Physics ATAR - Year 12
Particles Waves and Quanta
2019

Name: **SOLUTIONS**

Mark: / 59

= %

Time Allowed: 50 Minutes

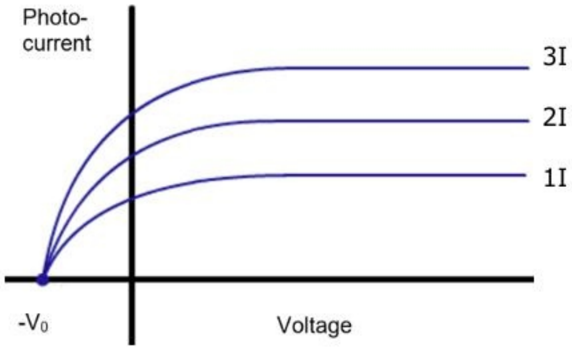
Teacher: JRM HKR
(please circle)

Notes to Students:

1. You must include **all** working to be awarded full marks for a question.
2. Marks will be deducted for incorrect or absent units and answers stated to an incorrect number of significant figures.
3. **No** graphics calculators are permitted – scientific calculators only.

Question 1 **(11 marks)**

Philipp Leonard (1862 – 1947) is often overlooked in the story of the Photoelectric Effect, yet his findings were influential for Albert Einstein and Max Plank to develop the model of light and the atom further. Leonard shone monochromatic light upon a freshly polished metal surface and varied the intensity of the light incident upon it. The following graph demonstrates his findings.



(a) Explain what $-V_0$ signifies.

(2 marks)

Stopping Voltage.

The Voltage/Energy required to stop the most energetic photo electron.

(b) Making reference to the features of the graph, state and explain which model of light was supported and which model of light was refuted.

(4 marks)

- The wave model suggested that increasing the intensity of light would increase the energy of the ejected photoelectrons, hence increase $-V_0$
- However, all intensities were stopped by the same $-V_0$
- This refuted the wave model of light
- And suggested that light came in discrete quanta called photons, supporting the particle model of light

Suppose Leonard shone monochromatic light upon a metal surface and measured the maximum voltage to reduce the photo-current to zero to be 1.60 V.

(b) Provide the statements that can be made about the energies of the electrons ejected from the surface of the metal, **and** the light incident upon the metal.

(2 marks)

- Most energetic electrons have E_k = 1.60 eV
- Photons must have energy = W + 1.60 eV (If no mention of work function of metal, no mark)

(c) If the metal has a work function of 3.50 eV, calculate the wavelength of the monochromatic light.

(3 marks)

Eph = $\frac{hc}{\lambda}$ = W + E_k = 3.50 + 1.60 = 5.10 eV (1)

$$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}(3.00\times10^{8})}{5.10\times1.60\times10^{-19}}$$ (1)

= 2.44 x10^{-7} m (1)

If student omits work function Eph = 3.5eV, λ= 3.55 x10^{-7}m (maximum 2 marks)

Question 2 **(6 marks)**

A 140g cricket ball is being thrown down a cricket pitch by a bowler at 32.0 ms^{-1}

(a) Calculate the de Broglie wavelength of this cricket ball.

(3 marks)

$$\lambda = \frac{h}{mv}$$ (1)

$$= \frac{6.63\times10^{-34}}{(0.14)(32)}$$ (1)

= 1.48 x10^{-34} m (1)

Electrons can exhibit wave behavior such as diffraction when passing through crystal lattice structures such as thin films of metals, where the distance between the atoms in the lattice are roughly equal to the de Broglie wavelength of the electron.

(b) If the atomic spacing in the metal is 1.00 x10^{-10} m, calculate the speed of the electron if it is to exhibit diffraction.

(3 marks)

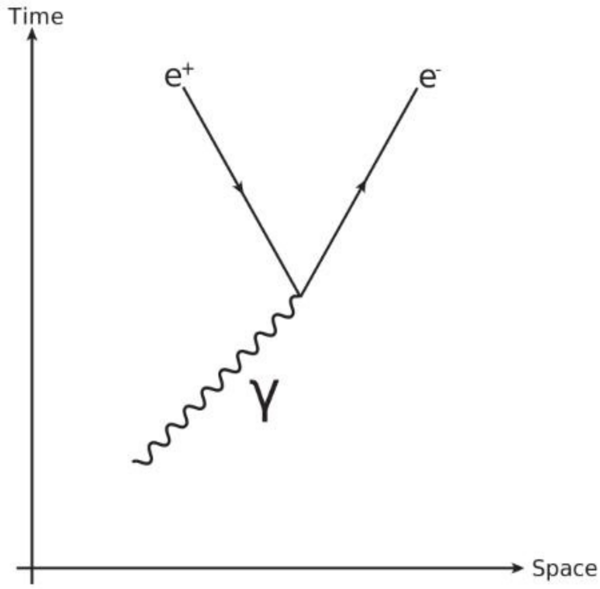
$$\lambda = \frac{h}{mv} \leftrightarrow v = \frac{h}{m\lambda}$$ (1)

$$= \frac{6.63\times10^{-34}}{(9.11\times10^{-31})(1.00\times10^{-10})}$$ (1)

= 7.28 x10^{6} ms^{-1} (1)

Question 3 **(14 marks)**

When a photon passes through matter, it can interacts with the nucleus or the electrons. There are four main interactions that a photon can under go:



1. The *Photoelectric Effect*

2. *Electron Excitation* within energy levels

3. The photon can be scattered and impart momentum in the *Compton Effect.*

4. *Pair Production*, where a single high energy photon is converted into matter, shown in the Feynman diagram; a positron and an electron.

(a) Use your knowledge of the Standard Model to prove that this Pair Production interaction obeys the conservation of Baryon number and Lepton Number.

(2 marks)

$\gamma \rightarrow e^+ + e^-$

B# 0 → 0 + 0 (allowed)

L# 0 → -1 + 1 (allowed)

(b) State one other physical quantity not mentioned in (a) that must be conserved in a Pair Production interaction.

(1 marks)

Momentum, charge, mass-energy equivalence

(c) Calculate the minimum energy, in joules, of a photon that can produce an electron-positron pair.

(3 marks)

$E = 2x\ m_0c^2$ (1)

$= 2\ (9.11x10^{-31})(3.00x10^8)^2$ (1)

$= 1.64\ x10^{-13}$ J (1)

Suppose the electron and positron were observed to be produced via Pair Production with creation speeds of 0.500c.

(d) Calculate the energy of the photon, in MeV, required to produce the positron and electron.

(4 marks)

$E = 2x\ \gamma m_0 c^2$ (1)

$= \frac{2(9.11\times10^{-31})(3.00\times10^{8})^2}{\sqrt{1-\frac{0.5c^2}{c^2}}}$ (1)

$= 1.89\ x10^{-13}$ J (1)

$\div (1.60\ x\ 10^{-19}\ x10^{6})$

= 1.18 MeV (1)

(e) Calculate the wavelength of this required photon and state which region of the electromagnetic spectrum it belongs to. (If you could not complete (d), use $E = 2.00\ x10^{-13}$ J)

(4 marks)

$\lambda = \frac{hc}{E}$ (1)

$= \frac{6.63\times10^{-34}(3.00\times10^{8})}{1.89\times10^{-13}}$ (1)

$= 1.05\ x10^{-12}$ m (1) ($9.95x10^{-13}$ if provided value used)

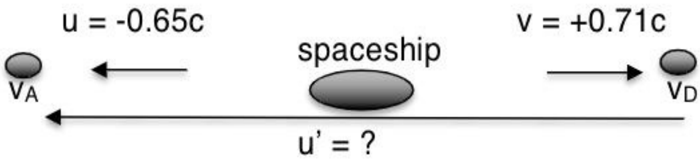
= X-rays or gamma rays (1)

Question 4 **(9 marks)**

A spaceship in distress sends out two escape pods named “Alpha” and “Delta” in opposite directions. Relative to the spaceship, Alpha travels at speed v_A = -0.650c and Delta travels at speed v_D = +0.710c.

(a) Calculate the speed of escape pod Alpha as observed from escape pod Delta’s frame of reference.

(3 marks)



$u' = \frac{u-v}{1-\frac{uv}{c^2}}$ (1)

$= \frac{-0.65c-0.71c)}{1-\frac{(-0.65c)(0.71c)}{c^2}}$ (1/2)

$= \frac{-1.36c}{1+0.4615}$ (1/2)

= -0.931 c (1)

(b) Both escape pods have two detectors placed 17.0 m apart at the front and back of the pod. Calculate the distance between the two detectors in one escape pod, as observed from the other. (If you could not complete (a), use a relative speed of 0.900 c)

(3 marks)

$L = L_0\sqrt{1-\frac{v^2}{c^2}}$ (1)

$= 17.0\sqrt{1-\frac{(0.931c)^2}{c^2}}$ (1)

= 6.21 m (1) (7.41 m if provided value used)

(c) If the escape pods have a rest mass m_0 of 2.32 x10^4 kg, calculate the observed momentum of escape pod Alpha as measured from the spaceship.

(3 marks)

$p = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$ (1)

$= \frac{2.32\times10^4(0.65\times3.00\times10^8)}{\sqrt{1-0.65^2}}$ (1) allow students to use $\beta = v/c$ = 0.650

= 5.95 x10^{12} kgms^{-1} (1)

Question 5 **(9 marks)**

Some properties of the 6 known quarks are shown below.

Name	Symbol	Charge (Q)	Baryon number (B)	Strangeness (S)	Charm (c)	Bottomness (b)	Topness (t)
Up	u	$+\frac{2}{3}e$	$\frac{1}{3}$	0	0	0	0
Down	d	$-\frac{1}{3}e$	$\frac{1}{3}$	0	0	0	0
Strange	s	$-\frac{1}{3}e$	$\frac{1}{3}$	−1	0	0	0
Charmed	c	$+\frac{2}{3}e$	$\frac{1}{3}$	0	+1	0	0
Bottom	b	$-\frac{1}{3}e$	$\frac{1}{3}$	0	0	−1	0
Top	t	$+\frac{2}{3}e$	$\frac{1}{3}$	0	0	0	+1

(a) State whether the following hadrons can exist including an explanation for each.

i. udd (1 marks)

Can exist as B# = 1/3 +1/3 +1/3 =1 (whole integer)

or q = 2/3 + -1/3 + -1/3 (whole integer)

ii. $\boldsymbol{ud}$ (1 marks)

Cannot exist as B# = 1/3 + 1/3 = 2/3 (cannot be fractional)

or q = 2/3 + -1/3 = 1/3 (cannot be fractional)

iii. $\bar{u}d$ (1 marks)

Can exist as B# = 1/3 + -1/3 = 0 (whole integer)

or q = -2/3 + -1/3 = -1 (whole integer)

(b) Complete the table below showing the known gauge bosons and particles their interactions. (2 marks)

Gauge Boson	Force it mediates	Particle it interacts with
Photon	Electromagnetic	Charged Leptons, Mesons, Baryons
Gluon	Strong Nuclear	Mesons, Baryons
W and Z boson	Weak nuclear	Leptons, Mesons, Baryons
Graviton	Gravity	All particles

(c) Using the conservation laws of charge, Baryon # and Lepton #, complete each table (by stating Yes or No) and hence, state whether the following particle interactions are possible. (working space is provided below, but not required for your answer.)

i. $p \rightarrow n + e^{-} + \overline{\upsilon_e}$ (1 mark)

Conservation	Is law conserved (Y/N)
Charge	N
Baryon #	Y
Lepton #	Y
Interaction possible?	N

ii. $n + p \rightarrow n + n + \bar{p}$ (1 mark)

Conservation	Is law conserved (Y/N)
Charge	N
Baryon #	N
Lepton #	Y
Interaction possible?	N

iii. $\bar{p} + p \rightarrow e^{+} + e^{-}$ (1 mark)

Conservation	Is law conserved (Y/N)
Charge	Y
Baryon #	Y
Lepton #	Y
Interaction possible?	Y

iv. $e^{-} + e^{+} \rightarrow 2\gamma$ (1 mark)

Conservation	Is law conserved (Y/N)
Charge	Y
Baryon #	Y
Lepton #	Y
Interaction possible?	Y

No mark awarded if ANY row in the table is incorrect.

Question 6 **(4 marks)**

A charge of mass *m* is accelerated from rest through a potential difference of *V*. Derive an expression that defines the De Broglie wavelength *λ*, of the mass in terms of h, *q*, *m* and *V*.

$W = \Delta E = E_f - E_i \qquad E_i = 0$ (1)

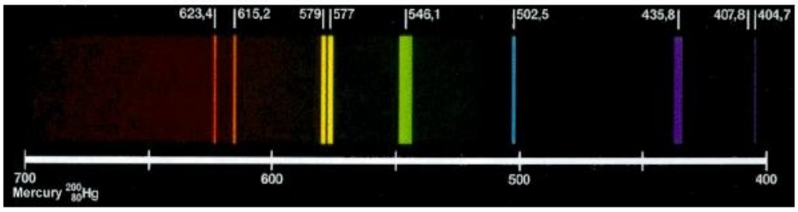
$W = qV = \frac{1}{2}mv^2 \qquad \therefore v = \sqrt{\frac{2qV}{m}}$ (1)

Since $\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2qV}{m}}}$ (1)

$\lambda = \frac{h}{\sqrt{2qVm}}$ (1)

Question 7 **(6 marks)**

A student observes the spectrum emitted by a mercury vapour lamp and notices that each line has a different colour, as represented by the figure to the right.



(a) Explain the origin of the different colours observed in the mercury spectrum. (2 marks)

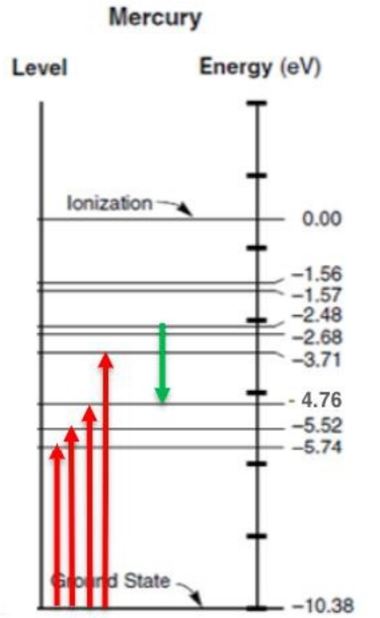
- Each coloured line corresponds to a specific energy of a photon emitted
- When an excited electron transitions from a higher energy state to a lower energy state.

The figure below shows some of the energy levels for atomic mercury.

(b) On the energy level diagram, draw all of the possible excitations that could occur if a ground state electron is bombarded with electrons of energy 6.67 eV (1 marks)

There is a strong green line in the emission spectra of wavelength 546.1 nm. This is produced by photons with an energy of 2.28 eV.

(c) Show the electron transition that produced this **green line** on the energy level diagram. (1 marks)



A Few Energy Levels for the Mercury Atom

(d) State and explain the differences, if any, to Q(b) if the mercury atoms were exposed to light of energy 6.67 eV, rather than electrons. (2 marks)

- Only one excitation possible (ground to -3.71eV)
- As the entire photon energy must be used to promote the orbital electron to a higher state.

END OF TEST