Christ Church Grammar School

Science Department
Year 12 2020

ATAR PHYSICS
UNIT 4: WAVE PARTICLE AND QUANTA
TOPIC TEST 2020

Teacher: JRM HKR
(Please circle)

Time allowed for this paper **NAME:** **SOLUTIONS**

Working time for paper: 50 minutes.

Instructions to candidates:

- You must include **all** working to be awarded full marks for a question. Answers should be expressed to 3 significant figures unless otherwise indicated.
- Marks may be deducted if diagrams are not drawn neatly with a ruler and to scale (if specified).
- Marks will be deducted for incorrect or absent units.
- **No** graphics calculators are permitted – scientific calculators only.

Mark:	/ 60
=	%

Question 1 **(3 marks)**

Explain, making reference to the relevant postulates of the Bohr Model of the atom, the phenomenon of emission spectra of atoms.

Description	Marks
Electrons exist in discrete energy levels.	1
Electrons can absorb or emit a discrete quantum of energy corresponding to the difference in these allowed energy levels	1
When an electron decays to a lower energy level, it emits a photon of energy corresponding to this difference.	1
Total	3

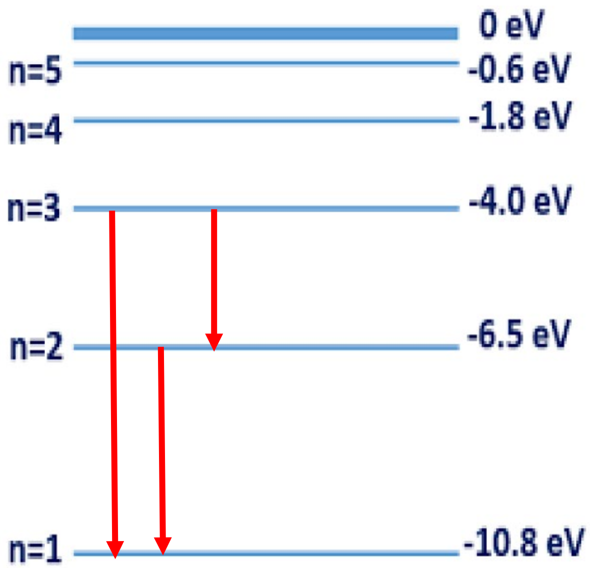
Question 2 **(3 marks)**

Some postulates of various models of the atomic physics and relativity are listed below. State the physicist that was responsible for the postulate by completing the table.

Postulate	**Physicist**
The atom is composed of electrons surrounded by a soup of positive charge to balance the electrons' negative charges.	J.J. Thompson
The electrons orbit the nucleus similar to planets orbiting the sun.	Rutherford
Every particle travelling with momentum has an associated wavelength and, in some circumstances, can exhibit wave behavior.	De Broglie
When an electron moves from a higher energy level to a lower energy level, it emits a photon of energy corresponding to the difference in those energy levels.	Bohr
The speed of light is a constant, independent of the relative motion of the source or the observer.	Einstein
The energy of oscillators in a black body is quantised and is given by $E = nhf$	Planck

Question 3 **(6 marks)**

The figure at right illustrates some of the valence electron energy levels in a gaseous atom of a particular element. The energies of the levels are given in electron volts (eV) and the valence electron of the atom is in the lowest energy level shown.



(a) Calculate the ionisation energy of the atom in joules.

(1 mark)

Description	Marks
$10.8 \times 1.6 \times 10^{-19}$ $= 1.73 \times 10^{-18}$ J	1
Total	1

(b) State two physical processes by which an electron in the ground state can move to a higher energy level.

(2 marks)

Description	Marks
Collisions with incident electrons	1
Absorption of photons	1
Total	2

A cold gaseous sample of the element is bombarded by electrons of energy 6.90 eV and observed to emit electromagnetic radiation.

(c) Show on the diagram above the energy level transitions that cause this emission of electromagnetic radiation

(1 mark)

(d) Calculate the longest wavelength of the emitted electromagnetic radiation.

(3 marks)

Description	Marks
$E = -4.0 - (-6.5) = 2.50 \times 1.60 \times 10^{-19} = 4.00 \times 10^{-19}$ J	1
$E = hf \quad c = f\lambda \quad E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}(3.00\times10^{8})}{4.00\times10^{-19}}$	1
$= 497$ nm	1
Total	3

Question 4 **(14 marks)**

An alpha particle of rest mass 6.64 x10^{-27} kg is emitted from a nucleus with a speed of 0.250 c.

(a) Calculate the relativistic momentum as measured by a stationary observer.

(3 marks)

Description	Marks
p = $\frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$ allow students to use $\beta = v/c$ = 0.250	1
= $\frac{6.64\times10^{-27}(0.25\ x 3.00\times10^{8})}{\sqrt{1-0.250^2}}$	1
= 5.14 x10^{-19} kg m s^{-1}	1
Total	3

(b) Given the following equation for relativistic kinetic energy, calculate the observed kinetic energy of the alpha particle in MeV

(4 marks)

$$E_k = \frac{m_0c^2}{\sqrt{1-\frac{v^2}{c^2}}} - m_0c^2 = m_0c^2(\gamma - 1)$$

Description	Marks
$E_k = (\gamma - 1)\ m_0c^2$	1
= $\left(\frac{1}{\sqrt{1-0.250^2}} - 1\right)(6.64\times10^{-27})(3.00\times10^{8})^2$	1
= 1.96 x10^{-11} J	1
÷1.60 x10^{-19} x10^{6} = 123 MeV	1
Total	4

Suppose the emitted alpha particle travels in a vacuum tube (travelling right as observed by a stationary observer) where it is then struck by another particle travelling at 0.900 c in the opposite direction as measured from a stationary observer.

(c) Calculate the speed in terms of 'c' of the particle from the frame of reference of the alpha particle.

(3 marks)

Description	Marks
$u' = \frac{u-v}{1-\frac{uv}{c^2}}$ take alpha particle as + (v = + 0.250 c)	1
$= \frac{-0.900c-(-0.25c)}{1-\frac{(-0.900c)(0.250c)}{c^2}}$	1
= - 0.939 c	1
Total	3

(d) Calculate the speed in terms of 'c' that the alpha particle must be travelling at to have an observed relativistic momentum 20.0% greater than its classical momentum.

(4 marks)

Description	Marks
$p_{rel} = \gamma mv$, $p_c = mv$, $p_{rel} = 1.2\ p_c$ $\therefore \gamma = 1.2$	1
$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1.20$	1
$1-\frac{v^2}{c^2} = 0.694$ $\frac{v^2}{c^2} = 0.3055$	1
$\frac{v}{c} = 0.553$, v = 0.553 c ($= 1.66 \times 10^8\ m\ s^{-1}$)	1
Total	4

Question 5 **(6 marks)**

(a) State two characteristics of leptons that distinguish them from hadrons.

(2 marks)

Description	Marks
Do not experience the strong nuclear / do not interact with gluons	1
Have no internal structure / no finite dimensions	1
Total	2

Table of Baryons and their quarks

Name	Symbol	*B*	*S*	*c*	*b*	*t*	Quarks
Proton	p	+1	0	0	0	0	uud
Anti-proton	$\bar{p}$	−1	0	0	0	0	$\overline{uud}$
Neutron	n	+1	0	0	0	0	udd
Anti-neutron	$\bar{n}$	−1	0	0	0	0	$\overline{udd}$
Lambda-plus	Λ^+	+1	0	+1	0	0	udc
Lambda-zero	Λ^0	+1	−1	0	0	0	uds
Sigma-plus	Σ^+	+1	−1	0	0	0	uus
Sigma-zero	Σ^0	+1	−1	0	0	0	uds
Sigma-minus	Σ^-	+1	−1	0	0	0	dds
Xi-zero	Ξ^0	+1	−2	0	0	0	uss
Xi-plus	Ξ^+	+1	−2	0	0	0	dss
Omega-minus	Ω^-	+1	−3	0	0	0	sss

Table of Mesons and their quarks

Name	Symbol	*B*	*S*	*c*	*b*	*t*	Quarks
Pion-plus	π^+	0	0	0	0	0	$u\bar{d}$
Pion-minus	π^-	0	0	0	0	0	$\bar{u}d$
Kaon-plus	K^+	0	+1	0	0	0	$u\bar{s}$
Kaon-minus	K^-	0	−1	0	0	0	$\bar{u}s$
Rho-plus	ρ^+	0	+1	0	0	0	$u\bar{d}$
Rho-minus	ρ^-	0	−1	0	0	0	$\bar{u}d$
phi	φ	0	0	0	0	0	$s\bar{s}$
D-plus	D^+	0	0	+1	0	0	$c\bar{d}$
D-zero	D^0	0	0	+1	0	0	$c\bar{u}$
D-plus-s	$D^+{}_s$	0	+1	+1	0	0	$c\bar{s}$
B-minus	B^-	0	0	0	−1	0	$b\bar{u}$

(b) State which of the following particle interactions are possible. For those forbidden, explain what conservation law/s are violated.

(i) $\pi^- + p \rightarrow p + e^- + \bar{\nu}_e$

(1 mark)

B# 0 + 1 = 1 + 0 + 0 conserved interaction possible

L# 0 + 0 = 0 + 1 + -1 conserved

q -1 + 1 = + 1 + - 1 + 0 conserved

(ii) $K^- + p \rightarrow \Lambda^0 + \pi^0$

(1 mark)

B# 0 + 1 = 1 + 0 conserved interaction possible

L# 0 + 0 = 0 + 0 conserved

q -1 + 1 = 0 + 0 conserved

(iii) $\pi^+ + p \rightarrow K^+ + \Sigma^+$

(1 mark)

B#	0 + 1 = 0 + 1	conserved	Interaction possible
L#	0 + 0 = 0 + 0	conserved	
q	1 + 1 = 1 + 1	conserved	

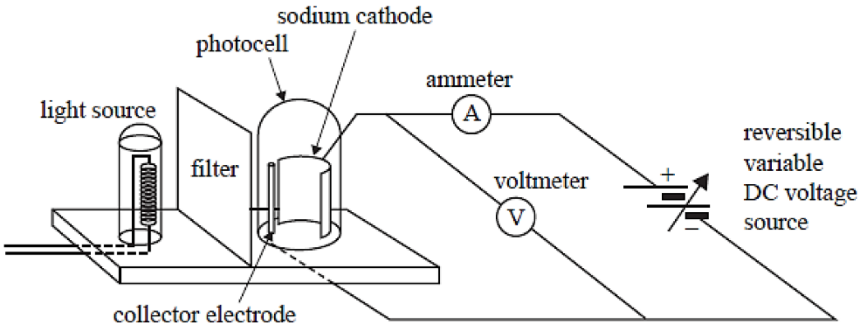
(iv) $\gamma = e^- + \pi^+$

(1 mark)

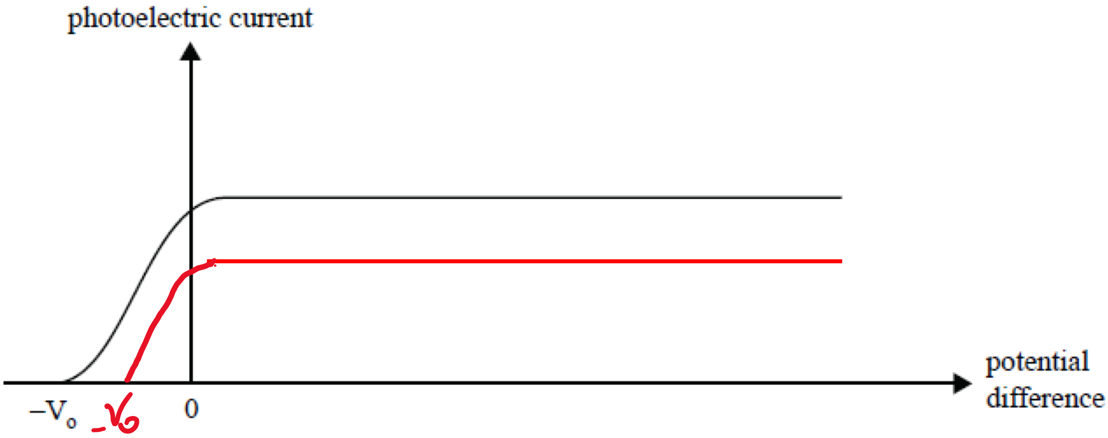
B#	0 = 0 + 0	conserved	Interaction NOT possible, Lepton number Is not conserved.
L#	0 = 1 + 0	conserved	
q	0 = -1 + 1	conserved	

Question 6 **(15 marks)**

In an experiment, violet light of frequency 7.25×10^{14} Hz is shone onto the sodium cathode of a photocell. The apparatus is shown in the diagram. The threshold frequency for sodium is 5.50×10^{14} Hz.



The graph of photoelectric current versus potential difference across the photocell is shown below.



(a) State what is meant by threshold frequency.

(2 marks)

Description	Marks
The minimum frequency required to	1
Eject an electron from the surface of a metal	1
Total	2

(b) Calculate the maximum speed of the ejected photoelectrons.

(5 marks)

Description	Marks
$E_{ph} = E_k + \phi$, $E_k = E_{ph} - \phi$ or $E_{ph} - hf_0$, $E = hf$	1
$= (6.63 \times 10^{-34})(7.25 \times 10^{14}) - (6.63 \times 10^{-34})(5.50 \times 10^{14})$	1
$= 1.16 \times 10^{-19}$ J	1
$E_k = \frac{1}{2} mv^2$ $1.16 \times 10^{-19} = \frac{1}{2} (9.11 \times 10^{-31}) v^2$	1
$v = 5.05 \times 10^5$ m s^{-1}	1
Total	5

(c) Calculate the cut-off potential, V_0, when the violet light is shone onto the sodium cathode. (If you could not complete part (b) use $E_k = 1.50 \times 10^{-19}$ J)

(3 marks)

Description		Marks
W = qV = Ef – Ei		1
1.60×10^{-19} (V) = 1.16×10^{-19}		1
V = 0.725 V	(V = 0.938 V)	1
	Total	3

(d) On the graph of photoelectric current versus potential difference graph, sketch the curve expected if the light is changed to red light with a lower intensity than the violet light.

(1 mark)

The results of photoelectric effect experiments in general provide strong evidence for the particle nature of light.

(e) State and explain two observations from the photoelectric experiment that do not support the wave model of light.

(4 marks)

Description	Marks
Ejection of photoelectrons were instantaneous	1
Wave model predicted a time delay which was not observed.	1
OR	
All intensities of light with the same frequency were stopped by the stopping voltage.	1
The wave model suggested that higher amplitudes would lead to a high stopping voltage which was not observed.	1
OR	
As the frequency of light increased, the stopping voltage increased proportionately	1
Wave model suggested that frequency of light would not effect stopping voltage.	1
Total	4

Question 7 **(7 marks)**

TV signal is broadcast in Australia in a band of frequencies from 90.0 MHz and 108.0 MHz. When the TV signal travels into the upper regions of the atmosphere, it's speed changes, is reflected back down to the earth's surface and its electric field becomes aligned to the horizontal plane. The antenna, as shown in the diagram below can then receive the TV signal by interacting with the electric field of the signal. These EM wavelengths are larger than other regains of the EM spectrum which enables the wave to pass around large objects as it is broadcast.

(a) State one phenomena described in the passage and state which model of light this phenomena supports.

(1 mark)

Description	Marks
Polarisation of light supports transverse wave model	1
Diffraction of signal around objects support the wave model	1
Time varying electric field interacting with electrons supports wave model	1
Total internal reflection of wave in atmosphere supports wave model	1
Total	1

Receiving antenna for these TV signals must be installed horizontally and have a range of lengths in order to best receive the signals from different frequencies. Typically, the antenna length must be equal to half of the wavelength it is receiving.

(b) Explain why the antenna must be installed horizontally.

(2 marks)

Description	Marks
The electric field is polarized to the horizontal plane	1
The electrons in the antenna must be aligned horizontally also to allow for them to interact with the electric field and hence, receive the signal	1
Total	2

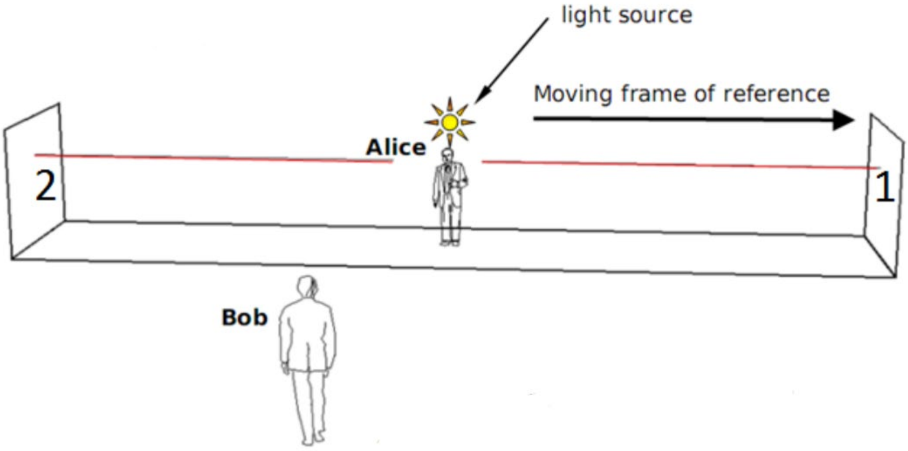
(c) Calculate the maximum and minimum ideal lengths of the TV aerial to be used in Australia.

(4 marks)

Description		Marks
$c = f\lambda$		1
$3.00 \times 10^8 = 90.0 \times 10^6 \lambda$	$3.00 \times 10^8 = 108 \times 10^6 \lambda$	1
$\lambda = 3.33$	$\lambda = 2.78$ m	1
L = 3.33 / 2 = 1.67 m	L = 2.78 / 2 = 1.39 m	1
	Total	4

Question 8 **(6 marks)**

Consider the following though experiment: Alice is in a train moving at speed v. Bob is stationary at a platform. At the instance that Bob and Alice align, a light source in the train flashes.



(a) Explain what Alice and Bob each observe in relation to order of the light striking the ends of the carriage labelled 2 and 1.

(4 marks)

Description	Marks
Alice is in the same inertial reference frame as the light source (at rest relative to the event).	1
Thus, when the light bulb turns on, they will see the light travel with velocity c to reach the ends 1 and 2 at the same time. Thus, events will appear simultaneous to Alice	1
From Bob's different reference frame: he is moving with respect to the event, thus he will see the light bulb turn on as the light will travel towards the ends.	1
However, the train is also moving with a velocity thus end 2 will move towards the light source while end 1 moves away: Bob sees the light strike end 2 before 1	1
Total	4

(b) What conclusion can be drawn from this thought experiment about the concept of "simultaneity".

(2 marks)

Description	Marks
Events which appear simultaneous to one observer will not appear simultaneous to another observer.	1
in a frame of reference moving relative to the first observer.	1
Total	2

END OF TEST