Physics ATAR - Year 12
Particles Waves and Quanta
2017

Name: SOLUTIONS

Mark: / 58

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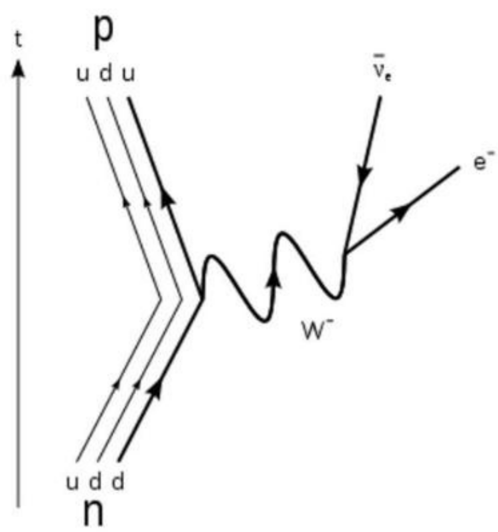
Time Allowed: 50 Minutes

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)**

The following Feynman diagram shows the Beta (-) decay process in a nuclei, as described by the standard model of matter.



(a) Name the Boson(s) present in the diagram.
(1 mark)

W- boson

(b) Name the Baryons(s) present in the diagram.
(1 marks)

Proton and neutron
(0 marks if one omitted)

(c) Name the Lepton(s) present in the diagram.
(1 mark)

electron
(accepted anti-neutrino also)

(d) Explain why an anti-neutrino must be emitted in the beta (-) decay process.
(2 marks)

- To conserve Lepton number
- The Lepton number must equal zero in the beta decay process
  - e (L# = 1)
  - $\bar{\nu}$ (L# = -1)

The table below shows the quark composition of some common particles.

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	$b\bar{u}$
Upsilon	Υ	0	0	0	0	0	$b\bar{b}$

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

(e) Determine whether the following particle interactions are possible by using two conservations laws found in particle interactions.

(4 marks)

i. $\pi^+ + p \rightarrow K^+ + \Sigma^+$

B# 0 + 1 = 0 + 1 conserved

L# 1 + 1 = 1 + 1 conserved

S# 0 + 0 = 0 + 0 conserved

q 1 + 1 = 1 + 1 conserved

ii. $n \rightarrow p + e^- + \nu$

B# 1 = 1 + 0 + 0 conserved

L# 0 = 0 + 1 + 1 Not conserved

S# 0 = 0 + 0 + 0 conserved

q 0 = 1 + -1 + 0 conserved

(f) State the quark constituents, charge and name of the anti-particle of the Kaon-plus particle.

(2 marks)

$\bar{u}s$ (-2/3 + -1/3) = -1 Kaon – meson.

-1 mark for omission of any of the above

Question 2 **(14 marks)**

A 275 m long spaceship rushes past a stationary observer at a speed of 2.40×10^8 ms^{-1}

(a) Calculate the length of the spaceship as measured by the stationary observer as it rushes past.

(3 marks)

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

$= 275\sqrt{1-\frac{(2.40\times10^8)^2}{(3\times10^8)^2}}$ (1)

= 165 m (1)

(b) If an atomic clock on the spaceship has an oscillating period of 1.40 nanoseconds (relative to a stationary reference frame), calculate the period that would be measured by the stationary observer as the atomic clock travels past.

(3 marks)

$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$ (1)

$= \frac{1.4\times10^{-9}}{\sqrt{1-\frac{(2.40\times10^8)^2}{(3\times10^8)^2}}}$ (1)

$= 2.33 \times 10^{-9}$ s (1)

(c) An astronaut has a rest mass of 60.0 kg, calculate her relativistic kinetic energy as observed by a stationary observer. The equation for relativistic kinetic energy is below:

(2 marks)

$E_k = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} - mc^2$

$= mc^2(\gamma - 1)$

$=(60)(3.00\times10^8)^2 \times \left(\frac{1}{\sqrt{1-\frac{\left(2.40\times10^8\right)^2}{\left(3\times10^8\right)^2}}} - 1\right)$ (1)

$= 3.60 \times 10^{18}$ J (1)

(d) Both observers argue that their measurement of time of the oscillating atomic clock is correct and the other person is wrong. Using your knowledge of special relativity, explain who is correct with an appropriate justification.

(3 marks)

- Both observers are correct.
- The speed of light is invariant (second postulate of special relativity) order to keep the speed of light the same, the time must dilate.
- Both observers see the distance the light travelling increasing, so to keep the speed of light the same, they both measure time dilation occurring.

A second spaceship then travels towards the 275 m long spaceship at a speed of 2.10×10^8 ms^{-1} (measured by the stationary observer).

(e) Calculate the relativistic speed of one spaceship as observed from the reference frame of the other.

(3 marks)

$v = +2.10 \times 10^8$ ms^{-1} → $u = -2.40 \times 10^8$ ms^{-1} ←

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

$= \frac{(-2.40 \times 10^8)-2.10 \times 10^8}{1-\frac{(-2.40 \times 10^8)(2.10 \times 10^8)}{c^2}}$ (1)

$= 2.88 \times 10^8$ ms^{-1} (1)

* Or interpret that spaceships are travelling in the same direction

(3 marks)

$v = +2.10 \times 10^8$ ms^{-1} → $u = +2.40 \times 10^8$ ms^{-1} →

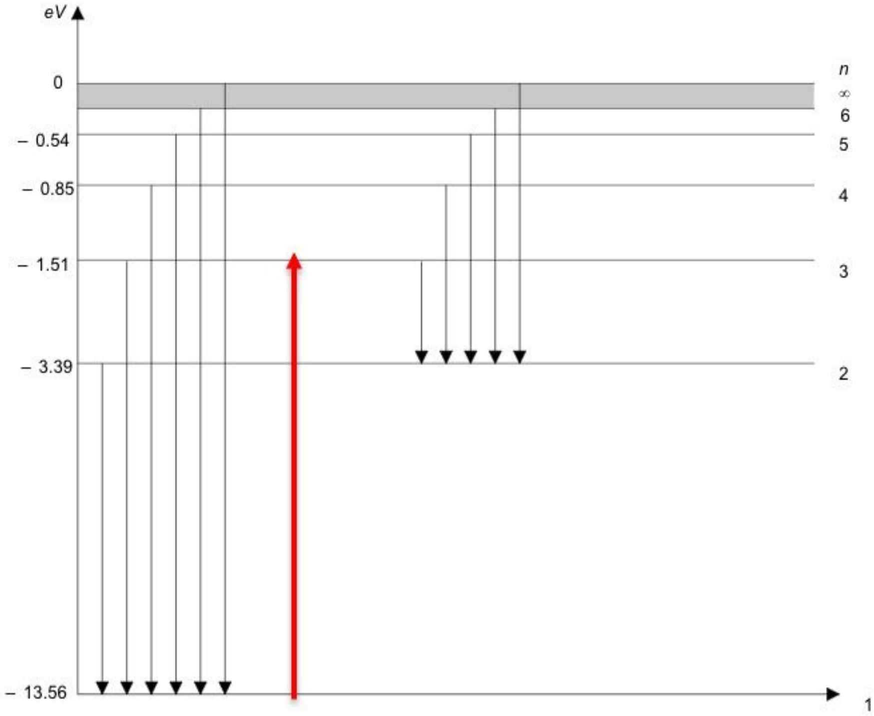
$u' = \frac{u-v}{1-\frac{uv}{c^2}}$ (1)

$= \frac{(2.40 \times 10^8)-2.10 \times 10^8}{1-\frac{(2.40 \times 10^8)(2.10 \times 10^8)}{c^2}}$ (1)

$= 6.82 \times 10^7$ ms^{-1} (1)

Question 3 **(11 marks)**

The first few energy levels of hydrogen are shown below. Use the values provided for required calculations.



(a) Photons of wavelength 103.07 nm are found to be absorbed by hydrogen. Show this absorption process by means of an arrow on the above diagram. You must justify your choice with a calculation.

(3 marks)

$E = \frac{hc}{\lambda}$ (½)

$= \frac{(6.63\times10^{-34})(3\times10^{8})}{103.07\times10^{-9}}$ (½)

$= 1.93 \times 10^{-18} \div 1.60 \times 10^{-19} = 12.05$ eV (½) (½)

E3 – E1

-1.51 - (-13.56)

= 12.05 ev (1)

(b) Of the transitions present on the diagram, calculate the wavelength of the least energetic photon and state what region of the EMR spectrum this photon belongs in.

(4 marks)

$E_{3\to2} = E_3 - E_2$

*Must show full working out for 1.88 eV

(1) = -1.51 – (-3.39)

= 1.88 eV x $1.60 \times 10^{-19} = 3.01 \times 10^{-19}$ J (½)

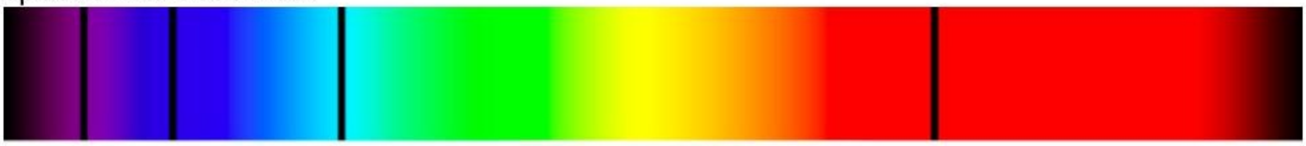
$\lambda = \frac{hc}{E} = \frac{(6.63\times10^{-34})(3\times10^{8})}{3.01\times10^{-19}}$ (½) $661\ nm$ (1) visible (1)

(c) If an external source of energy excites electrons into the n = 4 energy level, state the number of possible lines there would be in the emission spectrum.

(1 mark)

6

When white light is passed through a cold source of hydrogen gas, the following absorption spectrum is observed:



(d) Explain why the majority of the photons pass through the hydrogen unaffected.

(3 marks)

- only photons with energy corresponding to the allowed energy transitions can be absorbed.
- The continuous spectrum has all possible photon energies
- Which pass through the gas if they do not have the allowed transition energy.

Question 4 **(6 marks)**

A 5.00 mW 'class 3A' laser emits visible light of wavelength 532 nm.

(a) Calculate the energy of a photon in eV.

(2 marks)

$E = \frac{hc}{\lambda}$ (½)

$= \frac{(6.63\times10^{-34})(3\times10^{8})}{532\times10^{-9}}$ (½)

$= 3.74 \times 10^{-19} \div 1.60 \times 10^{-19} = 2.34$ eV (1)

It has been determined that the photon emission of the laser light is due to the transition from n = 2 to n = 1 of an Aluminium gallium arsenide (GaAlAs) crystal.

(b) On the energy level diagram below, complete the energy axis of the diagram.

(2 marks)

n = 5	------------------------------------	- 0.60 eV
n = 4	------------------------------------	- 0.85 eV
n = 3	------------------------------------	- 1.57 eV
n = 2	------------------------------------	- 2.90 eV
n = 1	------------------------------------	-5.24 eV

(c) Calculate the number of photons emitted per second by the laser.

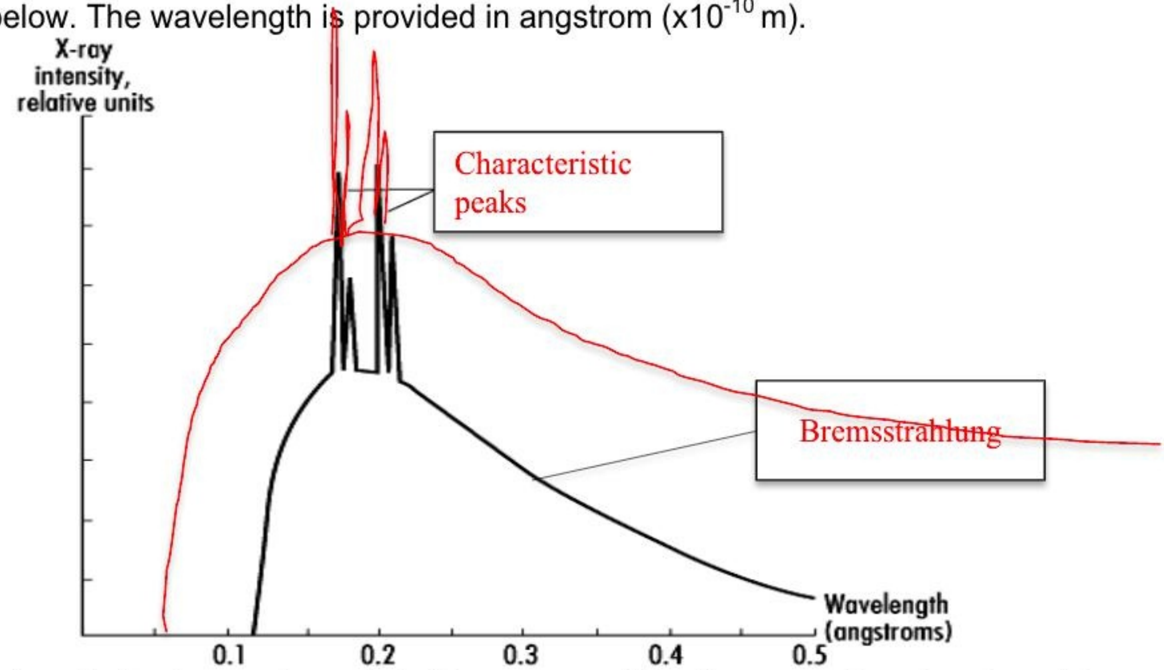
(2 marks)

$\frac{5.00\times10^{-3}}{3.74\times10^{-19}} = 1.34 \times 10^{16}$ photons

(1) (1)

Question 5 **(10 marks)**

The relative intensity of X-rays emitted from a Tungsten target is shown on the graph below. The wavelength is provided in angstrom ($\times10^{-10}$ m).



(a) In the boxes above, label the names of the X-rays produced and provide an explanation of how one of these X-ray types are produced.

(3 marks)

Bremsstrahlung

- Incident electron decelerates around the nucleus of the trget anode.
- Releasing EMR in the Xray region.

Characteristic peaks

- Incident electron knocks an orbital electron out of the K or L shell.
- An orbital electron falls into this vacancy, releasing EMR in the Xray region

(b) Calculate the accelerating voltage of the X-ray tube.

(3 marks)

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

$V = \frac{hc}{\lambda q} = \frac{(6.63\times10^{-34})(3\times10^{8})}{0.12\times10^{-10}(1.60\times10^{-19})}$ (1)

$= 103\times10^{3}$ V (1)

(c) On the graph above, sketch a new curve if the accelerating voltage is doubled.

(2 mark)

-1 mark for: minimum wavelength not halved
intensity not increased
Characteristics peaks not present

(d) Complete the table below by adding the appropriate effect (on the variable listed) caused by the modifications. The first modification has been completed for you.

(2 marks)

Modification to X-ray Tube	**Variable affected**	**Effect**
X-ray tube filled with low pressure air	Relative Intensity of X-rays	**Reduced**
Voltage decreased	Minimum wavelength emitted	**increased**
Voltage decreased	Relative Intensity of X-rays	**decreased**

Question 6 **(6 marks)**

State and explain one observation or experiment that supports the wave model of light and one observation or experiment that supports the particle model of light.

Wave:
Double slit experiment
Refection Refraction
Diffraction + 2 marks for appropriate explanation
Polarisation
Doppler Effect
Interferometry

Particle:
Photoelectric effect + 2 marks for appropriate explanation
Compton Scattering
Emission and Absorption Spectra
Xray production
LASERs

END OF TEST