Original Questions

Book 7

Chapter Exercise

Take $h = 6.63 \times 10^{-34}$ J s, $e = 1.60 \times 10^{-19}$ C and $c = 3 \times 10^{8}$ m s^{-1}. For other physical constants, see the Appendix.

Multiple-choice Questions

1. A metal surface is illuminated by yellow light of wavelength 570 nm but no photoelectrons are emitted. It can be concluded that

(1) the yellow light is not intense enough to induce the emission of photoelectrons.

(2) the work function of the metal is larger than 2.18 eV.

(3) photoelectrons will be emitted if the surface is illuminated by blue light of wavelength 470 nm.

A. (1) only B. (2) only

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

2. Ultraviolet radiation of frequency f is directed onto the cathode of a photocell of work function ϕ. If a photoelectron is able to reach the anode of the photocell, its KE when emitted MUST be

A. $= hf - \phi$. B. $\geq hf - \phi$.

C. $\geq hf + \phi$. D. $\leq hf - \phi$.

3. Photoelectrons are emitted by a metal surface S when ultraviolet radiation from a source X falls on it. A glass plate is then placed between S and X. Which of the following will decrease?

(1) The number of photons emitted from X

(2) The number of photoelectrons emitted per second

(3) The work function of the metal

A. (1) only B. (2) only

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

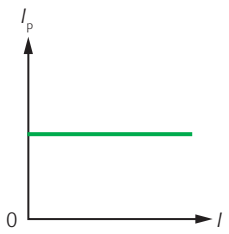
4. Photoelectrons are emitted when electromagnetic radiation of a certain wavelength is directed onto the cathode of a photocell. Which of the following graphs is correct?

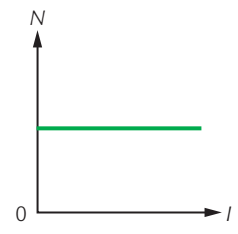
N = number of photoelectrons emitted per second

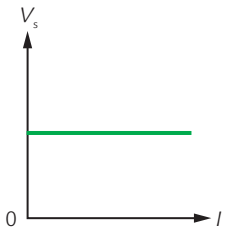
I = radiation intensity

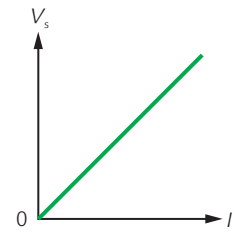
I_p = photoelectric current

V_s = stopping potential

A. 

B. 

C. 

D. 

5. A student has a few photocells having cathodes of different work functions. Radiation beams of the same intensity but different frequencies are directed onto the cathodes of the cells.

photocell	work function / eV
P	2.8
Q	3.3
R	4.0

radiation	frequency / 10^{14} Hz
X	9.0
Y	10.0
Z	11.0

Which combination of photocell and radiation will result in the smallest stopping potential?

A. P and X B. P and Z

C. Q and X D. R and Y

6. In a photocell experiment studying the photoelectric effect, the following data is obtained.

wavelength of light / nm	cathode material	work function / eV	photocurrent / 10^{-12} A
320	aluminium	4.1	0
320	lithium	2.3	1.0

What is the stopping potential for the photoelectrons emitted from lithium when shone with light of wavelength 320 nm?

Given $hc = 1243$ eV nm.

A. $\left(\frac{1243}{320} - 4.1\right)$ V B. $\left(\frac{1243}{320} - 2.3\right)$ V

C. 4.1 V D. 2.3 V

7. A beam of red light falling on the cathode of a photocell yields a photoelectric current. If a beam of equal intensity but higher frequency is used, what happens to the following quantities? Assume the ratio of electrons emitted to photons absorbed remains the same.

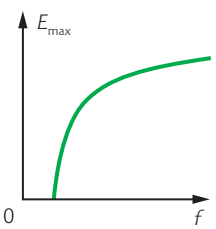
K_{avg}: the **average** KE of the photoelectrons
I: the magnitude of the photoelectric current

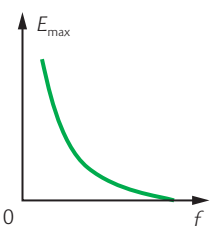
	K_{avg}	I
A.	increase	increase
B.	increase	stay the same
C.	increase	decrease
D.	stay the same	decrease

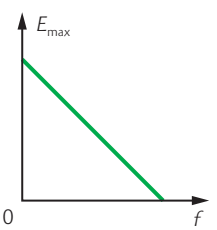
8. A beam of blue laser falls on the cathode of a photocell and electrons are emitted. The blue laser is then replaced by a green laser of the same intensity. Which of the following would increases as a result of the change? Assume the ratio of electrons emitted to photons absorbed remains the same.

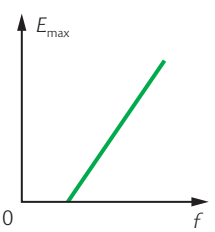
A. The max KE of the photoelectrons
B. The energy of the each photon falling on the cathode
C. The number of the photons falling on the cathode per second
D. The magnitude of the stopping potential

9. **IB Higher Level Nov 2008** Light of frequency f is incident on a clean metal surface. The maximum energy of the electrons emitted from the surface is E_{max}. Which of the following sketch-graph best shows the variation with f of E_{max}?

A.


B.


C.


D.


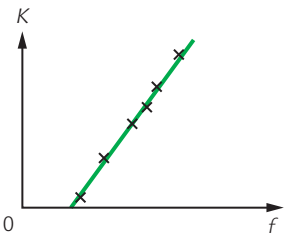
10. **IB Higher Level Nov 2009** Which of the following is a correct statement associated with the photoelectric effect?

A. Electron emission is instantaneous.
B. Electrons are only emitted if the incident light is above a certain minimum wavelength.
C. The energy of the emitted electrons depends on the light intensity.
D. The energy of the emitted electrons does not depend on the frequency of the incident light.

11. **HKDSE 2012** Photons with energy 7 eV are incident on the cathode of a photocell. The maximum kinetic energy of the photoelectrons 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

12. **HKDSE 2012** In studying the photoelectric effect, a certain metal is illuminated by ultraviolet radiation of different frequency f and the 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

13. **HKDSE 2014** When photons each of energy 3.41 eV are incident on a metal surface, the maximum kinetic energy of the photoelectrons emitted is 0.54 eV. What is the threshold frequency of this metal?

A. 4.33×10^{33} Hz
B. 9.53×10^{14} Hz
C. 8.23×10^{14} Hz
D. 6.93×10^{14} Hz

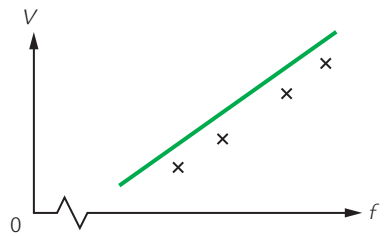
14. **HKDSE 2014** A beam of light of frequency f falls on the cathode of a photocell so that photoelectrons are emitted. If the light beam is replaced by another one with the same intensity but having a frequency of $2f$, how would each of the following physical quantities change? Assume that each incident photon can emit one photoelectron.

V_s: stopping potential

I: magnitude of the saturation photoelectric current

	V_s	I
A.	increases	increases
B.	increases	decreases
C.	remains unchanged	decreases
D.	decreases	increases

15. **HKALE 1994**



A student measures the pd V to stop photoelectrons emitted in a photocell illuminated by monochromatic light of various frequencies f. The resulting points when plotted on a V–f graph (as shown) do not lie on the solid line drawn from standard results obtained with a similar photocell. The reason could be

A. the standard results are obtained with light of higher intensity.

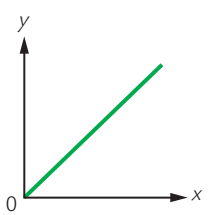
B. he has used a voltmeter which has a fixed zero error.

C. he has read the wrong scale on his voltmeter so that his readings always double the actual readings.

D. he has connected the variable dc supply with the wrong polarities to the photocell.

E. he has plotted the wavelength of light in place of the frequency on the horizontal axis.

16. **HKALE 2000** In a series of photoelectric emission experiments on a certain metal surface, relationships between the following quantities were investigated.



f = frequency of incident light

I = intensity of incident light

i = photoelectric current

K = maximum kinetic energy of photoelectrons

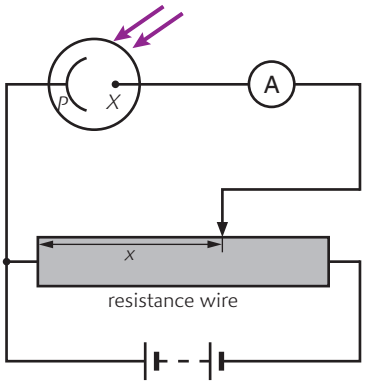
Two of these quantities, when plotted on a graph of y against x, would give a straight line through the origin. Which of the following correctly identifies x and y?

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

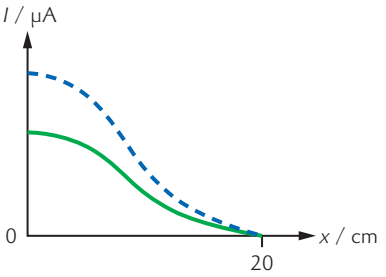
	x	y
A.	K	i
B.	f	K
C.	f	i
D.	I	K
E.	I	i

Structured Questions

17. A photocell is connected to a 6 V battery and a sensitive ammeter via a rheostat (a sliding contact and a uniform resistance wire) as shown.



A beam of electromagnetic radiation of wavelength 200 nm is directed onto the cathode of the photocell and the ammeter reads a current. The graph below (solid curve) shows how this current I varies with the length of the resistance wire x. The ammeter has a negligible resistance.



(a) Explain why the current drops as x increases and remains at zero after x has reached 20 cm.

(2 marks)

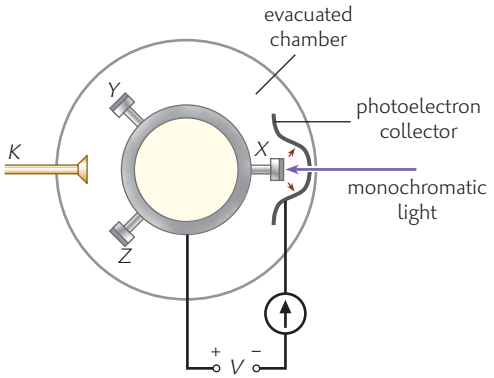
(b) Given that the total length of the resistance wire is 30 cm, calculate the work function and threshold frequency of this photocell. (5 marks)

(c) (i) Describe and explain how the horizontal intercept of this graph depends on the work function of the photocell and the radiation frequency. (2 marks)

(ii) Describe and explain how the vertical intercept of this graph depends on the number of photons delivered to the photocell per second. (2 marks)

(iii) Another radiation beam is used and the corresponding I–x graph (dotted curve) is plotted. Compare the intensities and frequencies of the two beams. (4 marks)

18. Millikan's experiment: Below shows the set-up of an experiment verifying Einstein's photoelectric equation in 1909. Three metal pieces, lithium, sodium and potassium, are mounted on X, Y and Z respectively.



(a) Explain why the walls of the chamber have to be non-photoemissive. (1 mark)

(b) The following table shows Millikan's data of the radiation wavelengths λ and the corresponding stopping potentials V_s for lithium.

λ / nm	V_s / V
405	0.220
365	0.563
313	1.15
254	2.10
210	3.14

(i) Plot the graph of V_s against frequency f for the metal. If the Einstein's idea is correct, the graph should be a straight line. (3 marks)

(ii) If we plot the graph of V_s against wavelength λ, will the graph be a straight line? (1 mark)

(iii) Calculate the work function of the metal. (2 marks)

(iv) Use the graph to give an estimate for the Planck constant h. Find the percentage error with respect to the standard value of 6.626×10^{-34} J s. (4 marks)

19. A student wishes to investigate the maximum kinetic energy of the photoelectron emitted in a photocell when it is illuminated by certain monochromatic radiation.

(a) Describe and explain an experiment to measure this maximum kinetic energy with the aid of a diagram. (5 marks)

(b) Using the quantum theory of light, describe and explain how the following will affect the result in (a).

(i) Use radiation of shorter wavelength. (2 marks)

(ii) Use radiation of the same wavelength but greater intensity. (2 marks)

(iii) Replace another photocell with an identical cathode but the distance between the cathode and the anode is shorter. (2 marks)

(iv) Place the radiation source closer to the photocell. (2 marks)

(c) Explain why the photoelectrons are emitted with a range of kinetic energy even though all the photons from the radiation source carry the same energy. (2 marks)

20. Ultraviolet radiation of wavelength 200 nm and intensity 200 W m^{-2} falls on the magnesium cathode of a photocell. The cathode has area 16 mm^2 and work function 3.66 eV.

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

(ii) Calculate the stopping potential and the maximum kinetic energy of the photoelectrons emitted. (3 marks)

(b) (i) Find the number of photons delivered by the radiation per second. (2 marks)

(ii) If 3% of the photons can induce the emissions of photoelectrons, find the number of photoelectrons emitted per second. (2 marks)

21. (a) State the conditions for the emission of photoelectrons to occur on a metal surface. (1 mark)

(b) Describe how photoelectrons are emitted from a metal surface with the concept of the photon. (3 marks)

We now compare the wave theory with the quantum theory of light.

(c) What is the difference in the absorption of radiation between the two theories? (2 marks)

(d) Compare the dependence of the emission of photoelectrons in the photoelectric effect on the intensity and frequency of the radiation in two theories. (4 marks)

22. **HKDSE Practice Paper**

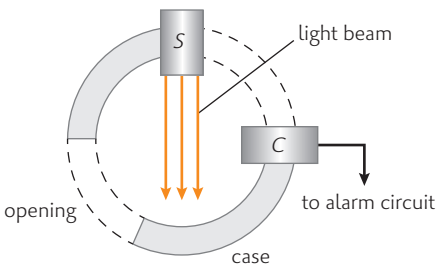
(a) In studying the photoelectrons emitted from sodium, it was found that no photoelectrons were emitted when the wavelength of the incident light was longer than 5.27×10^{-7} m.

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

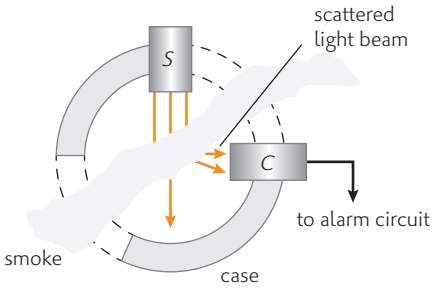
(ii) Determine the work function for sodium. Express your answer in electron-volts. (3 marks)

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

(b) Fig. a 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 Fig. 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.



Q22a

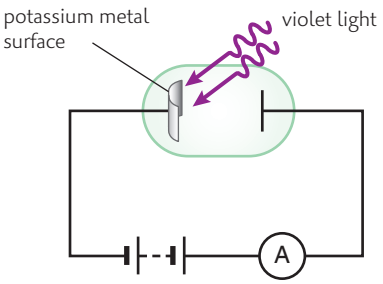


Q22b

(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)

(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)

23. **HKDSE 2013** A potassium metal surface is illuminated by violet light of a certain wavelength and the maximum kinetic energy of the electrons emitted from the metal surface is 0.81 eV. The work function of potassium is 2.30 eV.



(a) (i) Find the energy of a violet light photon in unit of eV. (1 mark)

(ii) Not all the electrons emitted can have maximum kinetic energy. Explain. (1 mark)

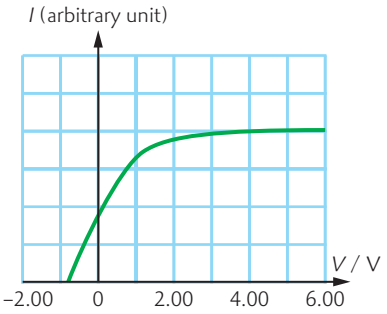
The intensity of the violet light used is 0.01 W m^{-2}.

(b) (i) According to classical wave theory, an atom has to absorb enough energy from light waves to eject an electron. Estimate the minimum time required for a potassium atom to absorb energy so as to eject an electron. Take the effective area of a potassium atom in absorbing energy as 0.01 nm^2 (1 nm = 10^{-9} m). (2 marks)

(ii) Explain why in experiments almost no time delay is observed for electrons to be ejected from the metal surface even though the intensity of light is very weak. (1 mark)

(c) If the area of the potassium metal surface receiving violet light is 4.00×10^{-4} m^2, how many photons hit the surface per second? Find the maximum photoelectric current if one electron is emitted for every 10 photons hitting the surface. (3 marks)

(d) The curve of the photoelectric current I against the potential difference across the cathode and the anode V is shown in the graph below.



COPY THE GRAPH TO YOUR ANSWER BOOK. If the light intensity is reduced to half of its original value, use a dotted line to sketch the corresponding curve in the graph you have copied. (2 marks)

24. **HKALE 1996** 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.

Given: Planck constant = 6.63×10^{-34} J s
charge of an electron = 1.6×10^{-19} C

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

(b) Explain why photoelectrons are emitted with different speeds though the energy of each incident photon is fixed. (1 mark)

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

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

(d) 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)

(e) 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)

25. **HKALE 2005** A group of students carried out a series of experiments investigating the emission of electrons from metals that are illuminated by electromagnetic radiation. They found that

(1) more electrons are ejected from the metal when a higher intensity of incident radiation at a constant frequency is used to illuminate the metal;

(2) the maximum kinetic energy of the ejected electrons is independent of the intensity of the incident radiation;

(3) no electrons are emitted from the metal if the frequency of the incident radiation is below a certain value.

(a) Describe briefly how you would demonstrate the observation (2). (4 marks)

(b) According to the wave theory of electromagnetic radiation, energy is delivered continuously and it is solely determined by the intensity of the radiation.

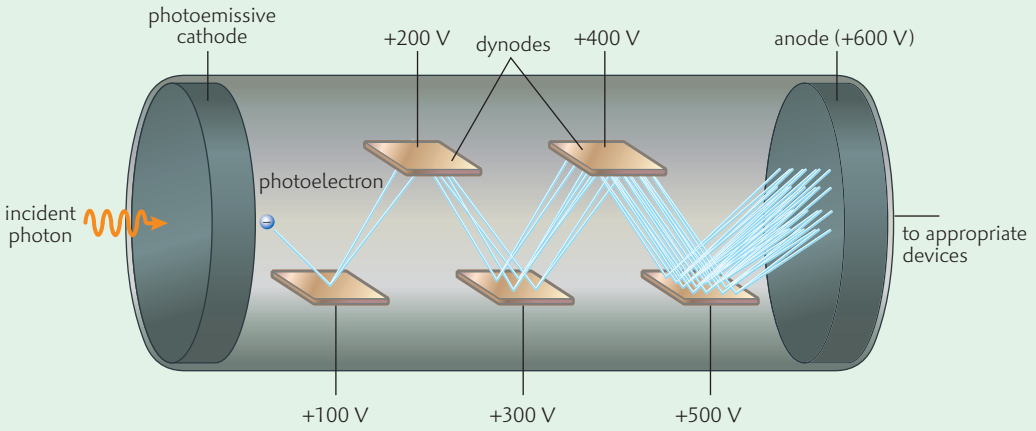
(i) Describe clearly which two observations are contrary to the predictions of wave theory. (3 marks)

(ii) Einstein suggested a theory to explain the two observations in (i). Briefly explain Einstein's theory and use it to account for these two observations. (4 marks)

26. Read the following article about the photomultiplier tube and answer the questions that follow.

Photomultiplier tube

A photomultiplier tube (PMT) can convert weak light to strong electrical signals. It is an evacuated glass tube which contains a photoemissive cathode, a series of positive electrodes called dynodes, and an anode. The dynodes are arranged in increasing electric potentials.



▲ The internal structure of a photomultiplier tube

Incident photons will cause the emission of electrons from the cathode. These electrons are then attracted to the first dynode. When they hit the dynode, they cause it to emit additional electrons. This happens at each dynode as the electrons move through the tube. The chain effect results in a strong electrical pulse at the anode with about 10^5 electrons corresponding to one incident photon. The signal can then be read using appropriate devices.

(a) (i) Why can photons cause the emission of electrons from the cathode? (1 mark)

(ii) Do you think a PMT can detect light of all wavelengths? Why? (2 marks)

(b) Why are the dynodes arranged in increasing potentials? (2 marks)

(c) PMTs can greatly amplify weak light signals and they find applications in particle physics, medical imaging and astronomical detectors. Briefly explain why PMTs are used in astronomical detectors. (2 marks)

Chapter Exercise

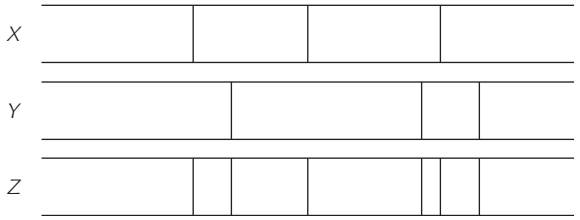
Given: **electron mass = 9.11×10^{-31} kg**
electron charge (magnitude) = 1.60×10^{-19} C
speed of light in a vacuum = 3×10^{8} m s^{-1}
Planck constant = 6.63×10^{-34} J s

Multiple-choice Questions

1. According to the classical theory, what would happen if the electron in Rutherford's atomic model loses energy continuously?

A. It would spiral inward and crash into the nucleus.
B. It would stay in its orbit.
C. It would spiral outwards and escape from the nucleus.
D. It would oscillate in its orbit.

2. Shown below are the line spectra of three gases *X*, *Y* and *Z*.

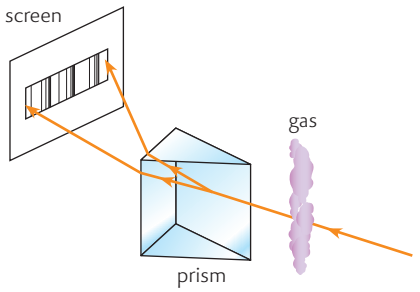


Which of the following statements is/are correct?

(1) *Z* is a constituent of *X*.
(2) A mixture of *X* and *Y* produces a line spectrum with the same pattern as that of *Z*.
(3) Discrete lines are formed in the spectra because the gases emit EM waves in specific directions.

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

3. A beam of white light passes through a gas and then a prism. The spectrum formed consists of discrete dark lines at certain wavelengths.

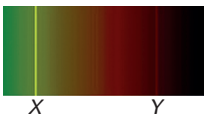


It can be deduced that

(1) the elements responsible for the dark lines are absent from the gas.
(2) the gas absorbs radiation of those wavelengths.
(3) the gas can emit radiation of those wavelengths.

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

4. Shown below are two neighbouring emission lines in the spectrum of a hot gas.



Line *X* is brighter than line *Y*. Which of the following may be its cause?

A. *X* is at a higher frequency.
B. *X* is produced by the light coming from a hotter region in the gas.
C. More gas atoms undergo the transition that produces *X*.
D. The transition that produces *X* occurs at higher levels.

5. A sodium lamp works by exciting sodium vapour at a low pressure.

The emission spectrum of sodium contains two lines at wavelengths 589.0 nm and 589.6 nm. These two lines are produced by transitions that end at the same level. It can be deduced that the sodium spectrum may have an emission line at wavelength

A. 1.66×10^{-3} m
B. 5.79×10^{-4} m
C. 2.64×10^{-4} m
D. 1.97×10^{-4} m

6. Niels Bohr proposed some postulates for his model of the hydrogen atom. Which of them are regarded as *classical*?

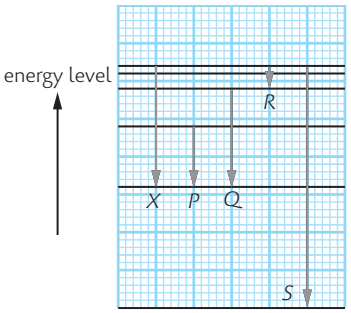
A. The electron in the atom revolves around the nucleus in a circular orbit.
B. Photons can only be emitted and absorbed when the atom transits from one energy state to another.
C. The total energy of the atom is quantized.
D. The angular momentum of the atom is quantized.

7. When an atom transits from a state a to b, a photon of frequency 5×10^{14} Hz is emitted. When it transits from a state b to c, a photon of frequency 6×10^{14} Hz is absorbed. Which of the following statements is/are correct?

(1) a is the highest among the three energy states.
(2) The ratio of the energy difference between states a and b to that between states b and c is 6 : 5.
(3) A transition from state a to c requires the absorption of a photon of frequency 1×10^{14} Hz.

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

8. The figure shows some energy levels of an atom. The energy levels are drawn on scale.



In transition X, the atom emits a photon of wavelength λ. Which transition would result in the emission of a photon of wavelength 2λ?

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

9. The energy levels of the electron in a hydrogen atom is given by

$$E_n = -\frac{k}{n^2}$$

where k is a constant and n is any positive integer. When an electron jumps from the level $n = m + 1$ to $n = m$, what is the energy of the photon emitted?

A. $-\dfrac{2k}{m(m+1)^2}$
B. $\dfrac{k(2m-1)}{m^2(m+1)^2}$
C. $\dfrac{2k}{m(m+1)^2}$
D. $\dfrac{k(2m+1)}{m^2(m+1)^2}$

10. The lowest three energy levels of a certain atom are $-4E$, $-2E$ and $-E$ (where E is positive). If a photon of wavelength λ carries the energy just enough to ionize the atom in the ground state, then photons of which wavelength(s) may be absorbed by the atom in the ground state?

(1) $2\lambda/3$
(2) $4\lambda/3$
(3) 2λ

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

11. **HKDSE 2012** 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 in the second excited state is

A. 1 : 2.
B. $1 : \sqrt{2}$.
C. 4 : 9.
D. 2 : 3.

12. **HKDSE 2013** In an α-particle scattering experiment, the electrons of the atoms have negligible effects on the path of the incident α-particles. The most probable reason is that

A. electrons are so small that α-particles do not collide with them.
B. electrons are uniformly distributed inside an atom, thus the resultant force on an α-particle is zero.
C. there is no electrical interaction between electrons and α-particles.
D. the kinetic energy change of α-particles colliding with electrons is negligible.

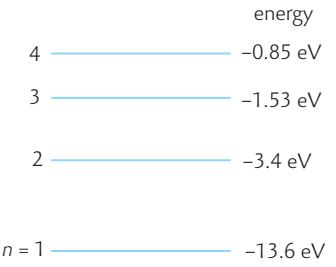
13. **HKDSE 2013** According to classical electromagnetic theory, what deductions about Rutherford's atomic model can be made?

A. Atoms are stable and atomic spectra are continuous spectra.
B. Atoms are stable and atomic spectra are line spectra.
C. Atoms are unstable and atomic spectra are continuous spectra.
D. Atoms are unstable and atomic spectra are line spectra.

14. **HKDSE 2014** A hydrogen atom in the ground state absorbs a photon of wavelength λ so that it is excited from quantum number $n = 1$ to $n = 3$. The ionization energy, in eV, of a hydrogen atom in the ground state is given by

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

15. **HKDSE 2014**



The lowest four energy levels of a hydrogen atom are shown on the right. Which statement about a hydrogen atom in the ground state is INCORRECT?

A. The collision between an electron of kinetic energy 10 eV and the atom is perfectly elastic.

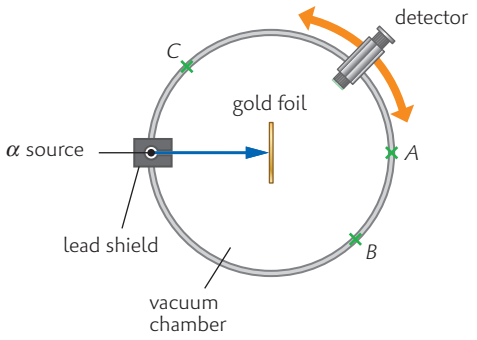
B. The collision between an electron of kinetic energy 12 eV and the atom can be inelastic.

C. A photon of energy 12 eV can excite the atom to the first excited state.

D. A photon of energy 14 eV can ionize the atom.

Structured Questions

16. The figure below shows the set-up of the famous Rutherford scattering experiment.



(a) What is the function of the lead shield? (1 mark)

(b) Why must the experiment be performed in a vacuum chamber? (1 mark)

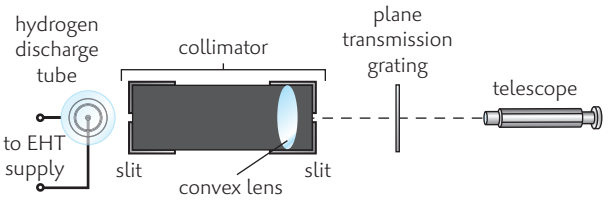
(c) At which positions (*A*, *B* or *C*) can we detect the most and the least numbers of α particles respectively? (2 marks)

(d) Some of the features of Rutherford's atomic model can account for the results in (c). State the features and explain how they can account for the results. (4 marks)

(e) Rutherford's atomic model is inconsistent with the classical electromagnetic theory. Describe such inconsistency. (2 marks)

(f) Name TWO uses of scattering experiments in modern particle physics. (2 marks)

17. The following set-up is used to study the visible light emitted by a hydrogen discharge tube.



(a) What is the function of the collimator? (1 mark)

(b) If Rutherford's atomic model were correct, what would be the expected result of this experiment? Explain briefly. (2 marks)

(c) An emission line is observed when the telescope is rotated about the plane transmission grating at an angle of 14.1°. The grating has 500 lines per mm.

(i) Find the wavelength of the emission line. (2 marks)

(ii) Find the energy of the photon with the wavelength in (i). (2 marks)

(iii) State the transition that gives rise to the emission line. (3 marks)

18. In the hydrogen absorption spectrum, the Balmer series refers to the set of spectral lines produced by transitions that start at the first excited state.

(a) Describe briefly how the hydrogen absorption spectrum can be observed. (2 marks)

(b) Using Bohr's model of the hydrogen atom, prove that the wavelengths of the spectral lines in the Balmer series can be calculated using the equation:

$$\lambda = B\left(\frac{m^2}{m^2 - 2^2}\right)$$

where B is a constant and m is any integer greater than 2. Show that $B = 364.5$ nm. (3 marks)

(c) Calculate the shortest and longest wavelengths in the Balmer series. In which part of the electromagnetic spectrum do the spectral lines in the Balmer series belong to? (3 marks)

(d) Can a hydrogen atom absorb a photon of wavelength 420 nm? Explain your answer. (2 marks)

19. (a) (i) Calculate the ionization energy of hydrogen. (2 marks)

(ii) Calculate the minimum excitation energy of hydrogen in the ground state. (2 marks)

(b) The atoms in a gas can be excited by heating the gas directly.

(i) Describe how an atom can be excited by direct heating. (3 marks)

(ii) The average kinetic energy of the atoms in a hydrogen gas at temperature T (in kelvins) is given by

$$E_{avg} = \frac{3}{2}kT$$

where k is a constant of value 1.38×10^{-23} J K^{-1}. Find the temperature at which the average kinetic energy equals the ionization energy of hydrogen. (2 marks)

(iii) In practice, ionization occurs in a hydrogen gas at a temperature much lower than the temperature in (ii). Explain briefly. (2 marks)

(c) Suggest ONE way to ionize an atom apart from direct heating. (1 mark)

20. **IB Higher Level May 2005** This question is about the Bohr model of the hydrogen atom and the extension of the model to include singly ionised helium. In his theory of the hydrogen atom, Bohr refers to *stable electron orbits*.

(a) State the Bohr postulate that determines which stable orbits are allowed. (1 mark)

(b) Describe how the existence of such orbits accounts for the emission line spectrum of atomic hydrogen. (3 marks)

The Bohr model of the hydrogen atom can be extended to singly ionised helium atoms. The model leads to the following expression for the energy E_n of the electron in an orbit specified by the integer n.

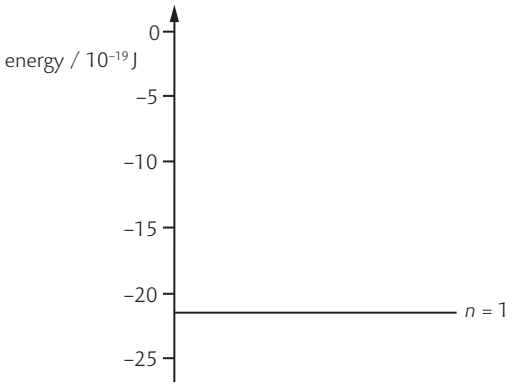
$$E_n = -\frac{k}{n^2}$$

where k is a constant.

In the spectrum of singly ionised helium, the line corresponding to a wavelength of 362 nm rises from electron transitions between the orbit $n = 3$ to the orbit $n = 2$.

(c) Deduce the value of the ionisation energy of singly ionised helium atoms. (4 marks)

21. **OCR A-level 2864/01 Jan 2007** This question is about the energy levels of the electron in a hydrogen atom.



Q21a

(a) The energy E_n of the electron in a hydrogen atom is given by

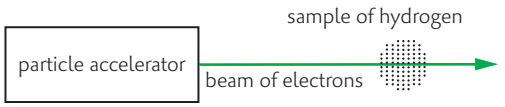
$$E_n = \frac{E_1}{n^2} \qquad \text{where } n = 1,2,3\ldots$$

(i) The value of E_1 is about −14 eV. Show that the energy of the electron in its lowest energy state ($n = 1$) is about -2×10^{-18} J. (1 mark)

(ii) On the energy level diagram of Fig. a, draw lines to show the energy levels of the electron for $n = 2$ and $n = 3$. Label them with their value of n. (2 marks)

(iii) Explain why the energy of an electron needs to be greater than zero if it is to escape from the atom. (2 marks)

(b) Fig. b shows a sample of hydrogen being bombarded with a beam of electrons from a particle accelerator. Each electron in the beam has an energy of 18×10^{-19} J when it approaches the sample.



Q21b

(i) Use Fig. a to explain why some of the electrons leave the sample with an energy of only about 1×10^{-19} J. (2 marks)

(ii) The sample of hydrogen emits photons as the electrons pass through. Calculate the wavelength of the photons.
[Take $h = 6.6 \times 10^{-34}$ J s.] (2 marks)

(iii) The energy of the electrons in the beam is raised to 20×10^{-19} J. Explain why the sample of hydrogen now emits photons of three different wavelengths, instead of just one. You may use a diagram. (2 marks)

22. **Edexcel SH Physics Jan 2009**

1814 – Joseph von Fraunhofer invents a spectroscope and identifies hundreds of dark lines in the spectrum of light from the Sun. This becomes known as an **absorption spectrum** and the lines are used to identify elements present in the Sun.

1922 – Niels Bohr receives the Nobel Prize for Physics 'for his services in the investigation of the structure of atoms and of the radiation emanating from them' after explaining the formation of atomic spectra in terms of **energy levels** and **photons**.

(a) Explain what is meant by an **energy level**. (2 marks)

(b) Explain what is meant by a **photon**. (2 marks)

(c) Explain the production of an **absorption spectrum** in terms of energy levels. (3 marks)

(d) Explain why only certain **lines** are seen in an absorption spectrum. (2 marks)

(e) Describe the differences in the production and appearance of emission spectra and absorption spectra. (2 marks)

23. **HKDSE 2012** The energy level of an electron in a hydrogen atom is given by:

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

(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)

24. **HKALE 2004**

(a) (i) Several energy levels of a mercury atom are shown in Fig. a. (Given: electronic charge = 1.6×10^{-19} C; Planck constant = 6.63×10^{-34} J s)

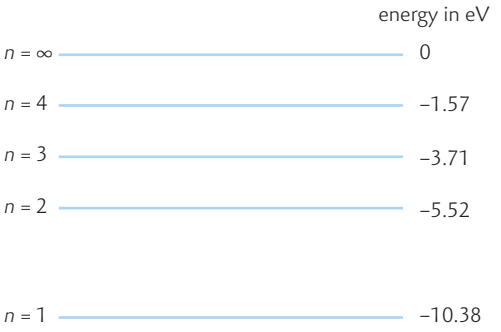


Diagram NOT to scale

Q24a

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. Fig. b shows some of the energy levels of a coating atom.

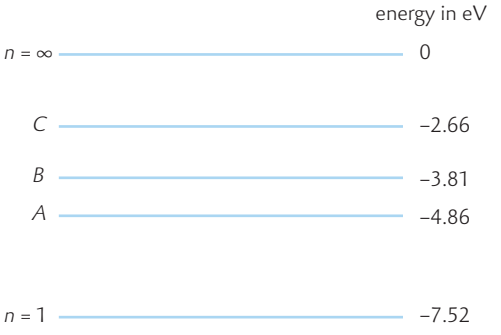


Diagram NOT to scale

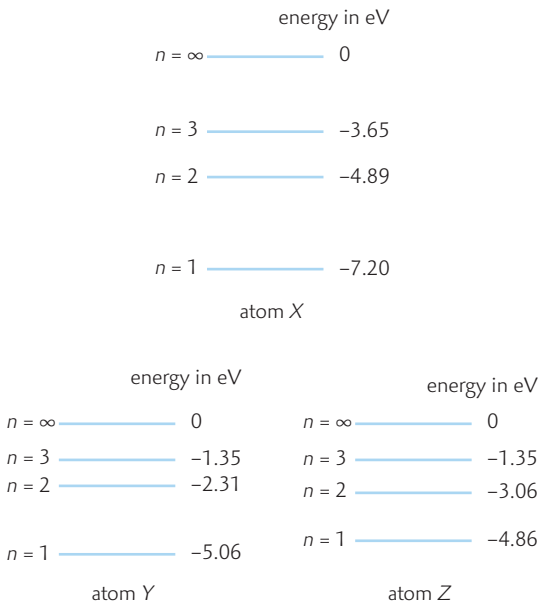
Q24b

(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)

(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 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.



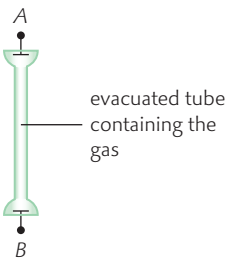
Q24c

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

colours of visible light emitted	energy of emitted photon/eV	name of coating atom (atoms *X*, *Y* or *Z*)
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)

25. **HKALE 2010** 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* shown in the figure below. Explain how Rutherford could prove that α-particles are actually helium nuclei by using this set-up. (3 marks)

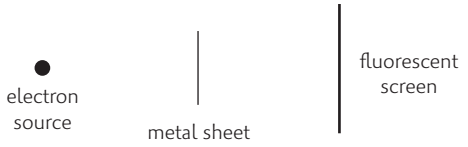


Chapter Exercise

Given: **electron mass = 9.11×10^{-31} kg**
electron charge (magnitude) = 1.60×10^{-19} C
speed of light in a vacuum = 3×10^{8} m s^{-1}
Planck constant = 6.63×10^{-34} J s

Multiple-choice Questions

1. A beam of electrons is shot at a thin metal sheet and forms a series of concentric bright and dark rings on a fluorescent screen.



Which of the following statements is/are correct?

(1) The formation of the rings shows that electrons exhibit wave-like behaviour.
(2) The slower the electrons, the wider apart the rings are.
(3) The rings become wider apart if the electron beam is replaced by a proton beam travelling at the same speed.

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

2. An optical microscope has an aperture size of 4 mm and uses light of wavelength 600 nm to illuminate the specimen. Estimate the minimum angular separation between two objects that are resolvable by a microscope.

A. 1.8×10^{-4} rad
B. 8.1×10^{-4} rad
C. 1.8×10^{-2} rad
D. 8.1×10^{-2} rad

3. A TEM can achieve resolving power higher than an optical microscope by making use of

(1) the photoelectric effect.
(2) the diffraction of light.
(3) the short wavelength of electrons.

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

4. Which of the following statements about an STM is/are correct?

(1) The specimen surface MUST conduct electricity.
(2) The specimen MUST be thin enough for electrons to pass through.
(3) Electrons MUST be accelerated through a large pd before passing through the specimen.

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

5. Sample *P* contains the nanoform of a certain material while sample *Q* contains the bulk form of the same material. Which of the following may be possible?

(1) *P* is transparent while *Q* is opaque.
(2) *P* is an electrical insulator while *Q* is an electrical conductor.
(3) *P* is much more stronger than *Q*.

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

6. Which of the following statements best describes a phenomenon that can explain the Lotus effect?

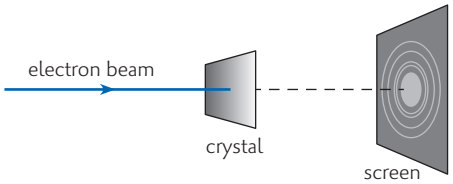
A. Water falling on a lotus leaf is attracted by the leaf surface and spreads out into a water film.
B. Water falling on a lotus leaf is repelled by the leaf surface and forms a water globule.
C. The organic dirt particles on a lotus leaf are broken down in the presence of sunlight.
D. The bacteria on a lotus leaf are killed by the coating of nanoparticles on the leaf surface.

7. Why are scientists worried about the use of nanoparticles in commercial products?

(1) Nanoparticles do NOT exist in nature.
(2) Accidental release of nanoparticles into the atmosphere may result in widespread and uncontrollable pollution.
(3) The health effects of nanoparticles have NOT been fully studied.

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

8. **HKDSE Practice Paper** A beam of electrons is incident on a thin film of crystal. A pattern of bright and dark rings is observed on a fluorescent screen. Which physical phenomenon explains the formation of the pattern?



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

9. **HKDSE Practice Paper** Which of the following are possible means by which nano particles could get into the human body?

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

10. **HKDSE 2013** The minimum resolvable length of a typical transmission electron microscope (TEM) is about 0.2 nm. If a particle has the same charge of an electron and its mass is four times that of an electron, and a beam of such particles is accelerated through the same voltage in a TEM, the minimum resolvable length becomes

A. 0.05 nm.
B. 0.1 nm.
C. 0.4 nm.
D. 0.8 nm.

11. **HKDSE 2014** Which statements about nanotechnology are correct?

(1) Glass can be made self-cleaning by coating it with titanium oxide in nanoscale.
(2) Carbon nanotubes and diamonds have the same spatial arrangement of carbon atoms.
(3) When gold is reduced to nanoscale, its melting point would be different from that of its bulk form.

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

Structured Questions

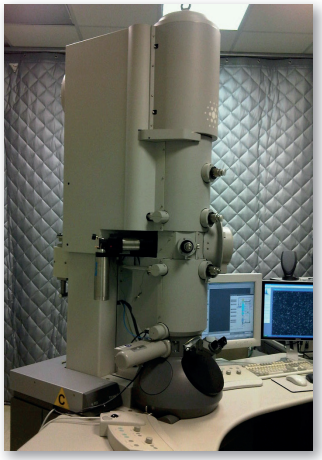
12. (a) Discuss whether an electron can be regarded as a wave. Briefly describe the experimental evidence to support your answer. (3 marks)

(b) Explain why optical microscopes CANNOT be used to observe a single atom (size ~ 10^{-10} m) and how TEMs overcome the limitation. (3 marks)

(c) Estimate the order of magnitude of the energy of the electrons needed to observe a single atom using a TEM. Express your answer in eV. (2 marks)

(d) Estimate the order of magnitude of the energy of the photons needed to observe a single atom using an optical microscope. (2 marks)

13. The figure shows a TEM. It can be used to observe specimens in the nanoscale.



(a) Explain why it is important that the electrons in the beam have the same speed. (2 marks)

(b) Compare a TEM with a traditional optical microscope in terms of

(i) the wave used to illuminate the specimen.
(ii) the lens system for magnifying and focusing.
(iii) the image formed. (3 marks)

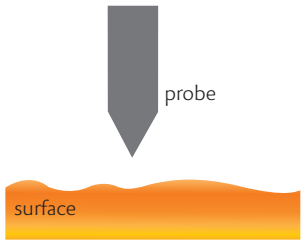
(c) A voltage is applied across the anode and the cathode of a TEM.

(i) Explain why the voltage is needed. (1 mark)
(ii) If the voltage of a TEM is 50 kV, find the de Broglie wavelength of the electrons hitting the specimen. (3 marks)

(d) A number of precautions must be taken when using a TEM. Explain why

(i) the chamber in the microscope has to be evacuated. (1 mark)
(ii) the specimen MUST be extremely thin. (1 mark)

14. The figure below shows the probe of an STM scanning across a specimen surface.



Q14a

(a) How large is the tip of the probe in an STM? Hint: See p.120. (1 mark)

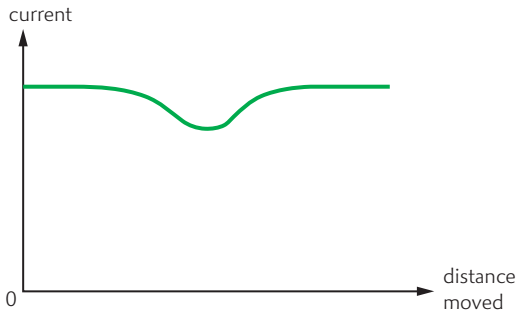
(b) When a pd is applied across the probe and the surface, an electric current is detected.

(i) Name the phenomenon that produces the current. (1 mark)

(ii) Explain why the pd is necessary. (1 mark)

(c) Why does the gap between the probe and the surface have to be sufficiently narrow? Explain briefly. (1 mark)

(d) When the probe is moved horizontally at a fixed height across the surface, the electric current between the probe and the surface changes as shown in Fig. b.



Q14b

Explain the change in the current. (2 marks)

(e) Briefly explain how the structural details of the surface can be studied by keeping the electric current between the probe and the surface constant. (1 mark)

(f) State ONE advantage and ONE disadvantage of an STM over a TEM. (2 marks)

(g) Apart from imaging, what else can an STM do? (1 mark)

15. Carbon nanotubes are probably the most well-known nanomaterial because they can be used to make a variety of products, such as electric wires and the body of a spacecraft.

(a) What is meant by *nanomaterials*? (1 mark)

(b) What makes carbon nanotubes advantageous over traditional materials in producing

(i) electrical wires? (1 mark)

(ii) the body of a spacecraft? (1 mark)

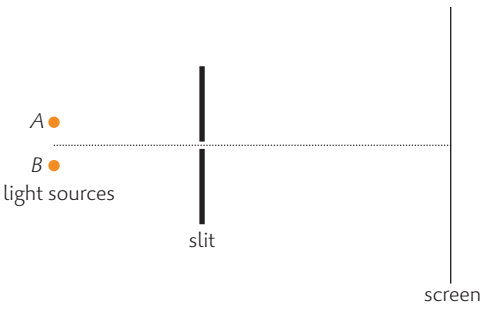
(c) Name ONE instrument that can be used to study the three-dimensional structure of carbon nanotubes. (1 mark)

(d) Carbon nanotubes are more chemically reactive than diamond despite the fact that both of them are made up of carbon atoms. Give ONE reason for this and briefly explain your answer. (2 marks)

(e) Explain how the use of nanomaterials may affect our health and the environment. (2 marks)

(f) State another use of nanomaterials in commercial products and briefly describe how such use improves the products. (2 marks)

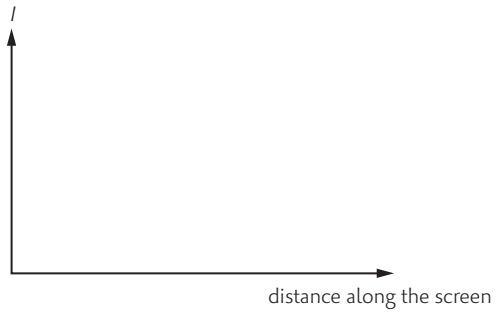
16. **IB Higher level May 2005** This question is about optical resolution. The two point sources shown in the diagram below (not to scale) emit light of the same frequency. The light is incident on a rectangular, narrow slit and after passing through the slit, is brought to a focus on the screen.



Q16a

Source *B* is covered.

(a) Using the axes below, draw a sketch graph to show how the intensity I of the light from A varies with distance along the screen. Label the curve you have drawn A.



Q16b (2 marks)

Source B is now uncovered. The images of A and B on the screen are just resolved.

(b) Using the same axes as in (a), draw a sketch graph to show how the intensity I of the light from B varies with distance along the screen. Label this curve B. (1 mark)

The bright star Sirius A is accompanied by a much fainter star, Sirius B. The mean distance of the stars from Earth is 8.1×10^{16} m. Under ideal atmospheric conditions, a telescope with an objective lens of diameter 25 cm can just resolve the stars as two separate images.

(c) Assuming that the average wavelength emitted by the stars is 500 nm, estimate the apparent, linear separation of the two stars. (3 marks)

17. OCR GCE AS-level Jun 2007

(a) Two of the most important equations from quantum physics are listed below.

equation 1 $E = hf$

equation 2 $\lambda = \frac{h}{mv}$

Complete the following sentences:

(i) Equation 1 describes _____ behaviour of electromagnetic waves. (1 mark)

(ii) Equation 2 describes _____ behaviour of a particle such as an electron. (1 mark)

(b) In this question two marks are available for the quality of written communication.

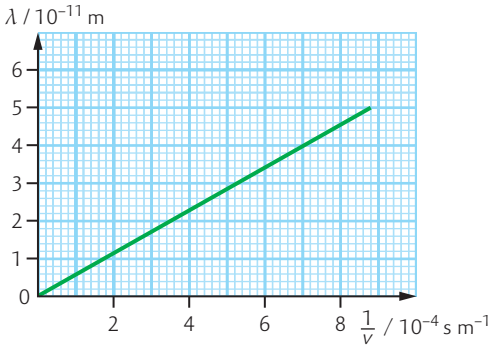
A negatively charged metal plate is illuminated by light. Electrons escape from the metal when blue light of weak intensity is used. No electrons are released when weak or intense red light is used. Use the ideas of the photoelectric effect to explain these observations. (6 marks)

(c) In a laser beam, each photon has energy 2.0 eV.

(i) Show that the wavelength of the electromagnetic waves emitted by the laser is about 6×10^{-7} m. (2 marks)

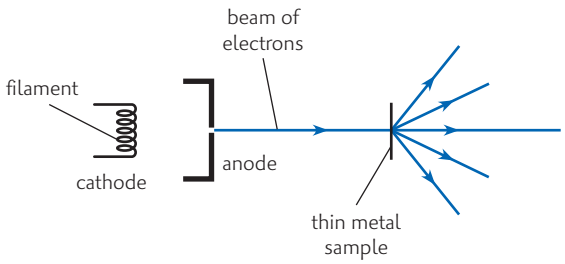
(ii) Identify the region of the electromagnetic spectrum to which the waves emitted by the laser belong. (1 mark)

(d) Lithium ions are accelerated to a speed v. The figure below shows a graph of the de Broglie wavelength λ of the ions against $1/v$.



Determine the gradient of the graph in the figure and hence calculate the mass m of a single ion of lithium. (3 marks)

18. AQA A-level PHYA5/2D Jun 2011 In the figure below, a beam of monoenergetic electrons is produced by thermionic emission from a wire filament in an evacuated tube. The beam is directed at a thin metal sample at normal incidence and it emerges from the sample in certain directions only, including its initial direction.



(a) (i) Name the physical process occurring at the thin metal sample in the figure which shows the electrons behaving as waves. (1 mark)

(ii) Explain why the electrons need to be monoenergetic in order for them to emerge in certain directions only. (2 marks)

(b) A TEM operating at an anode potential of 25 kV is used to observe an image of a thin sample.

(i) Calculate the momentum of the electrons emerging from the anode, stating an appropriate unit. (4 marks)

(ii) Describe and explain how the resolution of the image would change if the anode potential were increased. (3 marks)

19. **AQA GCSE CHY2H Jun 2011** Read the article and then answer the questions.

TOXIC SOCKS?

Silver nanoparticles are added to the fibres used to make some socks. Silver has the special property that it can kill bacteria. As a result there are no unpleasant smells when wearing these socks.

Some scientists are concerned about the use of silver nanoparticles in socks.

The silver can be released from the socks when they are washed. This silver may end up in rivers. Silver in rivers may kill fish.

Scientists found that some makes (牌子) of socks release the silver more easily than others. Socks in which the silver nanoparticles are trapped in the fibres released very little silver when washed.

(a) Suggest why silver stops unpleasant smells when wearing the socks. (1 mark)

(b) How is the size of silver nanoparticles different from normal sized silver particles? (1 mark)

(c) The silver nanoparticles are more effective at preventing unpleasant smells than normal sized silver particles. Suggest why. (1 mark)

(d) The silver nanoparticles should be trapped in the sock fibres. Use the information in the article to explain why. (2 marks)

20. **HKDSE Sample Paper 2009**

(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

$$\lambda \approx \frac{1.23}{\sqrt{V}}$$ (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)

21. **HKDSE 2014**

(a) In a Transmission Electron Microscope (TEM), electrons emitted from the cathode pass through the specimen and the four functional parts listed below before forming an image on a screen.

Functional parts: (1) objective magnetic lens
(2) projection magnetic lens
(3) condensing magnetic lens
(4) anode

Referring to the following block diagram of a TEM, match the functional parts represented by A, B, C and D in the diagram. (2 marks)

Cathode	A	B	Specimen	C	D	Screen

(b) (i) When an electron of mass m and charge e is accelerated from rest by a voltage V, show that its de Broglie wavelength λ is given by $\lambda = \frac{h}{\sqrt{2meV}}$ where h is the Planck constant. (2 marks)

(ii) The accelerating voltage of a TEM is 10 kV. Find λ. (2 marks)

(iii) Explain why the resolving power of a TEM is higher compared with an optical microscope. (2 marks)

(c) Both Scanning Tunnelling Microscopes (STM) and Transmission Electron Microscopes (TEM) have very high resolving powers. Now if the internal structure of a slice of metallic specimen is to be studied, which of the above microscopes would be suitable or are both suitable? Explain. (2 marks)