effect.

✓ (2) If the wavelength is too long, the frequency of the incident light would be too low, that the frequency may be lower than the threshold frequency, thus no photoelectrons are emitted, and thus the galvanometer has no reading.

× (3) If there are photoelectrons emitted, the galvanometer can show deflection even if the applied voltage is zero.

31. D

For wavelength λ :

metal X: $\frac{hc}{\lambda} = W_X + 1.0$ metal Y: $\frac{hc}{\lambda} = W_Y + 0.5$

$\therefore W_X + 1.0 = W_Y + 0.5$ ... ①

For wavelength $\lambda/2$:

metal X: $\frac{hc}{\lambda/2} = W_X + 3.0$ metal Y: $\frac{hc}{\lambda/2} = W_Y + K_Y$

$\therefore W_X + 3.0 = W_Y + K_Y$ ... ②

Combine ① and ② : $K_Y = 2.5$ eV

32. B

Energy of each photon : $E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^8)}{(400\times10^{-9})} = 4.97\times10^{-19}$ J = 3.1 eV

Maximum KE of photoelectrons : $K_{max} = 0.9$ eV

By Photoelectric equation : $E = W + K_{max}$

$\therefore (3.1) = W + (0.9)$

$\therefore W = 2.2$ eV

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3.00 \times 10^8\ \text{m s}^{-1}$
Charge of electron	$e = 1.60 \times 10^{-19}$ C
Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Planck constant	$h = 6.63 \times 10^{-34}$ J s

The following list of formulae may be found useful :

Einstein's photoelectric equation $\frac{1}{2} m_e v_{max}^2 = hf - \phi$

Part A :

The following question marked with {PP} is the Practice Paper question of the new DSE Examination.

Q1. {PP} (a) In studying the photoelectrons emitted from sodium, it was found that no photoelectrons were emitted when the wavelength of the incident light was longer than 5.27×10^{-7} m.

(i) Explain why the wave model of light cannot account for this phenomenon. (2 marks)

(ii) Determine the work function for sodium. Express your answer in electron-volts. (3 marks)

(iii) What is the physical meaning of work function ? (1 mark)

(b) Figure (a) below shows a photoelectric smoke detector Peter made for a science project competition. It consists of a light source S, a photocell C and an alarm circuit. When smoke enters the detector, light from S is scattered by the smoke particles and enters C as shown in Figure (b). Photoelectrons are produced in C when light is incident on its sodium surface. The alarm is triggered when the photoelectric current is larger than 1×10^{-8} A.

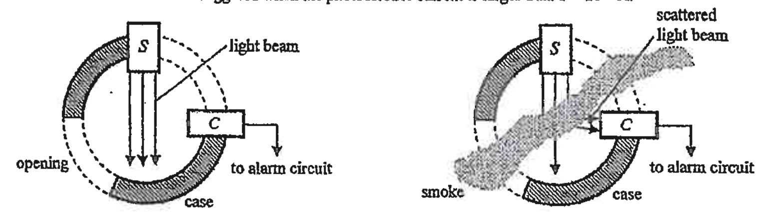


Figure (a)   Figure (b)

(i) If 5% of the photons incident on the sodium surface of C emit photoelectrons, what is the minimum number of photons incident on the sodium surface of C in 1 s when the alarm is triggered ? (2 marks)

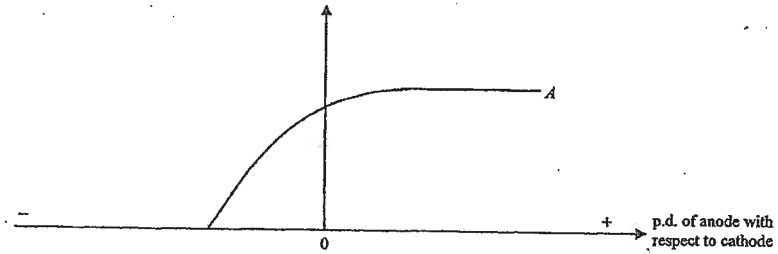
Q1. (b) (ii) Peter claimed that the detector will become more sensitive if a light source of the same type as S but of higher intensity is used. Comment on his suggestion. (2 marks)

Part B :

The following questions marked with [ ] are the past HKAL questions. The number inside the brackets represents the year of the examination.

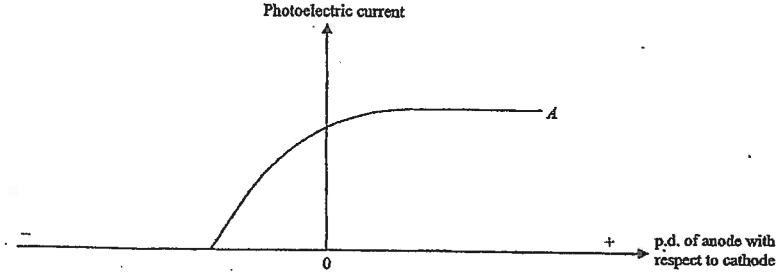
Q2. [81] In an experiment using a photoelectric cell, the photoelectric current was measured as a function of the potential difference of the anode with respect to the cathode.

(a) Curve A below shows the result when monochromatic light of certain intensity was used to illuminate the photocathode. Sketch to scale the curve you would expect to obtain if the intensity of the light were halved. Label your curve B. (2 marks)

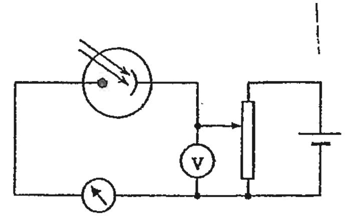


(b) State one way in which curves A and B contradict the wave theory of light. Explain clearly. (3 marks)

(c) Sketch on the below graph the form of the curve you would expect to obtain if light of the same intensity but double the frequency were used. Label your curve C. (3 marks)

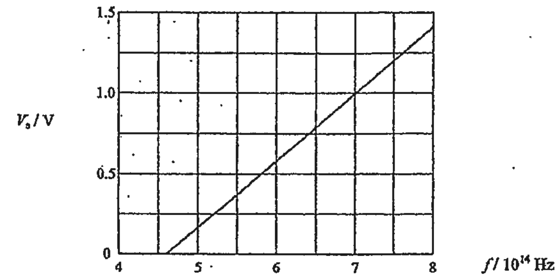


Q3. [92]



(a) In an experiment with an illuminated photocell using caesium as the cathode, a small current is detected by the ammeter even when the anode is made slightly negative with respect to the cathode, using the circuit shown in the above figure. Briefly account for this. (2 marks)

(b) The current falls to zero only when the reverse p.d. across the tube reaches a value V_s, which varies with the frequency f of the radiation used to illuminate the cathode. The figure below shows the relationship between V_s and f.



(i) What is the relationship between V_s and f as predicted by Einstein's photoelectric theory ? (2 marks)

(ii) What is the value of the threshold frequency for caesium ? (1 mark)

(iii) Estimate a value for the Planck constant. (2 marks)

(iv) Calculate the work function for caesium in electron-volt. (3 marks)

(v) Sketch on the above figure the corresponding variation between V_s and f for a photocell whose cathode has a larger work function than caesium. (2 marks)

Q4. [96] In a photoelectric experiment, a thin metal plate of dimension $(8.0 \times 10^{-3}) \times (8.0 \times 10^{-3})$ m^2 is illuminated with a parallel beam of ultraviolet light of wavelength 230 nm. The work function of the metal is 2.21 eV.

(a) What is meant by the work function of a metal ? (1 mark)

(b) (i) Calculate the maximum kinetic energy of the photoelectrons emitted. (2 marks)

(ii) Find the stopping potential. (1 mark)

(c) The intensity of the ultraviolet light used is 3 W m^{-2} and it falls normally on one side of the metal plate. Find, in the absence of the stopping potential, the number of photoelectrons emitted per second. Assume that every incident photon can successfully release a photoelectron. (3 marks)

(d) State the change in

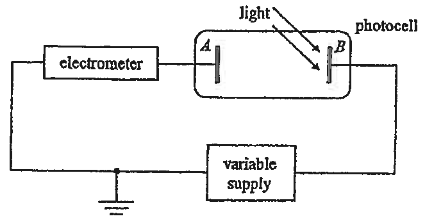
(i) the stopping potential ; and

(ii) the number of photoelectrons emitted per second,

if another source of ultraviolet light with the same intensity, but having a shorter wavelength, is used. Explain briefly. (4 marks)

Q5. [08] The set-up shown in Figure 1 is used to study photoelectric effect. Light of a certain frequency is directed towards the photo-sensitive electrode B of a photocell. The potential difference across the electrodes A and B can be varied by adjusting the variable supply.

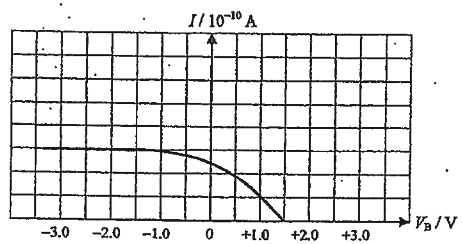
Figure 1



(a) When the voltage V_B of the electrode B is zero, the electrometer still detects a current. Explain this phenomenon and state the direction of the current in the photocell. (2 marks)

(b) The work function of electrode B is 2.3 eV. The graph in Figure 2 shows the variation of the current I with the voltage V_B when the variable supply is adjusted.

Figure 2



(i) Explain why the current drops when V_B is increased. (2 marks)

(ii) What is the maximum kinetic energy, in eV, of the photoelectrons produced ? Hence, find the wavelength of the light waves used and name this kind of light waves. (4 marks)

(c) (i) In Figure 2, sketch the current-voltage variation when the experiment is repeated with the light intensity doubled. (2 marks)

(ii) Referring to the graphs in Figure 2, elaborate one observation of the photoelectric effect that cannot be explained by the wave theory. (2 marks)

Q6. [09] (a) Explain the physical meaning of terms hf and ϕ in the Einstein's photoelectric equation : $K_{max} = hf - \phi$. (2 marks)

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____

(b) Light of wavelength 450 nm is incident on a metal surface. The power of the light reaching the metal surface is 5.0 mW.

(i) Find the number of photons arriving at the metal surface per second. (3 marks)

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(ii) If on average only one photoelectron is emitted for every two thousand photons absorbed by the metal surface, calculate the resulting photoelectric current. (2 marks)

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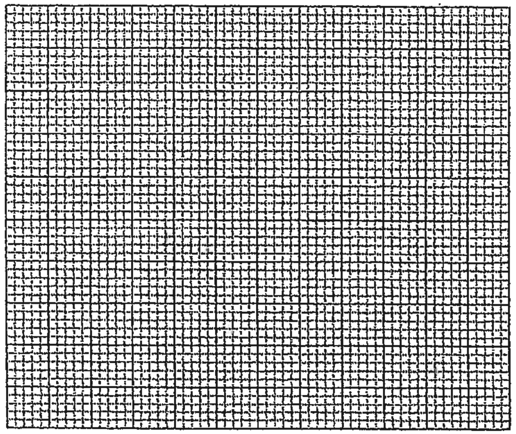
____

(c) Light of different wavelengths λ is allowed to illuminate the metal surface. The corresponding maximum kinetic energy KE_{max} of the photoelectrons emitted is tabulated below.

KE_{max} / eV	0.23	0.44	0.66	0.95
λ / nm	520	480	441	400

(i) Choose a suitable physical quantity to complete the table so as to plot a straight line graph. Use the graph to find the stopping potential which can reduce the current found in (b)(ii) to zero. Show your working. (6 marks)



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(ii) Suppose the experiment is repeated with another piece of metal of larger work function. Use a dotted line to sketch the expected result on the graph in (c)(i). (2 marks)

Q7. [11] The metal Caesium has a work function of 2.08 eV.

(a) Calculate the longest wavelength of visible light that can cause emission of photoelectrons from Caesium. (2 marks)

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____

(b) Light of wavelength 4.01×10^{-7} m is incident on Caesium. Find the maximum kinetic energy (in eV) of photoelectrons emitted from it. (2 marks)

____

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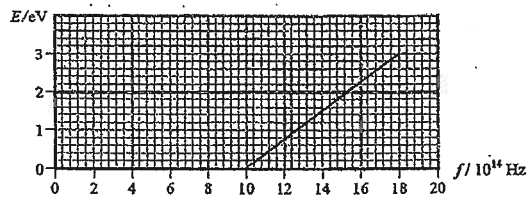
Part C :

The following questions are designed to give supplemental exercise for this chapter.

Q8. The graph shows how the maximum kinetic energy E of photoelectrons emitted from the surface of aluminium varies with the frequency f of the incident radiation.



(a) Explain why no photoelectrons are emitted below a frequency of 10×10^{14} Hz. (1 mark)

____

____

(b) Calculate the work function of aluminium in electron volts. (2 marks)

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(c) Calculate the gradient of the graph, and express the answer in SI unit. State what quantity it is. (3 marks)

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(d) Add a second line to the graph to show how E varies with f for a metal which has a work function less than aluminium. (2 marks)

Q9. In 1921, Albert Einstein won the Nobel Prize for his work on the photoelectric effect.

The results of experiments on the photoelectric effect show that :

* photoelectrons are not released when the incident radiation is below a certain threshold frequency ;
* the kinetic energy of the photoelectrons released depends on the frequency of the incident light and not its intensity.

Explain how these results support a particle theory, but not a wave theory of light. (6 marks)

Q10. (a) In a demonstration of photoelectric effect, ultraviolet light is incident on a zinc plate and electrons are emitted. Suppose now the intensity of the ultraviolet light is increased.

(i) Explain why the number of electrons emitted per second increases. (3 marks)

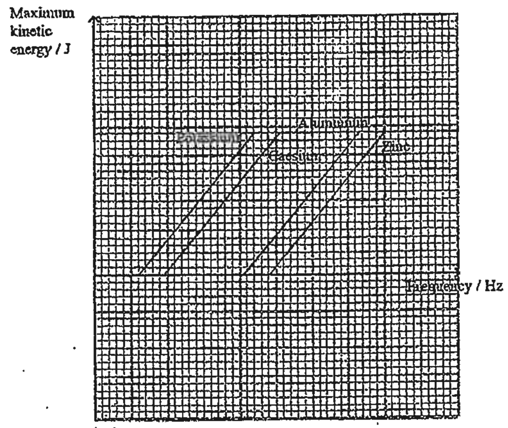
(ii) Give the reason that the maximum kinetic energy of an electron does not change. (2 marks)

(b) The table shows the work functions of four metals.

Metal	Work function / 10^{-19} J
Aluminium	6.53
Caesium	3.36
Potassium	2.30
Zinc	6.88

(i) Determine which of these metals can emit electrons when illuminated with visible light of frequency 5.88×10^{14} Hz. (3 marks)

Q10. (b) (ii) The graphs show how the maximum kinetic energy of the emitted electrons varies with the frequency of incident light for the four metals.



By using the photoelectric equation, explain why the lines are all parallel. (2 marks)

(iii) A school laboratory has a photoelectric cell for student use. The metal plate in the photoelectric cell is made of caesium and it can be used with a set of filters to obtain a graph similar to the one in (ii).

Explain why the metal plate is made of caesium rather than zinc. (2 marks)

Q1. (a) (i) According to wave theory, energy of light depends on the intensity. [1]

No matter what the frequency is, photoelectrons should be emitted when the incident light is intense enough. [1]

(ii) $\phi = hf_o = h\dfrac{c}{\lambda_o}$ [1]

$= (6.63\times10^{-34})\times\dfrac{3\times10^8}{5.27\times10^{-7}}$ [1]

$= 3.77\times10^{-19}$ J

$= \dfrac{3.77\times10^{-19}}{1.6\times10^{-19}}$ eV $= 2.36$ eV [1]

(iii) Work function is the minimum energy required to release an electron from a metal surface against the attractive electric force of the metal. [1]

(b) (i) Number of photoelectrons per second $= \dfrac{i}{e} = \dfrac{1\times10^{-8}}{1.6\times10^{-19}} = 6.25\times10^{10}$ [1]

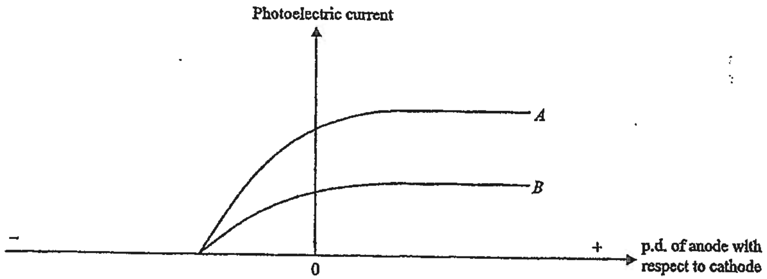
Number of photons per second $= 6.25\times10^{10} \div 5\% = 1.25\times10^{12}$ [1]

(ii) With a more intense light source of the same type, more photons are emitted. [1]

Sufficient photons will be scattered by a smaller amount of smoke. [1]

Hence, Peter's claim is correct.

Q2. (a)



< Stopping potential remains unchanged > [1]

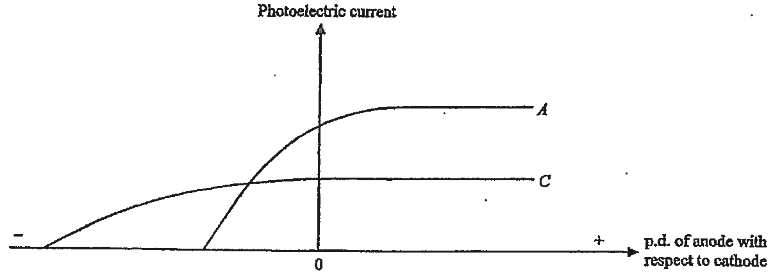
< Saturation current reduced to half > [1]

(b) The current is reduced to zero for the same negative stopping voltage [1]

This stopping voltage is proportional to the maximum kinetic energy of the emitted electrons. [1]

According to the wave theory, the K.E. of the emitted electrons should be greater for more intense light and therefore a greater value of the negative voltage would be expected. [1]

Q2. (c)



< shape correct > [1]

< For the stopping potential : $V_C > 2V_A$ but $V_C \neq 2V_A$ > [1]

< For saturation current : $I_C = \frac{1}{2}I_A$ > [1]

Q3. (a) Some emitted electrons have sufficient kinetic energy [1]

to overcome the opposing voltage between the anode and cathode. [1]

(b) (i) $eV_S = hf - \phi$ [1]

where ϕ is the work function [1]

(ii) threshold frequency : $f_o = 4.6\times10^{14}$ Hz [1]

(iii) slope of the graph $= \dfrac{h}{e}$

$\therefore\ (0.4\times10^{-14}) = \dfrac{h}{1.6\times10^{-19}}$ [1]

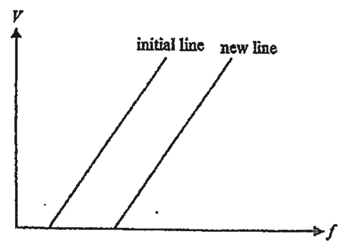
$\therefore\ h = 6.4\times10^{-34}$ J s [1]

(iv) $\phi = hf_o$ [1]

$= (6.4\times10^{-34})\times(4.6\times10^{14})\times\dfrac{1}{1.6\times10^{-19}}$ [1]

$= 1.84$ eV [1]

(v)



< same slope as the initial line > [1]

< greater intercept at the f-axis > [1]

Q4. (a) Work function is the minimum energy to remove an electron from the metal surface. [1]

(b) (i) $h\frac{c}{\lambda} = K_{max} + \phi$

$(6.63\times10^{-34})\times\frac{3\times10^{8}}{230\times10^{-9}} = K_{max} + (2.21\times1.60\times10^{-19})$ [1]

$\therefore\ K_{max} = 5.11\times10^{-19}$ J [1]

(ii) $V_s = \frac{5.11\times10^{-19}}{1.60\times10^{-19}} = 3.19$ V [1]

(c) Energy supplied per second $= 3\times(8.0\times10^{-3})^2$

$= 1.92\times10^{-4}$ J s^{-1} [1]

Energy of each photon $= 6.63\times10^{-34}\times\frac{3\times10^{8}}{230\times10^{-9}}$

$= 8.65\times10^{-19}$ J [1]

Number of photoelectrons emitted per second $= \frac{1.92\times10^{-4}}{8.65\times10^{-19}}$

$= 2.22\times10^{14}$ [1]

(d) (i) Since the energy of each photon increases, [1]

the maximum K.E. of the photoelectrons increases, thus the stopping potential increases. [1]

(ii) The number of photoelectrons emitted per second would decrease since intensity is constant [1]

and each photon has more energy, the number of photons arrived per second would decrease. [1]

Q5. (a) Since the photoelectrons are emitted with non-zero kinetic energy (OR speed). [1]

Direction of current is from A to B in the photocell. [1]

(b) (i) Those photoelectrons with kinetic energy less than eV_B [1]

do not have enough energy to reach the anode A, thus the current drops. [1]

(ii) $K_{max} = 1.5$ eV [1]

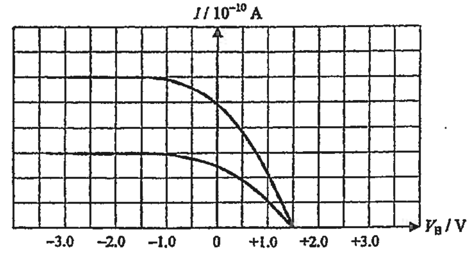
By $\frac{hc}{\lambda} = \phi + K_{max}$ [1]

$\therefore\ \frac{(6.63\times10^{-34})(3\times10^{8})}{\lambda} = (2.3+1.5)\times1.6\times10^{-19}$

$\therefore\ \lambda = 3.27\times10^{-7}$ m [1]

It is ultra-violet. [1]

Q5. (c) (i)



<saturation current doubled> [1]

<stopping potential unchanged> [1]

(ii) According to wave theory, the photoelectrons should have greater maximum K.E. [1]

However, the stopping potential and thus the maximum K.E. remain unchanged. [1]

Q6. (a) hf is the energy of each photon [1]

ϕ is the work function, it is the minimum energy required to remove an electron from the metal surface. [1]

(b) (i) $E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{(450\times10^{-9})} = 4.42\times10^{-19}$ J [1]

$P = \frac{N}{t}E$

$\therefore\ (5.0\times10^{-3}) = \frac{N}{t}(4.42\times10^{-19})$ [1]

$\therefore\ \frac{N}{t} = 1.13\times10^{16}$ s^{-1} [1]

(ii) Number of photoelectrons emitted per second :

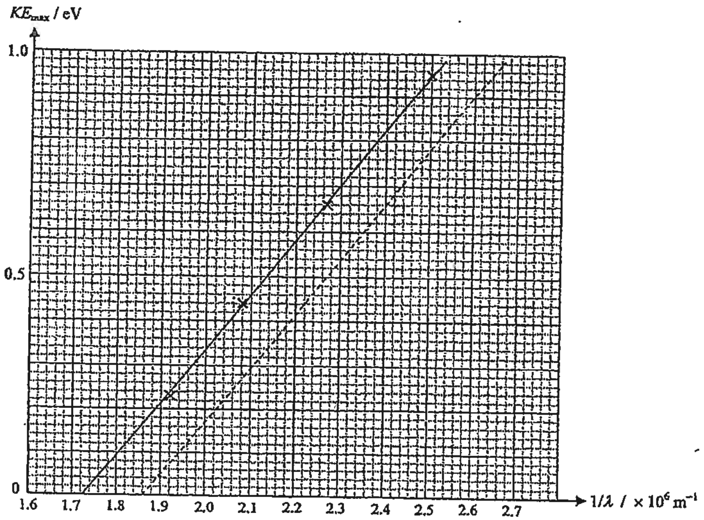
$\frac{n}{t} = 1.13\times10^{16}\times\frac{1}{2000} = 5.65\times10^{12}$ s^{-1} [1]

$i = \frac{n}{t}e = (5.65\times10^{12})\times(1.6\times10^{-19}) = 9.04\times10^{-7}$ A [1]

(c) (i)

KE_{max} / eV	0.23	0.44	0.66	0.95
λ / nm	520	480	441	400
$\frac{1}{\lambda}$ / $\times10^{6}$ m^{-1}	1.92	2.08	2.27	2.50

Q6. (c) (i)



< appropriate quantities (with units and axes labelled) > [1]

< suitable scales and correct points plotted > [1]

< best fit straight line drawn > [1]

When λ = 450 nm, $1/\lambda = 2.22 \times 10^6$ m^{-1},

from the graph, KE_{max} = 0.61 eV [1]

$KE_{max} = e\,V_o$ [1]

V_o = 0.61 V < accept 0.60 V to 0.62 V > [1]

(ii) < straight line drawn shifted to the right > [1]

< line with the same slope > [1]

Q7. (a) Work function : $W = hf_o = h\dfrac{c}{\lambda_o}$ [1]

$\therefore (2.08 \times 1.6 \times 10^{-19}) = (6.63 \times 10^{-34}) \times \dfrac{3\times10^8}{\lambda_o}$

$\therefore \lambda_o = 5.98 \times 10^{-7}$ m [1]

(b) $E = h\dfrac{c}{\lambda} = (6.63 \times 10^{-34}) \times \dfrac{3\times10^8}{4.01\times10^{-7}} \times \dfrac{1}{1.6\times10^{-19}} = 3.10$ eV [1]

$K_{max} = E - W = 3.10 - 2.08 = 1.02$ eV [1]

Q8. (a) The photon energy is less than the work function of the metal. [1]

(b) Threshold frequency : $f_o = 10 \times 10^{14}$ Hz [1]

Work function : $\phi = hf_o = (6.63 \times 10^{-34})(10 \times 10^{14}) = 6.63 \times 10^{-19}$ J = 4.14 eV [1]

(c) Gradient $= \dfrac{(3-0)\times(1.6\times10^{-19})}{(18-10)\times10^{14}}$ [1]

$= 6 \times 10^{-34}$ J s [1]

The gradient is the Planck's constant. [1]

(d) < The second line should be parallel to the original line. > [1]

< The x-intercept should be less than 10. > [1]

Q9. In Particle theory, light consists of packets of energy called photons.

Energy of each photon is expressed by $E = hf$. Higher frequency means photons of greater energy. [1]

If the energy of photon is below the work function, no photoelectrons can be released. [1]

Greater frequency means greater energy of photon that can release electrons of greater KE. [1]

More intense light means more photons, to produce more electrons. [1]

In Wave theory, wave energy depends on intensity. [1]

More intense light should give electrons of greater KE, but it does not happen. [1]

Q10. (a) (i) Light consists of photons, each photon has energy E where $E = hf$. [1]

Each photon can release one electron from the metal. [1]

If intensity of light is increased, the number of photons per second increases, [1]

thus number of electrons emitted per second increases.

(ii) Since the frequency is constant, the photon energy is unchanged, [1]

By $hf = \Phi + K_{max}$, and Φ is constant, thus the maximum KE of electron does not change. [1]

(b) (i) Energy of each photon $= hf = (6.63 \times 10^{-34})(5.88 \times 10^{14}) = 3.90 \times 10^{-19}$ J [1]

Electrons can be emitted if the energy of each photon is greater than the work function.

Electrons can thus be emitted from caesium and potassium. [2]

(ii) By $K_{max} = hf - \Phi$ [1]

As gradient = h, which is constant, thus they are all parallel. [1]

(iii) Caesium works with visible light. [1]

Zinc works with ultra-violet radiation, but there is no UV filters. [1]

2.3 Bohr's atomic model of hydrogen

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
Charge of electron	$e = 1.60 \times 10^{-19}$ C
Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Planck constant	$h = 6.63 \times 10^{-34}$ J s
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

The following list of formulae may be found useful :

Energy level equation for hydrogen atom $\quad E_n = -\frac{1}{n^2}\left\{\frac{m_e e^4}{8h^2\varepsilon_0^2}\right\} = -\frac{13.6}{n^2}$ eV

Part A :

The following questions marked with {SP} are the Sample Paper questions of the new DSE Examination.

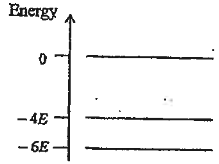
M1. The ionization potential of a hydrogen atom is 13.6 V. How much energy is required to excite an electron from the ground
{SP} state to the first excited state in a hydrogen atom ?

A. 10.2 eV
B. 6.8 eV
C. 3.4 eV
D. 1.9 eV

M2. The energy levels of a certain atom are as shown. Which of these may
{SP} undergo an inelastic collision with the atom ?

(1) an electron with kinetic energy 3 E
(2) a photon with energy 2 E
(3) a photon with energy 3 E

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only



Part B :

The following questions marked with {PP} are the Practice Paper questions of the new DSE Examination.

M3. The wavelength of the radiation emitted when an electron of an atom drops from the j^{th} excited state of energy E_j to a lower
{PP} k^{th} excited state of energy E_k is

A. $\frac{E_j - E_k}{h}$

B. $\frac{E_j - E_k}{hc}$

C. $\frac{hc}{E_j - E_k}$

D. $\frac{hc}{E_j} - \frac{hc}{E_k}$

M4. The ionization energy for a hydrogen atom in ground state is 13.6 eV. A photon of energy 4.53 eV strikes a hydrogen atom {PP} in ground state. The hydrogen atom will

A. not be excited to a higher energy level.

B. be excited to the first excited state.

C. be excited to the third excited state.

D. be ionized.

Part C :

The following questions marked with { } are the past DSE questions. The number inside the brackets represents the year of the examination.

M5. According to Bohr's model of the hydrogen atom, the ratio of the radius of the electron's orbit in the first excited state to that {12} in the second excited state is

A. $1:2$.

B. $1:\sqrt{2}$.

C. $4:9$.

D. $2:3$.

M6. Which of the following statements about spectra is/are correct ?

{12} (1) A tungsten-filament lamp emits a continuous spectrum.

(2) A line absorption spectrum can be obtained when a tungsten-filament lamp is viewed through some hydrogen gas.

(3) The emission spectrum of hydrogen consists of dark lines on a bright background.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

Part D :

The following questions marked with [ ] are the past HKAL questions. The number inside the brackets represents the year of the examination.

M7. An electron of mass m and charge e, is accelerated by a potential V, then strikes an atom, exciting it from its ground state to a [81] higher energy state. The electron is scattered with speed u, and the excited atom subsequently decays back to the ground state with the emission of a photon of frequency f. If h is the Planck constant, the value of u is

A. $2(eV+hf)$

B. $\dfrac{2(eV-hf)}{m}$

C. $\sqrt{\dfrac{eV+hf}{m}}$

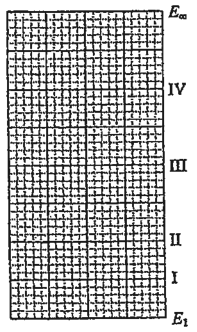
D. $\sqrt{\dfrac{2(eV-hf)}{m}}$

M8. The ionisation energy of an atom in its ground state is
[84] A. the energy required to separate all the electrons from the remainder of the atom.
B. the maximum energy required to separate one electron from the remainder of the atom.
C. the minimum energy required to separate one electron from the remainder of the atom.
D. the minimum energy required to add one electron to the atom.

M9. The ionization energy of a hydrogen atom is 13.6 eV. Which of the following energy levels is/are possible for the atom ?
[85] (1) -1.51 eV
(2) -3.40 eV
(3) -6.80 eV

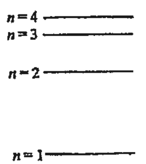
A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M10.
[86]



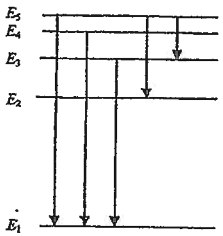
In the diagram above, E_1 and E_∞ represent (to scale) the energy levels of a hydrogen atom in its ground state and the ionised state respectively. Which of the drawn lines represents the energy level of the atom in its first excited state?
A. I
B. II
C. III
D. IV

M11.
[87]

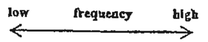


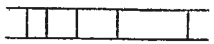
The figure shows the four lowest energy levels of a hydrogen atom. The hydrogen atom is excited from ground state to the energy level $n=3$ when an electron collides inelastically with it. What is the minimum energy required for the electron to do this ? (Ionization energy of hydrogen = 13.6 eV)
A. 4.9 eV
B. 12.1 eV
C. 12.8 eV
D. 15.1 eV

M12. [88]



The diagram shows the first five energy levels of an atom. Which of the spectra below best corresponds to the transitions indicated ?



A. 

B. 

C. 

D. 

M13. [89] When a beam of white light passes through iodine vapour, the spectrum of the emergent light shows dark lines. Which of the following statements is/are correct ?

(1) The iodine vapour absorbs from the light all frequencies except those which it emits.
(2) The iodine vapour emits less energy than it absorbs.
(3) The iodine vapour absorbs the same frequencies as it emits.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M14. [89] An atom emits light of wavelengths 122 nm and 103 nm when one of its electrons returns to its ground state from its first and second excited states, respectively. The wavelength of light emitted when the electron passes from the second excited state to the first excited state is

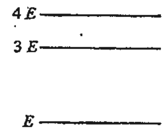
A. 112 nm.
B. 113 nm.
C. 225 nm.
D. 661 nm.

M15. [90] In a collision between an electron and an atom which leads to excitation of the atom without ionization, which of the below statements is/are correct ?

(1) An orbital electron escapes from the attraction of the nucleus.
(2) An orbital electron acquires energy.
(3) The energy transferred appears later as electromagnetic radiation.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M16. [90] The diagram shows the energy levels of a certain atom. When an electron changes energy from $4E$ to E, a photon of wavelength λ is emitted. Which of the following wavelengths of photons could be produced by other transitions between the energy levels shown ?



A. $\lambda/3$ and 3λ
B. $2\lambda/3$ and $3\lambda/2$
C. $2\lambda/3$ and 3λ
D. $3\lambda/2$ and 3λ

M17. Electron transitions occur in an atom resulting in the emission of the following light wavelengths :

[91] from level C to level A : 600 nm
from level B to level A : 500 nm

Which of the following statements is/are correct ?

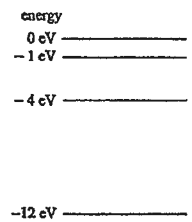
(1) Level A has a lower energy than both levels B and C.
(2) Level C has a higher energy level B.
(3) The wavelength of light emitted for the transition between C and B is 100 nm.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M18. [94] In a hydrogen atom, electron transitions from the first excited state to the ground state give photons of frequency f. If an electron falls from the second excited state to the first one, the frequency of the photon emitted would be

A. $0.19f$
B. $0.44f$
C. $0.84f$
D. $1.19f$

M19. [96]



A hypothetical atom has only four energy levels as represented above. It can change from any one level to any other. Which of the following statements about this hypothetical atom is INCORRECT ?

A. If the atom is at the level –4 eV, it can absorb a photon of energy 4 eV.
B. If the atom is at the level –4 eV, it can emit a photon of energy 8 eV.
C. If the atom is at the level –12 eV and collides with an electron of kinetic energy 10 eV, it can change to the level – 4 eV.
D. If the atom is at the level –12 eV and collides with two photons, each of energy 4 eV, it can change to the level – 4 eV.

M20. The transition of electrons between three energy levels in a particular atom gives rise to three spectral lines. The shortest and
[97] longest wavelengths of those spectral lines are λ_1 and λ_2 respectively. The wavelength of the other spectral line is

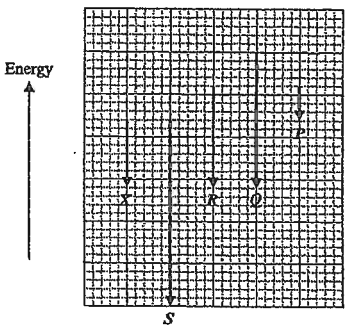
A. $\frac{\lambda_1 + \lambda_2}{2}$

B. $\lambda_2 - \lambda_1$

C. $\frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2}$

D. $(\frac{1}{\lambda_1} - \frac{1}{\lambda_2})^{-1}$

M21.
[98]



The above diagram shows some energy levels (drawn to scale) of a certain atom. Transition X results in the emission of a photon of wavelength 600 nm. Which transition (P to S) would result in the emission of a photon of wavelength 300 nm ?

A. P
B. Q
C. R
D. S

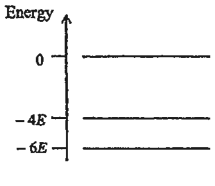
M22. When an electron in an atom falls from an excited state to the ground state, which of the following forms of radiation is not
[99] emitted ?

A. infra-red
B. gamma-ray
C. ultra-violet
D. visible light

M23. The energy levels of a certain atom are as shown in the figure. Which
[00] of the following may cause the excitation of an electron at the lowest energy level of the atom ?

(1) an electron with kinetic energy 3 E
(2) a photon with energy 2 E
(3) a photon with energy 3 E

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only



M24. Which of the following electron transitions between energy levels in a hydrogen atom will emit electromagnetic radiation of
[01] the highest frequency ?

A. $n=2$ to $n=1$
B. $n=3$ to $n=2$
C. $n=4$ to $n=3$
D. $n=4$ to $n=2$

M25. A hydrogen atom absorbs a photon of wavelength λ such that the electron in the ground state (energy level corresponding to
[02] $n=1$) is brought to an excited state (energy level corresponding to $n=3$). What is the maximum wavelength of a photon that can cause ionization of a hydrogen atom in the ground state ?

A. $\frac{8}{9}\lambda$
B. $\frac{9}{8}\lambda$
C. $\frac{3}{2}\lambda$
D. $\frac{2}{3}\lambda$

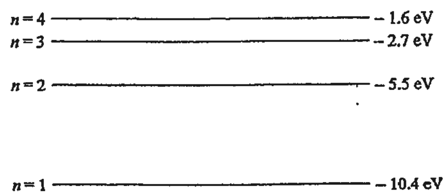
M26. The second line in the Lyman series (corresponding to the K-shell) of the hydrogen spectrum has a wavelength of 102 nm.
[03] What is the wavelength of the first line in the series ?

A. 93.5 nm
B. 121 nm
C. 136 nm
D. 153 nm

M27. The ionization energy for a hydrogen atom in ground state is 13.6 eV. If the atom is in the first excited state, the energy for
[04] ionizing it should be

A. 3.4 eV.
B. 4.5 eV.
C. 6.8 eV.
D. 10.2 eV.

M28.
[05]



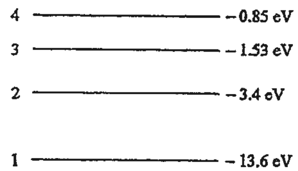
The figure shows the possible energy levels of a mercury atom. A free electron with kinetic energy 8.4 eV collides with a mercury atom, which is in its ground state. The change in kinetic energy of the mercury atom in the collision may be neglected. What is/are the possible value(s) for the kinetic energy of the electron after collision ?

(1) 0.7 eV
(2) 2.9 eV
(3) 3.5 eV

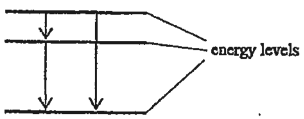
A. (1) only
B. (2) only
C. (2) & (3) only
D. (1) & (3) only

M29. [08] The figure shows the four lowest energy levels of a hydrogen atom. It is known that the wavelength of visible light ranges from 400 nm to 700 nm and the energy of a yellow light photon (about 600 nm) is 2 eV. If electrons having kinetic energy of 12.5 eV are used to bombard a large number of hydrogen atoms, how many spectral lines in the visible region can be obtained subsequently ?

A. 0
B. 1
C. 2
D. 3



M30. [09] The diagram shows the electron transitions within an excited atom. Light of wavelengths λ_1, λ_2 and λ_3 are emitted, where $\lambda_1 > \lambda_2 > \lambda_3$. Deduce the relationship between λ_1, λ_2 and λ_3.



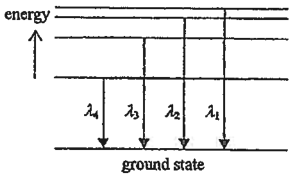
A. $\lambda_1 = \lambda_2 + \lambda_3$

B. $\lambda_2 = \dfrac{\lambda_1 + \lambda_3}{2}$

C. $\lambda_1 = \dfrac{\lambda_2\lambda_3}{\lambda_2 + \lambda_3}$

D. $\lambda_3 = \dfrac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$

M31. [10]

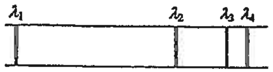


The diagram shows the energy levels available to the outer electron in an atom of a certain element drawn approximately to scale. λ_1, λ_2, λ_3 and λ_4 denote the respective wavelengths of the emitted photons corresponding to the electron transitions indicated. Which line spectrum shown on a linear scale of wavelength is correct ?

increasing wavelength

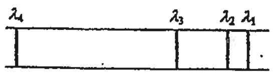
A.

B.



C.

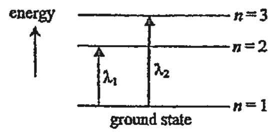
D.



M32. [11] An electron of negligible initial speed is accelerated through a p.d. of 12.0 V. The electron then undergoes inelastic collision with a gaseous atom at its ground state. As a result, the electron loses all its kinetic energy in the collision and the atom is excited to an energy level of –3.4 eV. Find the ionization potential of this atom.

A. 8.6 V
B. 12.0 V
C. 15.4 V
D. 18.8 V

M33. [11]



In a hydrogen atom, when the electron absorbs a photon of wavelength λ_1, it can jump from $n = 1$ state to $n = 2$ state. When the electron absorbs a photon of wavelength λ_2, it can jump from $n = 1$ state to $n = 3$ state. If the electron changes from $n = 3$ state to $n = 2$ state, what is the wavelength of the photon emitted from the hydrogen atom ?

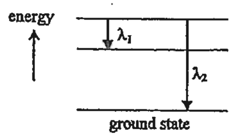
A. $\lambda_2 - \lambda_1$

B. $\lambda_1 - \lambda_2$

C. $\dfrac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}$

D. $\dfrac{\lambda_1\lambda_2}{\lambda_1 - \lambda_2}$

M34. [12]



The figure shows three adjacent energy levels of a hydrogen atom. Electron transitions between these energy levels can emit radiations of three different wavelengths. Two of them are of wavelengths λ_1 and λ_2 as shown, the wavelength of the third one is

A. $\lambda_1 - \lambda_2$

B. $\lambda_2 - \lambda_1$

C. $\dfrac{\lambda_1\lambda_2}{\lambda_1 - \lambda_2}$

D. $\dfrac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}$

Answers

1. A	6. A	11. B	16. D	21. B	26. B	31. C
2. A	7. D	12. D	17. A	22. B	27. A	32. C
3. C	8. C	13. B	18. A	23. C	28. D	33. D
4. A	9. C	14. D	19. D	24. A	29. B	34. C
5. C	10. D	15. D	20. D	25. A	30. D	

Solution

1. A

For hydrogen : $E_n = -\frac{E_o}{n^2}$

E_o = 13.6 eV

Energy level of the ground state : E_1 = − 13.6 eV

Energy level of the first excited state : E_2 $\therefore$ $E_2 = -\frac{13.6}{2^2} = -3.4$ eV

Excitation energy : ΔE = (−3.4) − (−13.6) = 10.2 eV

2. A

✓ (1) The electron can use 2 E to excite the atom from (−6 E) to (−4 E).
After collision, the KE of the electron decreases, thus the collision is inelastic.

× (2) Although the photon can excite the atom and the photon is absorbed,
the collision cannot be called inelastic, as photon has no mass, its energy is not KE.

× (3) This photon cannot be absorbed to excite the atom.

3. C

$\Delta E = E_j - E_k = hf = h\frac{c}{\lambda}$

$\therefore \lambda = \frac{hc}{E_j - E_k}$

4. A

For hydrogen : $E_n = -\frac{E_o}{n^2}$

E_1 = − 13.6 eV

E_2 = − 13.6 / 4 = − 3.4 eV

E_3 = − 13.6 / 9 = − 1.51 eV

There is no difference of two energy levels that is equal to 4.53 eV, thus the photon would not be absorbed and the hydrogen atom will not be excited to a higher energy level.

5. C

Radius of the electron's orbit in the first excited state is

Ground state : r_1

First excited state : r_2

Second excited state : r_3

$r_n = n^2 \frac{h^2 \varepsilon_o}{\pi m_e e^2}$

$\therefore r_n \propto n^2$

$\therefore \frac{r_2}{r_3} = \left(\frac{2}{3}\right)^2 = \frac{4}{9}$

6. A

✓ (1) A tungsten-filament lamp is a common light source that emits continuous spectrum.

✓ (2) When the continuous spectrum passes through hydrogen gas, some photons are absorbed, thus a line absorption spectrum is obtained.

× (3) The emission spectrum of hydrogen consists of discrete bright lines on a dark background.
Dark lines on a bright background are the absorption line spectrum.

7. D

During acceleration of electron by potential V: $\frac{1}{2} m v^2 = e V$.

The electron loses part of its kinetic energy that change to a photon of energy hf.

$\frac{1}{2} m v^2 = hf + \frac{1}{2} m u^2$

$\therefore\ eV = hf + \frac{1}{2} m u^2$

$\therefore\ u = \sqrt{\frac{2(eV - hf)}{m}}$

8. C

The minimum energy to remove an electron from an atom so that the atom becomes an ion is the ionization energy.

9. C

Energy at the 2nd excited state = $-\frac{13.6}{2^2} = -3.4$eV $\therefore$ (2) is correct.

Energy at the 3rd excited state = $-\frac{13.6}{3^2} = -1.51$eV $\therefore$ (1) is correct.

10. D

$E_2 = -\frac{E_1}{(2)^2} = -\frac{E_1}{4}$

Take $E_\infty = 0$, E_2 corresponds to level IV.

11. B

$$E = \left[-\frac{13.6}{(3)^2}\right] - \left[-\frac{13.6}{(1)^2}\right] = 12.1 \text{ eV}$$

12. D

By $\Delta E = hf$ $\therefore \Delta E \uparrow \Rightarrow f\uparrow$

13. B

× (1) Iodine vapour absorbs those frequencies which it emits, but it does not absorb other frequencies.

× (2) Energy emitted = energy absorbed

✓ (3) The photon with the same frequency can excite the iodine atom, thus can be absorbed.

14. D

$\Delta E_{31} = \Delta E_{32} + \Delta E_{21}$

$\therefore \frac{hc}{103} = \frac{hc}{\lambda} + \frac{hc}{122}$ $\therefore \lambda = 661$ nm

15. D

× (1) Since the atom undergoes excitation but not ionization, the electron can only excite but not escape.

✓ (2) Excitation is the transition of electron from lower energy level to higher energy level, thus energy is gained.

✓ (3) After excitation, the atom undergoes radiation to emit electromagnetic waves.

16. D

$4E - E = 3E = \frac{hc}{\lambda}$

$3E - E = 2E = \frac{hc}{\lambda_1}$ $\therefore \lambda_1 = 3\lambda/2$

$4E - 3E = E = \frac{hc}{\lambda_2}$ $\therefore \lambda_2 = 3\lambda$

17. A

✓ (1) Emission for $C \to A$ and $B \to A \Rightarrow A$ is the lowest energy level among the three

× (2) $C: \lambda\uparrow \Rightarrow E\downarrow$ (by $E = h \cdot \frac{c}{\lambda}$)

× (3) By conservation of energy,

$\Delta E_{AB} = \Delta E_{AC} + \Delta E_{CB}$ $\therefore \frac{hc}{500} = \frac{hc}{600} + \frac{hc}{\lambda}$ $\therefore \lambda = 3000$ nm

18. A

$\left(-\frac{E_o}{2^2}\right) - \left(-\frac{E_o}{1^2}\right) = hf$ $\therefore E_o = \frac{4}{3}hf$

$\left(-\frac{E_o}{3^2}\right) - \left(-\frac{E_o}{2^2}\right) = hf'$

$\left(\frac{4}{3}hf\right)\left(\frac{1}{4} - \frac{1}{9}\right) = hf'$ $\therefore f' = 0.19f$

19. D

✓ A. Transition of electron from level −4 eV to level 0 eV.

✓ B. Transition of electron from level −4 eV to level −12 eV.

✓ C. Absorbing 8 eV out of the 10 eV from the electron
$\Rightarrow$ transition of electron of the atom from level −12 eV to level −4 eV

× D. Excitation of atom can only occur by absorption of one photon
No energy level corresponds to −8 eV $\Rightarrow$ no transition of electron
$\Rightarrow$ no absorption of photons of energy 4 eV

20. D

As energy difference between higher energy levels is smaller than that of lower energy levels, $E_{12} > E_{23}$.

$\Delta E = h \cdot \frac{c}{\lambda} \propto \frac{1}{\lambda}$ $\therefore \lambda\downarrow \Rightarrow \Delta E\uparrow$ $\therefore E_{13} = \frac{hc}{\lambda_1}$ and $E_{23} = \frac{hc}{\lambda_2}$.

$E_{13} = E_{12} + E_{23}$ $\therefore \frac{hc}{\lambda_1} = \frac{hc}{\lambda} + \frac{hc}{\lambda_2}$ $\therefore \lambda = \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)^{-1}$

21. B

$E = h \cdot \frac{c}{\lambda} \propto \frac{1}{\lambda}$

$\frac{E_{300}}{E_{600}} = \frac{(600)}{(300)}$ $\therefore E_{300} = 2 \times (8) = 16$ smallest division

$\therefore$ Emission of photon of 300 nm $\Rightarrow$ energy difference = 16 smallest division $\Rightarrow Q$

22. B

γ-rays : the radiation is emitted from the nucleus, not from the transition of electrons

23. C

✓ (1) Inelastic collision occurs. The electron loses $2E$ and its kinetic energy becomes $1E$.
The electron in the atom would then excite from the level $-6E$ to the level $-4E$

✓ (2) The photon has the exact energy to cause the electron to excite from the level $-6E$ to the level $-4E$.
Thus, the photon would be absorbed.

× (3) The photon does not have energy exactly equal to the difference of two energy levels.
Thus, the photon would not be absorbed and the electron would not be excited.

24. A

To emit electromagnetic radiation of the highest frequency,

the transition between 2 energy levels should be the greatest.

Since the difference of energy level between the E_1 and E_2 is greatest, it gives the highest frequency.

25. A

$$\frac{hc}{\lambda} = (-\frac{E_o}{9}) - (-E_o) = \frac{8}{9}E_o$$

$$\frac{hc}{\lambda_{max}} = 0 - (-E_o) = E_o$$

$$\therefore \lambda_{max} = \frac{8}{9}\lambda$$

26. B

For hydrogen, energy of the nth shell follows : $E_n = -\frac{E_o}{n^2}$

Lyman series are emitted when the electron falls from higher energy level to the ground state of energy level E_1

Second line of Lyman series : $\frac{hc}{102} = (-\frac{E_o}{9}) - (-\frac{E_o}{1}) = \frac{8}{9}E_o$

First line of Lyman series : $\frac{hc}{\lambda} = (-\frac{E_o}{4}) - (-\frac{E_o}{1}) = \frac{3}{4}E_o$

$$\therefore \frac{\lambda}{102} = \frac{8/9}{3/4}$$

$$\therefore \lambda = 121 \text{ nm}$$

27. A

For hydrogen : $E_n = -\frac{E_o}{n^2}$

The first excited state is E_2 $\therefore E_2 = -\frac{13.6}{2^2} = -3.4$ eV

Energy needed for ionization $= 0 - (-3.4) = 3.4$ eV

28. D

✓ (1) Second excitation energy $= (-2.7) - (-10.4) = 7.7$ eV
After inelastic collision and excited the atom to second excited state, KE of e $= 8.4 - 7.7 = 0.7$ eV

× (2) Loss of kinetic energy of e $= 8.4 - 2.9 = 5.5$ eV.
However, there is no difference of any two energy levels equal to 5.5 eV. Thus, it is not possible.

✓ (3) First excitation energy $= (-5.5) - (-10.4) = 4.9$ eV
After inelastic collision and excited the atom to first excited state, KE of e $= 8.4 - 4.9 = 3.5$ eV

29. B

$\Delta E_{13} = (-1.53) - (-13.6) = 12.07$ eV $\quad \Delta E_{14} = (-0.85) - (-13.6) = 12.75$ eV

Electrons of energy 12.5 eV can excite the hydrogen atoms to level 3 but not level 4.

The transition from level 3 back to level 2 can radiate a visible light photon, which belongs to Balmer series.

However, the transitions from level 3 to 1 or from level 2 to 1 radiate ultra-violet photons, which belong to Lyman series.

Only 1 spectral line in the visible region (Balmer series) can be obtained.

30. D

Let the energy of the three energy levels be E_1, E_2 and E_3, where E_1 is the lowest energy level.

By $\Delta E = \frac{hc}{\lambda}$, $E_3 - E_1$ should give the shortest wavelength λ_3 and $E_3 - E_2$ should give the longest wavelength λ_1.

As $(E_3 - E_1) = (E_3 - E_2) + (E_2 - E_1)$

$$\therefore \frac{hc}{\lambda_3} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2} \qquad \therefore \frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} \qquad \therefore \lambda_3 = \frac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$$

31. C

λ_1 has the greatest energy level difference, thus greatest energy of photon and greatest frequency and shortest wavelength.

$\therefore \lambda_1 < \lambda_2 < \lambda_3 < \lambda_4$

As the difference of energy levels between λ_1 and λ_2 is smaller, λ_1 and λ_2 should be closer, thus answer is C.

32. C

Kinetic energy of the electron $= 12$ eV

Excitation energy of the atom $= 12$ eV

Energy of the ground state $= (-3.4) - 12 = -15.4$ eV

Ionization energy $= 15.4$ eV

Ionization potential $= 15.4$ V

33. D

$$\Delta E_{31} = \Delta E_{32} + \Delta E_{21} \qquad \therefore \frac{hc}{\lambda_2} = \frac{hc}{\lambda} + \frac{hc}{\lambda_1}$$

$$\therefore \frac{1}{\lambda_2} = \frac{1}{\lambda} + \frac{1}{\lambda_1} \qquad \therefore \frac{1}{\lambda} = \frac{1}{\lambda_2} - \frac{1}{\lambda_1} \qquad \therefore \lambda = \frac{\lambda_1\lambda_2}{\lambda_1 - \lambda_2}$$

34. C

$$\Delta E_{31} = \Delta E_{32} + \Delta E_{21} \qquad \therefore \frac{hc}{\lambda_2} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda}$$

$$\therefore \frac{1}{\lambda_2} = \frac{1}{\lambda_1} + \frac{1}{\lambda} \qquad \therefore \frac{1}{\lambda} = \frac{1}{\lambda_2} - \frac{1}{\lambda_1} \qquad \therefore \lambda = \frac{\lambda_1\lambda_2}{\lambda_1 - \lambda_2}$$

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
Charge of electron	$e = 1.60 \times 10^{-19}$ C
Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Planck constant	$h = 6.63 \times 10^{-34}$ J s
Permittivity of free space	$\varepsilon_o = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

The following list of formulae may be found useful :

Energy level equation for hydrogen atom $\quad E_n = -\dfrac{1}{n^2}\left\{\dfrac{m_e e^4}{8h^2\varepsilon_o^2}\right\} = -\dfrac{13.6}{n^2}$ eV

Part A :

The following question marked with { } is the past DSE question. The number inside the bracket represents the year of the examination.

Q1. The energy level of an electron in a hydrogen atom is given by :
{12}

$$E = -\frac{13.6}{n^2}\text{eV}$$

(a) Explain the physical meaning of the negative sign of E. (1 mark)

(b) State TWO postulates of Bohr's model of the hydrogen atom which are not "classical". (2 marks)

(c) Hydrogen gas in ground state is illuminated by an ultraviolet light beam of wavelengths 102.8 nm and 100.0 nm. It is found that the 102.8 nm ultraviolet light is absorbed by the hydrogen gas while the 100.0 nm ultraviolet light is unaffected.

(i) Calculate the energy of an ultraviolet light photon of wavelength 102.8 nm in eV. What is the quantum number of the hydrogen atom after absorbing such a photon ? (3 marks)

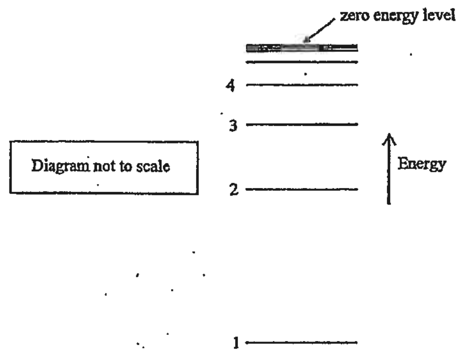
(ii) Why does the 100.0 nm ultraviolet light pass through the hydrogen gas without absorption ? (1 mark)

(iii) When the excited hydrogen atom returns to its ground state, how many transitions are possible ? State which one of these transitions gives visible light and explain your answer.
Given : the energy of a visible light photon ranges from 1.7 eV to 3.2 eV. (3 marks)

Part B :

The following questions marked with [ ] are the past HKAL questions. The number inside the brackets represents the year of the examination.

Q2. The figure below represents the energy levels of a hypothetical hydrogen-like atom :
[84]



(a) Mark on the above figure the ground state of the atom. (1 mark)

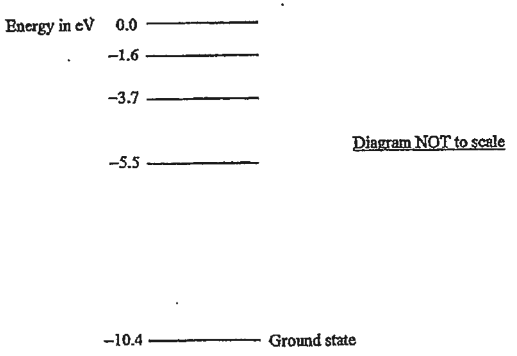
(b) Briefly explain what is meant by 'the ground state of the atom'. (1 mark)

(c) What is the significance of the zero energy level ? (1 mark)

(d) During the transition from level 3 to level 2 of the above atom, photons of wavelength 600 nm are emitted. Calculate the ionization potential energy for the atom. (3 marks)

(e) Determine the energy (in eV) corresponding to the levels 1, 2 and 3. (3 marks)

3. A glass tube contains mercury vapour at a low pressure. The diagram below shows the energy levels of a mercury atom.
1]



(a) From the above graph, estimate the lowest excitation energy for mercury. (2 marks)

(b) What is the wavelength of the radiation emitted by the mercury atoms as they return to their ground state from the first excited state? What kind of radiation does it belong to? (3 marks)

(c) What would you expect to happen to a photon of energy 9 eV when it collides with a mercury atom? Explain your answer briefly. (2 marks)

Q4. (a) (i) Several energy levels of a mercury atom are shown in Figure 1.
[04]

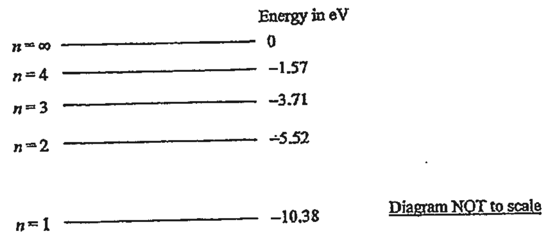


Figure 1

In a fluorescent tube, atoms in the mercury vapour are excited to the first excited state from its ground state by the bombardment of energetic electrons. Determine the wavelength of the radiation emitted by the excited mercury atom as it returns to the ground state. In which part of the electromagnetic spectrum does this radiation belong to? (4 marks)

(ii) The radiation in (a)(i) is then absorbed by the coating on the inner surface of the fluorescent tube. Figure 2 shows some of the energy levels of a coating atom.

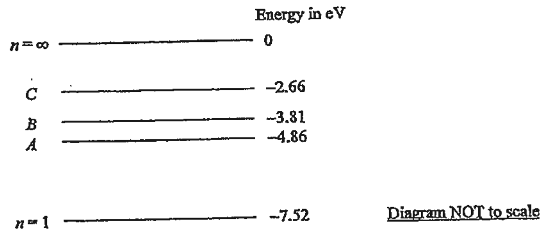


Figure 2

(I) After the absorption of the radiation in (a) (i), which energy levels, A, B, or C, would the ground state coating atom be excited to? (1 mark)

(II) The excited coating atom returns to the ground state through various intermediate states. State the TWO transitions of the coating atom that emit visible light. (Given: The visible spectrum runs from 400 nm to 700 nm approximately. A photon of wavelength 400 nm has 3.11 eV of energy.) (3 marks)

Q4. (b) Fluorescence occurs when an electron of a fluorescent coating atom is excited to an excited state, the excited electron will return to the ground state through various intermediate states and these transitions will emit photons.

The screen of a colour television set emits light of different colours also by fluorescence. On the inner surface of the screen, there are three kinds of coatings arranged as dots that emit red, green and blue light. Inside the cathode-ray tube of a television, three beams of electrons are accelerated to high speeds before they strike the corresponding coatings and excite the coating atoms.

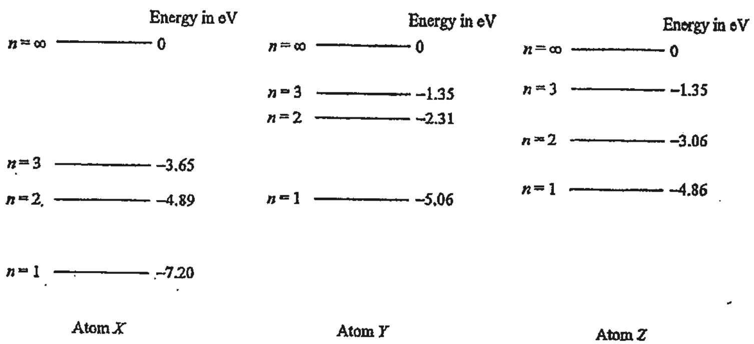


Figure 3

(i) Figure 3 shows the energy levels of the coating atoms, namely atoms X, Y and Z. Write the name of the coating atom that corresponds to each colour in the following table. (2 marks)

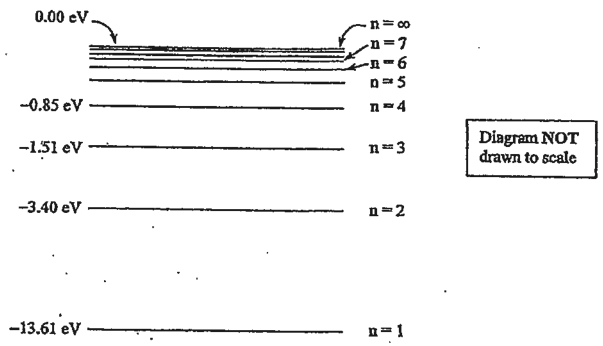
Colour of visible light emitted	Energy of emitted photon / eV	Name of coating atom
Red	1.80	
Green	2.31	
Blue	2.75	

(ii) The excitation energies of the three kinds of coating atoms are different. Can a single electron beam carrying a sufficient amount of energy excite these coating atoms? Explain briefly. (2 marks)

Q5. [06] The table below shows the literature values of the wavelengths of the emission lines from a hydrogen discharge tube.

	λ (nm)
Red	656.3
Cyan	486.1
Blue	434.1
Violet	410.2

The Figure below shows some of the allowed energy levels for hydrogen.

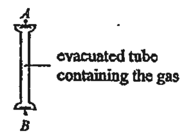


One of the electron transitions gives rise to the violet line in the above figure.

(a) Find the energy value of the energy level from which the above transition starts. (2 marks)

(b) Use an arrow to indicate this electron transition in the above figure. (1 mark)

Q6. [10] In 1909, Rutherford collected some α-particles which then changed into atoms of a gas by receiving electrons from the surroundings. The gas was trapped inside an evacuated tube with electrodes A and B as shown in the Figure. Explain how Rutherford could prove that α-particles are actually helium nuclei by using this set-up. (3 marks)



Part C :

The following questions are designed to give supplemental exercise for this chapter.

Q7. The following table lists some of the spectral lines of hydrogen spectrum from a discharge tube.

Wavelength λ / nm	656.3	486.1	434.0	410.2	364.6

(a) (i) Which line corresponds to red light ? (1 mark)

(ii) One of the lines cannot be seen by naked eyes. Name the region in the electromagnetic spectrum to which this line belongs. (1 mark)

(b) What activity within an atom gives rise to these emission lines ? What is the physical significance of the spectrum that consists of discrete lines ? (2 marks)

(c) In fact, the wavelengths of the emission lines satisfy the formula of the following series :

$$\lambda = (364.6 \text{ nm}) \frac{n^2}{n^2 - 4}, \text{ where } n = 3, 4, 5, \ldots$$

(i) Show that the formula can be transformed into

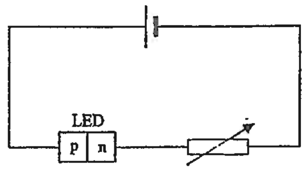
$$hf = K\left(\frac{1}{n^2} - \frac{1}{4}\right)$$

where f represents the frequencies of the emission lines, h is the Planck constant and K is a constant. (1 mark)

(ii) Find K in units of eV.

State the physical significance of the sign and the magnitude of the term $\frac{K}{n^2}$ in the formula of hf. (4 marks)

Q8. An LED is made up of two different semiconductor layers, namely p-type and n-type. The LED emits a monochromatic light of wavelength 688 nm. Assume that one photon is emitted when an electron passes through the LED. The Figure below shows the circuit for lighting up the LED.



(a) If the current in the LED is 8.0 mA, estimate the number of photons emitted by the LED per second. (2 marks)

(b) The energy of each photon emitted by the LED is 1.85 eV. Estimate the value of the Planck constant h. (2 marks)

Q1. (a) Negative value means that the electron is under attraction and cannot escape from the atom. [1]

OR

Negative value means that the electron is bounded by the atom and cannot escape from the atom. [1]

(b) The electron in a hydrogen atom can revolve in certain orbits of definite energy without emitting radiation. [1]

The angular momentum of the electron is quantized, which is an integral multiple of a certain value. [1]

(c) (i) $E = hf = \dfrac{hc}{\lambda} = \dfrac{(6.63\times10^{-34})(3\times10^{8})}{(102.8\times10^{-9})}\times\dfrac{1}{1.6\times10^{-19}} = 12.09\text{ eV}$ [1]

$E_n = (-13.6) + (12.09) = -1.51\text{ eV}$ [1]

$-\dfrac{13.6}{n^2} = -1.51 \qquad \therefore n = 3$ [1]

Quantum number of the hydrogen atom is 3.

(ii) There is no difference of any two energy levels equal to the energy of the photon. [1]

(iii) There are 3 possible transitions. [1]

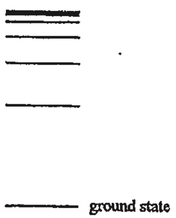
The transition from the second excited state to the first excited state gives the visible light. [1]

Since the energy of the photon in this transition is given by

$$\Delta E = (-\frac{13.6}{3^2}) - (-\frac{13.6}{2^2}) = 1.89\text{ eV}$$

which is within the range of visible light photon [1]

Q2. (a)



[1]

(b) The condition in which the electron is in the lowest energy state available. [1]

(c) The electron is free from the influence of the atom. [1]

(d) $E_o(\dfrac{1}{2^2}-\dfrac{1}{3^2}) = (6.63\times10^{-34})\times\dfrac{3\times10^{8}}{600\times10^{-9}}$ [1]

$\therefore E_o = 2.39\times10^{-18}\text{ J}$ [1]

Ionization potential energy $= \dfrac{2.39\times10^{-18}}{1.6\times10^{-19}} = 14.9\text{ eV}$ [1]

Q2: (e) Level 1 : -14.9 eV [1]

Level 2 : $-14.9\times\frac{1}{4} = -3.7\text{ eV}$ [1]

Level 3 : $-14.9\times\frac{1}{9} = -1.7\text{ eV}$ [1]

Q3. (a) $\Delta E_1 = (-5.5)-(-10.4)$ [1]

$= 4.9\text{ eV}$ <accept 7.84×10^{-19} J> [1]

(b) $E = hf$

$\therefore (4.9\times1.6\times10^{-19}) = 6.63\times10^{-34}\times\dfrac{3\times10^{8}}{\lambda}$ [1]

$\therefore \lambda = 250\text{ nm}$ [1]

The radiation is ultra-violet. [1]

(c) As there is no difference of any two energy levels corresponding to 9 eV, [1]

the photon will not be absorbed. [1]

<Elastic collision occurs : cannot be accepted>

Q4. (a) (i) $\Delta E = \dfrac{hc}{\lambda}$ [1]

$\therefore [(-5.52)-(-10.38)]\times(1.6\times10^{-19}) = \dfrac{(6.63\times10^{-34})\cdot(3\times10^{8})}{\lambda}$ [1]

$\therefore \lambda = 2.56\times10^{-7}\text{ m}$ [1]

The radiation is ultra-violet. [1]

(ii) (I) Energy of the photon emitted by the Mercury atom $= (-5.52)-(-10.38) = 4.86\text{ eV}$

After absorbing this photon, coating atom has energy :

$E = (-7.52)+4.86 = -2.66\text{ eV}$

The atom is excited to level C. [1]

(II) Energy of violet light $= 3.11\text{ eV}$

Energy of red light $= 3.11\times\dfrac{400}{700} = 1.78\text{ eV}$

Thus the energy difference between two levels should be within the range of 1.78 eV to 3.11 eV. [1]

Visible light is emitted :

① for transition from C to A ; and [1]

② for transition from A to ground state. [1]

Q4. (b) (i) [2]

Colour of visible light emitted	Energy of emitted photon / eV	Name of coating atom
Red	1.80	Atom Z
Green	2.31	Atom X
Blue	2.75	Atom Y

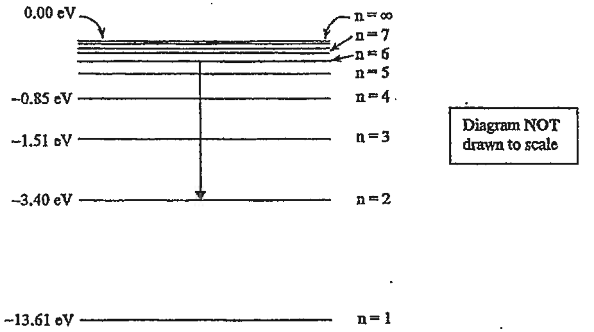
(ii) Yes, the energy of the electron beam can be the same. [1]

The coating atom can absorb only part of the kinetic energy of the incident electron. [1]

Q5. (a) $\Delta E = \dfrac{hc}{\lambda} = \dfrac{(6.63\times10^{-34})(3\times10^{8})}{(410.2\times10^{-9})} = 4.85\times10^{-19}\text{ J} = 3.03\text{ eV}$ [1]

Energy level from which it starts $= -3.40 + 3.03 = -0.37$ eV [1]

(b) [1]



Q6. When a high voltage is applied across electrodes A and B, [1]

the gas atoms at low pressure would be excited by the fast bombarding electrons. [1]

When these excited gas atoms return to the ground state,

a characteristic emission line spectrum would be produced, [1]

which is identical to that produced by the helium in the laboratory.

Q7. (a) (i) $\lambda = 656.3$ nm [1]

(ii) It belongs to ultra-violet radiation. [1]

Q7. (b) Electrons transitions from a high energy level to a lower energy one within an excited atom. [1]

Discrete lines show that energy levels in an atom are discrete. [1]

(c) (i) $\lambda = (364.6\text{ nm})\dfrac{n^2}{n^2-4}$ $\quad\therefore\ \dfrac{1}{\lambda} = \dfrac{1}{364.6}\times\left(\dfrac{n^2-4}{n^2}\right) = -\dfrac{1}{364.6}\times\left(\dfrac{4}{n^2}-1\right) = -\dfrac{1}{364.6}\times4\left[\dfrac{1}{n^2}-\dfrac{1}{4}\right]$

$hf = \dfrac{hc}{\lambda} = \dfrac{-hc}{364.6\text{nm}}\times4\left[\dfrac{1}{n^2}-\dfrac{1}{4}\right]$ [1]

(ii) $K = \dfrac{-6.626\times10^{-34}\times3\times10^{8}}{364.6\times10^{-9}}\times4\times\dfrac{1}{1.6\times10^{-19}}$ [1]

$= -13.6$ eV [1]

Negative value means the electron is under attraction force [1]

and the magnitude is the energy of that level with respect to E_∞ [1]

Q8. (a) No. of photons emitted per second $= \dfrac{8.0\times10^{-3}}{1.6\times10^{-19}}$ [1]

$= 5\times10^{16}$ [1]

(b) $E = \dfrac{hc}{\lambda}$ [1]

$(1.85\times1.6\times10^{-19}) = \dfrac{h(3\times10^{8})}{6.88\times10^{-7}}$

$\therefore\ h = 6.79\times10^{-34}$ J s $\quad$ <accept 6.71×10^{-34} J s to 6.86×10^{-34} J s> [1]

2.4 Particles or Waves

Speed of light in vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
Charge of electron	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
Electron rest mass	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$

The following list of formulae may be found useful :

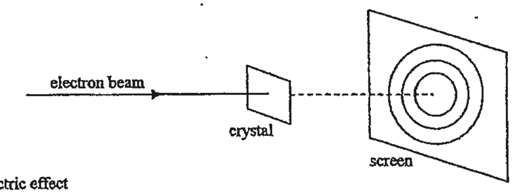
de Broglie formula $\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

Part A :

The following questions marked with {PP} are the Practice Paper questions of the new DSE Examination.

M1. The de Broglie wavelength of a particle at speed v is λ. If the speed of the particle is doubled, the de Broglie wavelength is
{PP} A. $\lambda/4$
B. $\lambda/2$
C. λ
D. 2λ

M2. A beam of electrons is incident on a thin film of crystal. A pattern of bright and dark rings is observed on a fluorescent
{PP} screen. Which physical phenomenon explains the formation of the pattern ?



A. Photoelectric effect
B. Electron diffraction
C. Ionization of atoms
D. Lotus effect

Part B :

The following question marked with { } is the past DSE question. The number inside the bracket represents the year of the examination.

M3. Which of the following has the shortest de Broglie wavelength ?
{12} A. A 60 kg person walking at 0.8 m $\mathrm{s^{-1}}$.
B. A bird of mass 0.3 kg flying at 20 m $\mathrm{s^{-1}}$.
C. A basketball of mass 0.6 kg moving at 12 m $\mathrm{s^{-1}}$.
D. A bullet of mass 0.05 kg moving at 800 m $\mathrm{s^{-1}}$.

Part C :

The following questions are designed to give supplemental exercise for this chapter.

M4. Which of the following suggests that electrons can behave like waves ?

(1) Electron shows diffraction pattern.
(2) When light is incident onto a metal surface, electrons are ejected.
(3) Electron beam is deflected by an electric field.

A. (1) only
B. (1) & (2) only
C. (2) & (3) only
D. (1), (2) & (3)

M5. An electron is accelerated from rest through a potential difference of 500 V. What is the final de Broglie wavelength of the electron ?

A. 4.4×10^{-11} m
B. 5.5×10^{-11} m
C. 6.6×10^{-11} m
D. 7.7×10^{-11} m

M6. Find the momentum of each photon of light with wavelength 6.52×10^{-7} m.

A. 1.0×10^{-27} kg m s^{-1}
B. 1.5×10^{-27} kg m s^{-1}
C. 2.0×10^{-27} kg m s^{-1}
D. 2.5×10^{-27} kg m s^{-1}

M7. Which of the following suggests that light can behave like particles ?

(1) Light shows interference pattern after passing through double slit.
(2) Light can emit electrons when it is incident onto a metal surface.
(3) Light transmits through the space by the oscillation of electric and magnetic field.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M8. Which of the following phenomena can only be explained by the wave nature of light ?

(1) reflection
(2) diffraction
(3) interference

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M9. A moving football does not show the wave properties because

(1) the momentum of the football is too large.
(2) the momentum of the football is too small.
(3) the de Broglie wavelength of the football is too long.
(4) the de Broglie wavelength of the football is too short.

A. (1) & (3) only
B. (1) & (4) only
C. (2) & (3) only
D. (2) & (4) only

M10. Arrange the de Broglie wavelengths of the following particles in ascending order.

(1) a proton of kinetic energy 1000 eV
(2) a neutron of kinetic energy 500 eV
(3) an electron of kinetic energy 500 eV

A. (1), (2), (3)
B. (1), (3), (2)
C. (2), (1), (3)
D. (3), (1), (2)

M11. Light of frequency 5×10^{14} Hz consists of photons of momentum

A. 4.0×10^{-40} kg m s^{-1}
B. 3.7×10^{-36} kg m s^{-1}
C. 1.7×10^{-28} kg m s^{-1}
D. 1.1×10^{-27} kg m s^{-1}

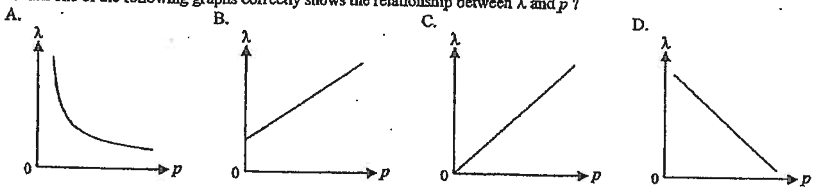
M12. The de Broglie wavelength of a rifle bullet of mass 0.02 kg which is moving at a speed of 300 m s^{-1} is

A. 7.3×10^{-36} m
B. 1.8×10^{-35} m
C. 1.1×10^{-34} m
D. 9.9×10^{33} m

M13. The wave nature of electrons is suggested by experiments on

A. line spectra of atoms
B. the production of X-rays
C. the photoelectric effect
D. electron diffraction by a crystalline material

M14. In 1923, de Broglie suggested that an electron of momentum p has properties corresponding to a wave of wavelength λ. Which one of the following graphs correctly shows the relationship between λ and p ?



M15. A beam of light of wavelength λ is totally reflected at normal incidence by a plane mirror. The intensity of the light is such that photons hit the mirror at a rate of n. Given that the Planck constant is h, the force exerted on the mirror by this beam is

A. $n h \lambda$
B. $n h / \lambda$
C. $2 n h \lambda$
D. $2 n h / \lambda$

M16. If the de Broglie waves associated with each of the following particles are to have the same wavelength, which particle must have the smallest velocity ?

A. proton
B. alpha particle
C. electron
D. neutron

M17. What is the de Broglie wavelength of a particle of mass m and kinetic energy E ?

A. $h\sqrt{2mE}$

B. $\frac{\sqrt{2mE}}{h}$

C. $\frac{h}{\sqrt{mE}}$

D. $\frac{h}{\sqrt{2mE}}$

M18. The intensity of a beam of monochromatic light is doubled. Which one of the following represents the corresponding change, if any, in the momentum of each photon of the radiation ?

A. increased fourfold

B. doubled

C. the same

D. halved

Answers

1. B	6. A	11. D	16. B
2. B	7. B	12. C	17. D
3. A	8. D	13. D	18. C
4. A	9. B	14. A	
5. B	10. A	15. D	

Solution

1. B

By $\lambda = \frac{h}{mv}$, if v is doubled, λ is halved.

2. B

The electron has wave properties with wavelength expressed by the de Broglie formula.

The electrons are diffracted by the crystal after they passes through the crystal to give the bright and dark rings.

3. A

By $\lambda = \frac{h}{p} = \frac{h}{mv}$, the one with the greatest momentum p gives the shortest de Broglie wavelength.

Momentum of the person $= 60 \times 0.8 = 48$ kg m s^{-1}

Momentum of the bird $= 0.3 \times 20 = 6$ kg m s^{-1}

Momentum of the basketball $= 0.6 \times 12 = 7.2$ kg m s^{-1}

Momentum of the bullet $= 0.05 \times 800 = 40$ kg m s^{-1}

Since the person has the greatest momentum, it has the shortest de Broglie wavelength.

4. A

✓ (1) Diffraction is the evidence of wave property.

× (2) This is photoelectric effect, which is an evidence that light behaves like particles, not electrons behave like waves.

× (3) This is the particle nature of electrons.

5. B

$KE = eV$

The de Broglie wavelength of the electron is given by $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

$$\therefore \lambda = \frac{6.63\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1.60\times10^{-19}\times500}} = 5.5\times10^{-11}\text{ m}$$

6. A

$$p = \frac{h}{\lambda} = \frac{(6.63\times10^{-34})}{(6.52\times10^{-7})} = 1.0\times10^{-27}\ \text{kg m s}^{-1}$$

7. B

× (1) This is the evidence that light behaves like waves.

✓ (2) This is photoelectric effect, which is an evidence that light behaves like particles.

× (3) This is the propagation of electromagnetic waves.

8. D

× (1) Both particle and wave can show reflection.

✓ (2) Only a wave can show diffraction.

✓ (3) Only a wave can show interference.

9. B

Since the momentum of a football is very large, by $\lambda = h/p$,
the de Broglie wavelength is very short,
thus the wave behaviour of diffraction and interference can hardly show.

10. A

Let the kinetic energy of the particle be E.

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$$

The neutron has less E than the proton, but their masses are similar,
thus the wavelength of the neutron is longer than the proton.

The electron has less mass than the neutron, but their kinetic energies are the same,
thus the wavelength of the electron is longer than the neutron.

The wavelength in ascending order (from short to long) is then (1), (2), (3)

11. D

$$\lambda = \frac{c}{f} = \frac{(3\times10^{8})}{(5\times10^{14})} = 6\times10^{-7}\ \text{m}$$

$$p = \frac{h}{\lambda} = \frac{(6.63\times10^{-34})}{(6\times10^{-7})} = 1.1\times10^{-27}\ \text{kg m s}^{-1}$$

12. C

$$p = mv = (0.02)(300) = 6\ \text{kg m s}^{-1}$$

$$\lambda = \frac{h}{p} = \frac{(6.63\times10^{-34})}{(6)} = 1.1\times10^{-34}\ \text{m}$$

13. D

Diffraction can show the wave nature of electrons.

14. A

By de Broglie relationship : $\lambda = \dfrac{h}{p}$

λ and p are inversely proportional, thus the curve in option A is correct.

15. D

Momentum of each photon : $p = h/\lambda$

Change of momentum after collision $= p - (-p) = 2p$

Force $=$ rate of change of momentum $=$ rate of collision × change of momentum

$$= n\times2p = n\times2h/\lambda = 2nh/\lambda$$

16. B

By $\lambda = h/p$, to have the same wavelength, they must have the same momentum p or mv.
The particle that has the smallest velocity v corresponds to the largest mass m.
Alpha particle has the largest mass among the four, thus it has the smallest velocity.

17. D

$$E = \tfrac{1}{2}mv^2 = \frac{(mv)^2}{2m} = \frac{p^2}{2m} \quad \therefore\ p = \sqrt{2mE}$$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$$

18. C

The intensity of light only affects the number of photons transmitted per second.
As the momentum of photon depends on the wavelength or frequency of the light,
the momentum of photon should remain the same.

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
Charge of electron	$e = 1.60 \times 10^{-19}$ C
Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Planck constant	$h = 6.63 \times 10^{-34}$ J s

The following list of formulae may be found useful :

de Broglie formula $\qquad \lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

Part A :

The following question marked with {SP} is the Sample Paper question of the new DSE Examination.

Q1. {SP} An electron is accelerated from rest through a potential difference V (in V). Show that its final de Broglie wavelength λ (in nm) is given by $\lambda = \dfrac{1.23}{\sqrt{V}}$. (2 marks)

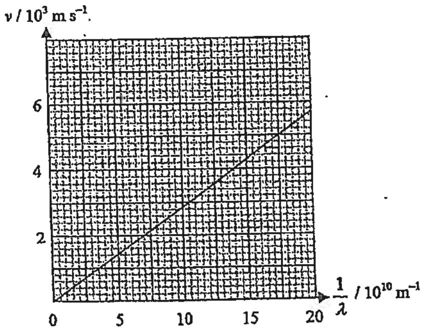
____

____

Part B :

The following question is designed to give supplemental exercise for this chapter.

Q2. The figure below shows the speed v of an ion against $1/\lambda$ where λ is the de Broglie wavelength of the ion.



(a) Find the slope of the graph, with suitable unit. (2 marks)

____

____

(b) Determine the mass of the ion. (2 marks)

____

____

Q1. After accelerated through the p.d. : $KE = eV$

Relation between KE and momentum,

$$KE = \frac{1}{2}mv^2 = \frac{(mv)^2}{2m} = \frac{p^2}{2m}$$

$$\therefore\ p = 2m \times KE = 2meV$$

The de Broglie wavelength of the electron is given by

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} \qquad [1]$$

$$= \frac{6.63\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1.60\times10^{-19}\times V}} \qquad [1]$$

$$= \frac{1.23}{\sqrt{V}}$$

Q2. (a) slope of the graph $= \dfrac{(5-0)\times10^3}{(17.5-0)\times10^{10}}$ [1]

$= 2.86\times10^{-8}\ \text{m}^2\,\text{s}^{-1}$ [1]

(b) By de Broglie relationship,

$$p = mv = \frac{h}{\lambda} \qquad \therefore\ v = \frac{h}{m}\cdot\frac{1}{\lambda}$$

$$\text{slope} = \frac{h}{m} \qquad [1]$$

$$(2.86\times10^{-8}) = \frac{(6.63\times10^{-34})}{m}$$

$$m = 2.32\times10^{-26}\ \text{kg} \qquad [1]$$

2.5 Probing into nano scale

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3.00 \times 10^8\ \mathrm{m\,s^{-1}}$
Charge of electron	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
Electron rest mass	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$

The following list of formulae may be found useful :

de Broglie formula	$\lambda = \frac{h}{p} = \frac{h}{mv}$
Rayleight criterion (resolving power)	$\theta \approx \frac{1.22\lambda}{d}$

Part A :

The following question marked with {SP} is the Sample Paper question of the new DSE Examination.

M1. Graphite is a conductor because of the 'delocalization' of electrons. Where are these delocalized electrons ?

{SP} A. formed on the surface of graphite

B. formed within the carbon layers of graphite

C. formed homogeneously within graphite

D. formed in a 'sea' of positive ions

Part B :

The following questions marked with {PP} are the Practice Paper questions of the new DSE Examination.

M2. Which of the following statements about different microscopes is/are correct ?

{PP} (1) The resolution of an optical microscope will increase if red light instead of blue light is used to illuminate the specimen.

(2) A transmission electron microscope (TEM) uses magnetic field to focus the electron beam.

(3) Only specimens that conduct electricity can be studied by a scanning tunnelling microscope (STM).

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M3. Which of the following are possible means by which nano particles could get into the human body ?

{PP} (1) The skin having direct contact with nano particles.

(2) Inhaling nano particles into the lungs while breathing.

(3) Ingesting food containing nano particles.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M4. Estimate the wavelength of electrons when they are accelerated in a transmission electron microscope (TEM) with a voltage {PP} of 76 kV.

A. 2.4×10^{-12} m
B. 4.5×10^{-12} m
C. 1.4×10^{-10} m
D. 9.6×10^{-9} m

Part C :

The following questions marked with { } are the past DSE questions. The number inside the brackets represents the year of the examination.

M5. Which of the following properties could explain Lotus effect ?
{12} A. water-attractive property
B. water-repelling property
C. wave-particle duality of matter
D. high electrical conductivity

M6. If substance is reduced in size to become particles of about 10 nm large, which of the following properties of these particles {12} would differ from those of the substance in bulk form ?

(1) optical
(2) mechanical
(3) electrical

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

Part C :

The following questions are designed to give supplemental exercise for this chapter.

M7. In a transmission electron microscope, electrons are accelerated by a potential difference of 50 kV. How many times is the resolving power greater than that of an optical microscope viewing object with an average wavelength of 550 nm ?

A. 10^3
B. 10^4
C. 10^5
D. 10^6

M8. Which of the following is NOT a possible form of nano materials ?

A. nano tubes
B. nano films
C. nano triangles
D. nano spheres

M9. Which of the following statements is/are correct ?

(1) Nanomaterial refers to materials having the size of exactly 1 nm.
(2) Nanotechnology can be started after the electron microscopes have been invented.
(3) The scale of nano is close to the atomic size.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M10. Nano materials have different properties compared with the large scale materials. Which of the following give(s) the correct reason ?

(1) In nano scale, the area to volume ratio largely increases.
(2) In nano scale, the de Broglie wavelength of matter becomes more significant.
(3) In nano scale, the atoms would become smaller.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M11. The pupil of a human eye has a diameter of about 4.8 mm. If the eye is viewing a red object having a wavelength of 700 nm, what is the angular resolution of the eye ?

A. 1.78×10^{-4} rad
B. 2.42×10^{-4} rad
C. 3.76×10^{-4} rad
D. 4.94×10^{-4} rad

M12. Which of the following concerning the structure of C_{60} molecule is/are correct ?

(1) It has 60 vertices.
(2) It has 90 edges.
(3) It has 32 faces.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M13. Which of the following is NOT a type of electron microscope ?

A. TEM
B. TSM
C. SEM
D. STM

M14. Which of the following is NOT the component of a STM ?

A. piezoelectric controlled scanner
B. distance control and scanning unit
C. electromagnetic lens system
D. vibration isolation system

M15. A typical TEM consists of 4 components :

(a) Electromagnetic lens system

(b) Imaging system

(c) Electron source

(d) Sample holder

List the 4 components in order that the electron beam would pass through.

A. (a), (b), (c), (d)
B. (c), (a), (d), (b)
C. (c), (d), (a), (b)
D. (c), (a), (b), (d)

M16. What is the characteristics of the surface of a Lotus leaf ?

(1) No dirt can be found on the leaf.

(2) No water can be found on the leaf.

(3) Water droplet can roll off the leaf easily.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

Answers

1. B	6. D	11. A	16. B
2. D	7. C	12. D	
3. D	8. C	13. B	
4. B	9. D	14. C	
5. B	10. C	15. B	

Solution

1. B

The free mobile delocalized electrons exist between layers of graphite.

2. D

× (1) As the wavelength of red light is increased,
the angular separation θ is increased by the Rayleigh Criterion : $\theta \approx 1.22\ \lambda / D$.
Thus the resolving power of red light is decreased, as smaller θ gives greater resolving power.

✓ (2) The electron beam is focused by the magnetic field of the electromagnets in a TEM.

✓ (3) Since a voltage is applied across the specimen and the scanning tip to give the fine beam of electrons, the specimen should conduct electricity.

3. D

✓ (1) Nano particles are so tiny that they enter the human body through the skin.

✓ (2) While breathing, the nano particles may move together with the air to enter the lungs.

✓ (3) The nano particles may enter the blood vessels through the digestive canal of the human body.

4. B

By $eV = \frac{1}{2} m v^2 = \frac{p^2}{2m}$

$\therefore p = \sqrt{2meV} = \sqrt{2(9.11\times10^{-31})(1.6\times10^{-19})(76\times10^{3})} = 1.488 \times 10^{-22}\ \text{kg m s}^{-1}$

De Broglie wavelength : $\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{1.488\times10^{-22}} = 4.5 \times 10^{-12}\ \text{m}$

5. B

The Lotus leaf has a super-hydrophobic surface, which is water-repelling,
so that water would not wet the leaf surface but forms droplets.

6. D

In nano scale, the substance would have different optical, mechanical and electrical properties.

7. C

By $eV = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

$\therefore p = \sqrt{2meV} = \sqrt{2(9.11\times10^{-31})(1.6\times10^{-19})(50\times10^3)} = 1.21\times10^{-22}$ kg m s^{-1}

De Broglie wavelength : $\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{1.21\times10^{-22}} = 5.49\times10^{-12}$ m

By Rayleigh criterion, resolving power : $\theta = 1.22\frac{\lambda}{D}$ $\therefore \theta \propto \lambda$

$\therefore$ Number of times that the resolving power is greater $= \frac{550\times10^{-9}}{5.49\times10^{-12}} = 10^5$

8. C

The form of nano triangles does not exist.

9. D

× (1) Nanomaterials refer to materials with sizes about 1 nm to 100 nm.

✓ (2) After the electron microscopes have been invented, the material in nano scale can then be viewed.

✓ (3) The size of atom is of the order of 10^{-10} m, which is close to the nano scale.

10. C

✓ (1) Much more atoms are at the surface in nano scale.

✓ (2) The effect of matter wave would be more significant.

× (3) Size of atom would not change.

11. A

$\theta = 1.22\frac{\lambda}{D} = 1.22\frac{700\times10^{-9}}{4.8\times10^{-3}} = 1.78\times10^{-4}$ rad

12. D

✓ (1) Each atom form a vertex, thus 60 atoms form 60 vertices.

✓ (2) Each atom is connected to 3 other atoms, thus the number of edges = $60\times3/2 = 90$

✓ (3) By Euler's formula : $F + V - E = 2$, the number of faces F is 32.

13. B

There is no microscope called TSM.

14. C

A STM does not contain electromagnetic lens system.

15. B

Electron beam passes through : electron source, electromagnetic lens system, sample holder, imaging system.

16. B

× (1) Dirt may be found on a Lotus leaf, but it may be washed away by water droplets if there is rainfall.

× (2) Water droplets may be found on the Lotus leaf.

✓ (3) Since the leaf surface is water repelling, the water droplet can roll of easily.

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3.00 \times 10^8$ m s^{-1}
Charge of electron	$e = 1.60 \times 10^{-19}$ C
Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Planck constant	$h = 6.63 \times 10^{-34}$ J s

The following list of formulae may be found useful :

de Broglie formula	$\lambda = \frac{h}{p} = \frac{h}{mv}$
Rayleight criterion (resolving power)	$\theta \approx \frac{1.22\lambda}{d}$

Remark : The following question marked with {SP} is the Sample Paper question of the new DSE Examination.

Q1. {SP} (a) An electron is accelerated from rest through a potential difference V (in V). Show that its final de Broglie wavelength λ (in nm) is given by $\lambda = \frac{1.23}{\sqrt{V}}$. (2 marks)

(b) In a transmission electron microscope (TEM), electrons are accelerated by a potential difference of 50 kV.

(i) Estimate the final de Broglie wavelength of the electrons. (1 mark)

(ii) Describe how the electrons are focused in the TEM and explain how the image of the sample is formed. (3 marks)

(iii) Suggest ONE method to increase the resolving power of the TEM. Explain. (2 marks)

(c) State ONE daily life application of nanotechnology and discuss any potential health risks associated with it. (2 marks)

Q1. (a) $KE = eV$

The de Broglie wavelength of the electron is given by

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} \quad [1]$$

$$= \frac{6.63\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1.60\times10^{-19}\times V}} \quad [1]$$

$$= \frac{1.23}{\sqrt{V}}$$

(b) (i) De Broglie wavelength :

$$\lambda = \frac{1.23}{\sqrt{50\times10^3}} = 0.0055 \text{ nm} \quad [1]$$

(ii) The electron beam is focused onto the sample by the magnetic field of the condenser lens. [1]

The transmitted beam through the sample is then projected by the objective and projector lenses onto an imaging device. [1]

Due to the different degree of transmission of electrons at different regions of the sample, the details of the sample can be displayed by the imaging device according to the information carried by the transmitted beam. [1]

(iii) The resolving power can be increased by increasing the accelerating voltage V so that [1]
the wavelength λ of the electrons can be further decreased so as to minimize the effects of diffraction. [1]

< OR >

The resolving power can be increased by increasing the accelerating voltage V so that [1]
the wavelength λ of the electrons can be further decreased,
and by Rayleigh criterion, the minimum angular separation angle can be further reduced. [1]

(c) Any ONE of the following OR other reasonable answers : [1]

* Nanoparticles used in cosmetic products to improve cleaning effect on our skin.
* A thin layer of nano paint containing nanoparticles possesses anti-bacterial and detoxicating abilities.

These nanoparticles are so small that they may enter our body through the skin.
Their long-term effects on human body are not known, and may pose threat to our health. [1]

< Accept other reasonable answers. >