Physics ATAR - Year 12
Particles Waves and Quanta
2018

Name:

Mark:	/ 57
=	%

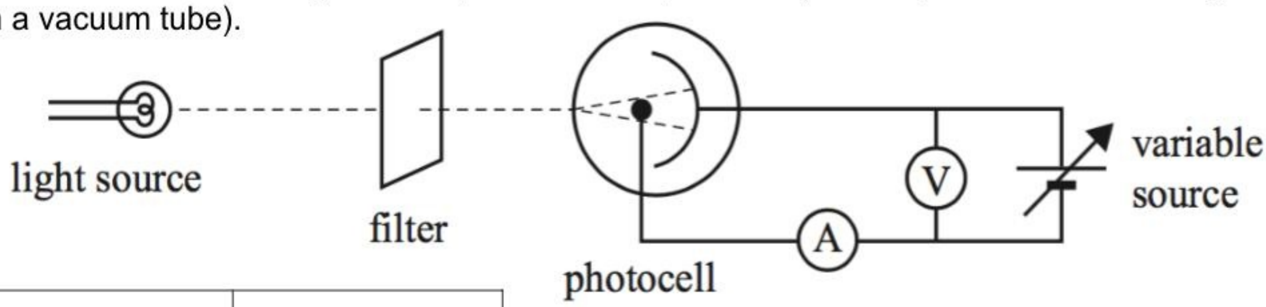
Time Allowed: 50 Minutes

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)**

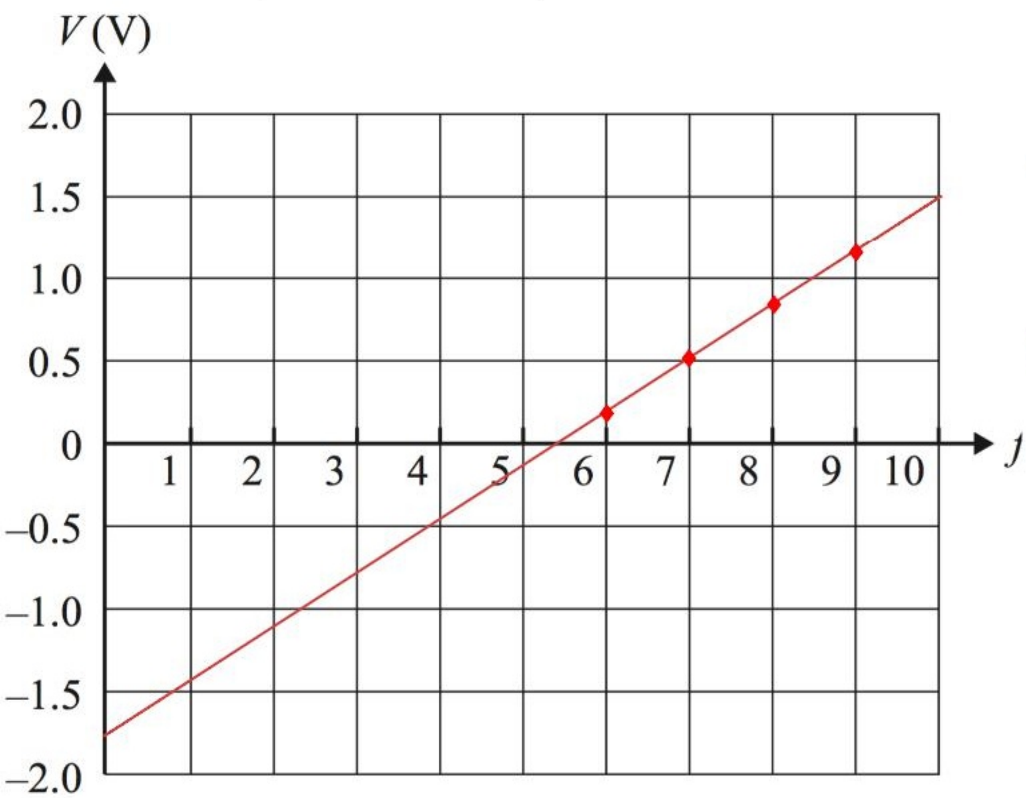
Alan is conducting an experiment to investigate the photoelectric effect. The apparatus is shown below. It consists of a light source, a filter and a photocell (a metal plate with a collecting electrode in a vacuum tube).



Frequency (Hz)	Voltage (V_0)
6.0×10^{14}	0.20
7.0×10^{14}	0.52
8.0×10^{14}	0.88
9.0×10^{14}	1.20

He uses various monochromatic filters to shine a particular wavelength on the photocell. He increases the voltage (V_0) until the current just goes to zero and records this voltage. Alan repeats this process for different frequencies. His results are shown in the table.

(a) On the axis below, plot Alan's data (2 marks)



Gradient = $\frac{1.5 - 0}{(10 - 5.4) \times 10^{14}}$

$= 3.3 \times 10^{-15}$ eV.s

OR 5.28×10^{-34} J.s

(b) From the graph, calculate (show full working above) the value Alan would find for each of the following:

(3 marks)

Planck's Constant	3.3×10^{-15} eV.s	(1 mark for working, 1 for answer)
Threshold Frequency	5.5×10^{14} Hz	(1/2 marks)
Work function of the metal	1.75 eV (accept V)	(1/2 marks)

(c) For each frequency, Alan doubles the intensity of the incident light. Describe the graph Alan will now obtain in comparison with the original graph and include an explanation.

(3 marks)

- no change.
- intensity will increase the number of photons but not the energy of the individual photons

- maximum kinetic energy of the photoelectrons (measured by the stopping voltage will not change
  OR
- threshold frequency of light, the energy required to liberate an electron will not change.

(d) Does the graph **support** the wave model or particle model of light? Justify how this model is supported by the experiment shown.

(3 marks)

- particle model of light
- quantization of light (light existing in discrete quanta)

- shows that energy of photon is proportional to frequency.

OR

- each photon carries a quanta of energy that can be measured by stopping voltage or threshold frequency

Note
Questions asks to refer to the graph: must mention frequency or stopping voltage.

Question asks to “support”, not disprove.
Stating evidence for disproving wave model = maximum 2 marks

Question 2 **(11 marks)**

A beam of electrons is produced in an electron gun. The de Broglie wavelength of each electron is 0.360 nm. An experiment is undertaken to compare the diffraction of these electrons and X-rays. With a similar gap spacing, the diffraction patterns are found to be identical.

(a) Calculate the speed of the electrons.

(3 marks)

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

$$v = \frac{h}{m\lambda} = \frac{6.63\times10^{-34}}{9.11\times10^{-31}(0.36\times10^{-9})}$$ (1)

$= 2.02 \times 10^{6}\ ms^{-1}$ (1)

(b) Calculate the energy of the X-rays.

(3 marks)

$E = hf \qquad f = \frac{c}{\lambda}$ (1)

$$= \frac{hc}{\lambda} = \frac{6.63\times10^{-34}(3.00\times10^{8})}{0.36\times10^{-9}}$$ (1)

$= 5.53 \times 10^{-16}$ J (1)

In part (a), the electrons were accelerated across a potential difference of 11.6 V. When the electron gun's accelerating voltage is increased to the order of kilovolts, relativistic effects must be considered. The following equation takes into account the relativistic effects of mass.

$$E_K = m_0c^2(\gamma - 1) \qquad \text{where } \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

(c) Calculate the relativistically corrected speed of the electron if it is accelerated, from rest, across a potential difference of 2.20 x10⁶ V.

(5 marks)

$W = qV = m_0c^2(\gamma - 1)$

$$\gamma = \frac{qV}{m_0c^2} + 1$$ (1)

$$= \frac{(1.60\times10^{-19})2.20\times10^{6}}{9.11\times10^{-31}(3.00\times10^{8})^2} = 5.29$$ (1)

Two marks for determining Lorentz factor

Four marks for determining v/c

$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 5.29 \rightarrow 1-\frac{v^2}{c^2} = 0.0357 \rightarrow \frac{v^2}{c^2} = 0.9643 \quad v/c = 0.982 \quad v = 2.95 \times 10^{8}\ ms^{-1}$

(½) (½) (1) (1)

Question 3 **(7 marks)**

The visible spectrum of the hydrogen atom is observed to emit photons of energy 2.60 eV.

(a) Calculate the wavelength of this spectral line emission.

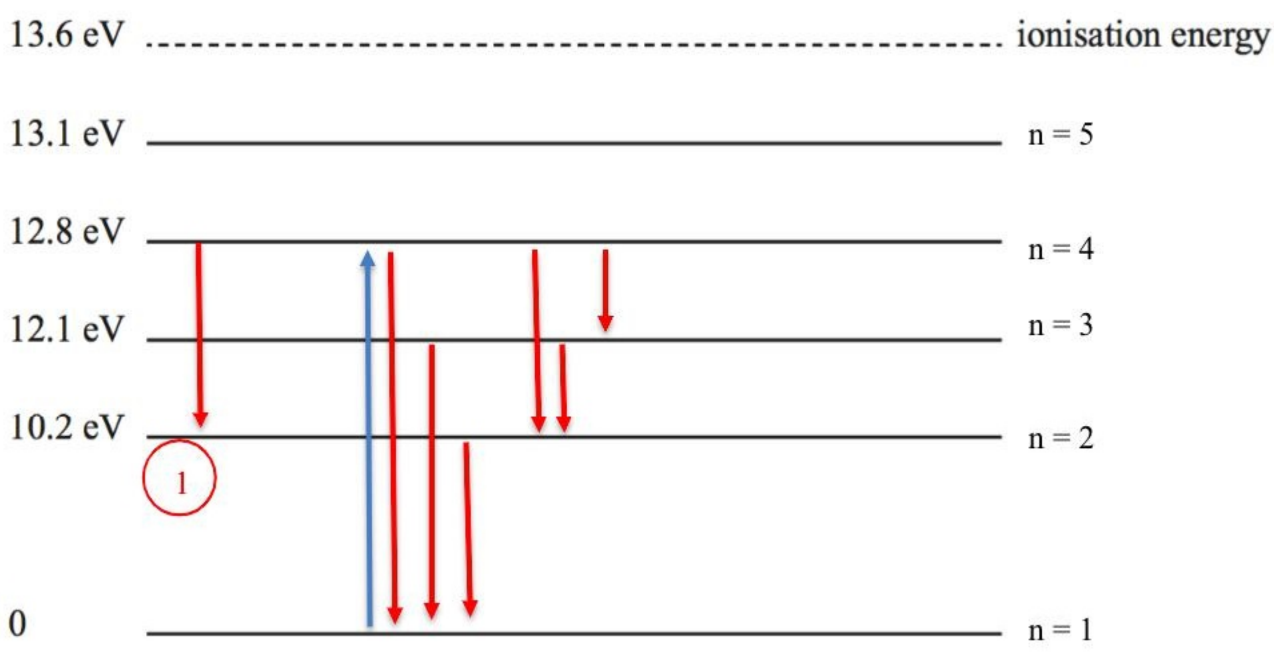
(3 marks)

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

$$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}(3.00\times10^{8})}{2.60 \times 1.60\times10^{-19}}$$ (1)

$= 4.78 \times 10^{-7}$ m (1)

The energy levels for the hydrogen atom are shown below.



(b) Draw an arrow on the diagram above to indicate the transition that could cause the spectral line calculated in (a) (1 mark)

(c) An electron in a Hydrogen atom is excited to the "12.8 eV" energy level. List all of the possible photon energies (in eV) that could be emitted as it returns to its ground state.

(3 marks)

To n = 1
1. 12.8 – 0 = 12.8 eV
2. 12.1 – 0 = 12.1 eV
3. 10.2 – 0 = 10.2 eV

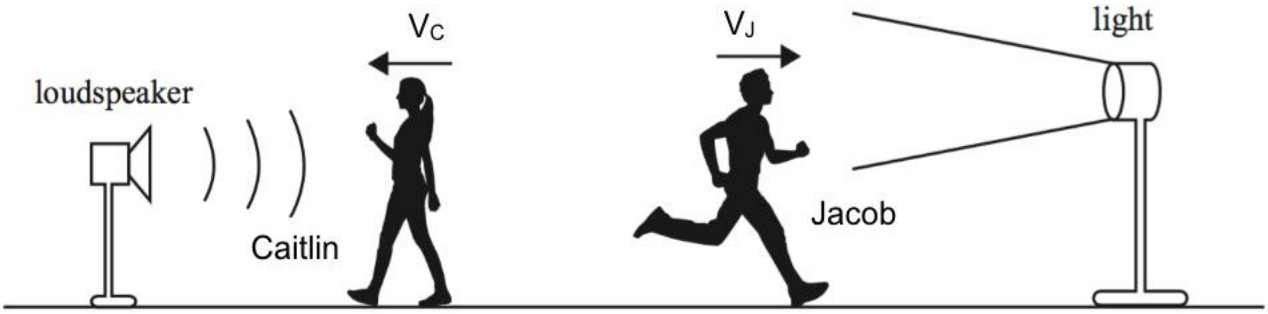
To n = 2
4. 12.8 – 10.2 = 2.6 eV
5. 12.1 – 10.2 = 1.9 eV

To n = 3
6. 12.8 – 12.1 = 0.7 eV

(-1/2 mark for each omission / error)
(Calculation or energy level diagram not required)

Question 4 **(6 marks)**

The diagram below shows Caitlin moving towards a loudspeaker at speed V_c and Jacob running towards a light source at speed V_J.



(a) Determine which of the following correctly shows the speed of sound relative to Caitlin and the speed of light relative to Jacob.
(The speed of sound in air is v_s and the speed of light is c).

(1 mark)

	Speed of sound relative to Caitlin	Speed of light relative to Jacob
A	V_S	c
B	$V_S + V_C$	$c + V_J$
(C)	$V_S + V_C$	c
D	$V_S - V_C$	$c - V_J$

(b) Explain your reasoning to your answer in regards to the speed of light relative to Jacob.

(2 marks)

(Einstein's 2nd postulate states that)…

- the speed of light is constant / invariant
- no matter the frame of reference of the observer.

(c) Use appropriate calculations to justify whether relativistic effects need to be taken into account in Jacob's measurement of time relative to a stationary observer.

(3 marks)

Set v ~ 4 m/s
since v<<c then the Lorentz factor will become:

allow suitable justification

limit of γ as v → 0 = 1

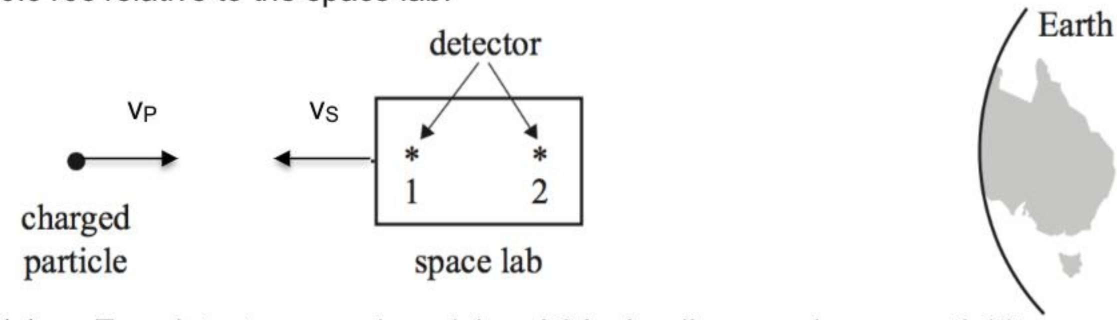
$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\frac{4^2}{(3.00\times10^8)^2}}}$$

= 1.00x to 3 significant figures

Since t = γt_0
there will be no difference in each time measurement.

Question 5 **(9 marks)**

A space lab travelling at 0.800c away from Earth's reference frame and can record high-energy charged particles passing through its detectors. One particle is travelling towards Earth at a speed 0.910c relative to the space lab.



(a) Two detectors, numbered 1 and 2 in the diagram above, are 2.00 m apart in the space lab's frame. Calculate the distance between the two detectors in the charged particle's frame of reference.

(3 marks)

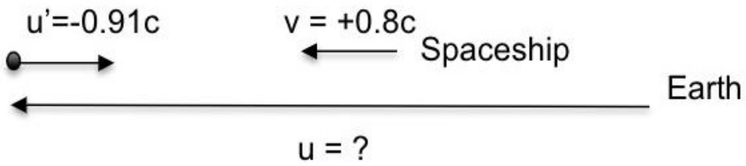
$L = L_0\sqrt{1-\frac{v^2}{c^2}}$ (1)

$= 2.00\sqrt{1-\frac{(0.91c)^2}{c^2}}$ (1)

$= 0.829$ m (1)

(b) Calculate the speed of the particle as observed by a person on Earth.

(3 marks)



(½)

$u = \frac{v+u'}{1+\frac{vu'}{c^2}} = \frac{0.8c+(-0.91c)}{1+\frac{(0.8c)(-0.91c)}{c^2}}$ (½)

$= \frac{-0.11c}{1-0.728}$ = 0.404 c (1)

$= 1.21\times10^{8}$ ms^{-1} (1)

(c) If the particle has a rest mass m_0 of 2.32×10^{-29} kg, calculate the observed momentum of the particle as measured from Earth. (if you could not to (b), use v = 1.50×10^{8} ms^{-1})

(3 marks)

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

allow students to use $\beta = v/c$ = 0.404

(Note: original version stated "from the space lab. Correct answer for this version: 1.53×10^{-20} kgms^{-1})

$= \frac{2.32\times10^{-29}(1.21\times10^{8})}{\sqrt{1-0.404^2}}$ (1)

$= 3.07\times10^{-21}$ kgms^{-1} (1)

(or 4.02×10^{-21} if sample v used)

Question 6 **(13 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. dd (2 marks)

Cannot exist as B# = 2/3 (cannot be fractional)
or q = -2/3 e (cannot be fractional)

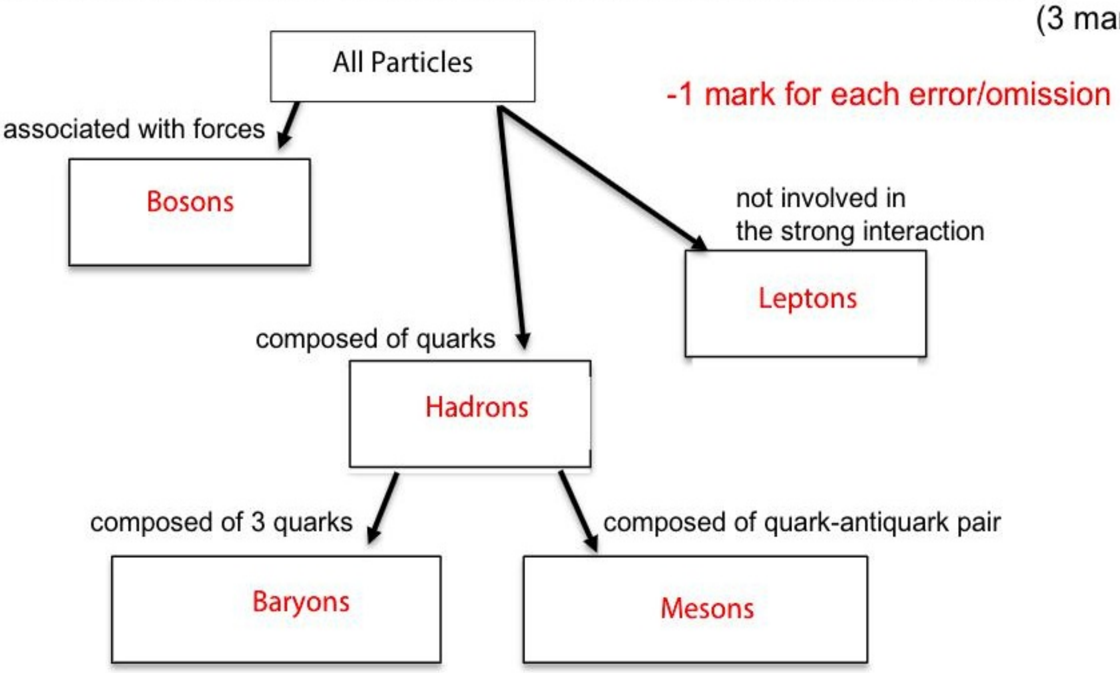
ii. $u\bar{u}d$ (2 marks)

Cannot exist as B# = 1/3 (cannot be fractional)
or q = -1/3 e (cannot be fractional)

iii. $\overline{udd}$ (2 marks)

Can exist as B# = -1 Anti-Baryon
or q = 0 Anti neutron

(b) Label following dichotomous key that categorises particles in the standard model. (3 marks)



(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.

i. $n \rightarrow p + e^- + \overline{\upsilon_e}$

(1 mark)

Conservation	Is law conserved?
Charge	YES
Baryon #	YES
Lepton #	YES
Interaction possible?	YES

ii. $p + n \rightarrow p + p + \bar{p}$

(1 mark)

Conservation	Is law conserved?
Charge	YES
Baryon #	NO
Lepton #	YES
Interaction possible?	NO

iii. $n \rightarrow n + e^- + \bar{p}$

(1 mark)

Conservation	Is law conserved?
Charge	NO
Baryon #	NO
Lepton #	NO
Interaction possible?	NO

ii. $e^- + e^+ \rightarrow 2\gamma$ (two gamma rays)

(1 mark)

Conservation	Is law conserved?
Charge	YES
Baryon #	YES
Lepton #	YES
Interaction possible?	YES

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

END OF TEST