Christ Church Grammar School

Science Department
Year 12 2022

ATAR PHYSICS
UNIT 4: REVOLUTIONS IN MODERN PHYSICS
TOPIC TEST 2022

Teacher: (Please circle)	CJO	HKR

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:	/ 51
=	%

Question 1 **(3 marks)**

Explain why hydrogen has many spectral lines.

Description	Marks
The one electron can occupy a large number of energy states within the atom	1
When the electron falls from a higher energy state to a lower energy state, it will release a photon with a frequency proportional to the difference in energy states.	1
A large number of transitions are possible, so there are a large number of spectral lines, as each line represents a photon of different frequency.	1
Total	3

Question 2 **(6 marks)**

For each of the following questions, select the appropriate answer and fully justify your response.

(a) A new particle discovered in 2014 contains five quarks. To which one of the following categories does the particle belong?

(3 marks)

(A) Baryon

(B) Boson

(C) Hadron Selection: C

Description	Marks
Correct selection : C	1
Hadrons can consist of any number of quarks, but Baryon's consist of 3 quarks and bosons can either have two quarks (mesons) or none	2
Total	3

Which of the following particles is governed by the weak force and is also influenced by electromagnetism? (3 marks)

(A) Neutrinos

(B) Quarks

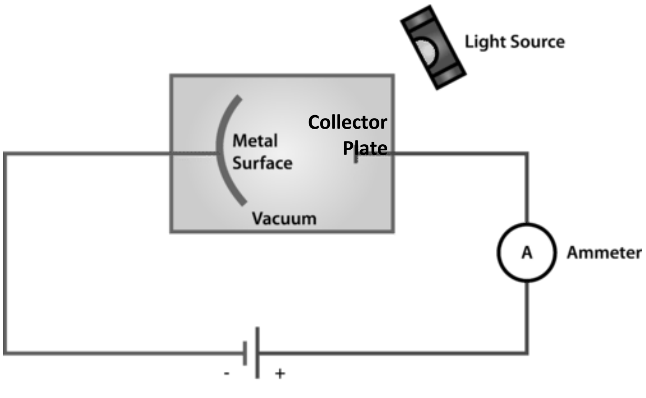
(C) Mesons

(D) Uncharged Leptons Selection: B or C

Description	Marks
Correct selection : B or C	1
Uncharged leptons (which are also neutrinos) do not experience the electromagnetic force.	1
Quarks have a fractional charge and some mesons are charged, hence affected by the electromagnetic force. Both particles contain quarks which are governed by the weak force.	1
Total	3

Question 3 **(14 marks)**

A photoelectric effect apparatus is set up as per the diagram below, so that when monochromatic light shines upon a metal surface, all of the electrons emitted from the metal surface can be detected by a simple circuit.



A light source of power 3.00 W emits light with a wavelength of 4.60×10^{-7} m. All of the light is incident on a metal surface with a threshold frequency of 5.45×10^{14} Hz and causes electrons to be emitted at a rate of 6.69×10^{18} electrons per second.

(a) Calculate the photoelectric current detected through the circuit.

(2 marks)

Description	Marks
$I = q/t = 6.69 \times 10^{18} \times 1.60 \times 10^{-19}$	1
$I = 1.07$ A	1
Total	2

(b) Calculate the maximum kinetic energy of a photoelectron ejected from the metal when it reaches the **collector plate**, if the variable voltage is set to 6.00 V.

(6 marks)

Description	Marks
Calculates work function of metal $W = hf_0 = 6.63 \times 10^{-34}(5.45 \times 10^{14}) = 3.61 \times 10^{-19}$ J	1
Energy gained through accelerating voltage $W = qV = (1.60 \times 10^{-19})(6.00) = 9.60 \times 10^{-19}$ J	1
$E_k = hf - W$ when liberated from the plate, where f of incoming light = c / λ $E_K = hc/\lambda - W$	1
$E_k = (6.63 \times 10^{-34})(3.00 \times 10^{8})/(4.60 \times 10^{-7}) - (3.61 \times 10^{-19})$ $E_k = 4.32 \times 10^{-19} - 3.61 \times 10^{-19} = 7.10 \times 10^{-20}$ J	1
$E_{K\ total} = 7.10 \times 10^{-20} + 9.60 \times 10^{-19}$	1
$E_k = 1.03 \times 10^{-18}$ J	1
Total	6

A new light source is now shone upon the metal plate, which has the same power output, but a longer wavelength of 6.90 x 10^{-7} m.

(c) Calculate the number of photons arriving on the plate per second.

(3 marks)

Description	Marks
$P = E/t$ where $E = nhc / \lambda$ $P = nhc / t\lambda$	1
$n = Pt\lambda /hc = 3(1)(6.90 \times 10^{-7}) / ((6.63 \times 10^{-34})(3.00 \times 10^{8}))$	1
1.04×10^{19} photons / second	1
Total	3

(d) Describe the impact on the photoelectron current of the above change and explain why.

(4 marks)

Description	Marks
Longer wavelength = lower frequency, hence less energy per photon as E=hf	1
If Power output is the same, then more photons are being emitted per second from light source	1
As light will be above the threshold, each photon will produce a photoelectron.	1
Hence more photoelectrons are liberated, all of which will reach the collector. Hence photo electric current increases.	1
Total	4

Note: typo on printed test named “shorter” wavelength above c, so inverse of the above answer was also accepted.

OR, if supported by calculation:

Description	Marks
Longer wavelength = lower frequency, hence less energy per photon as E=hf	1
If Power output is the same, then more photons are being emitted per second from light source	1
As light is below the threshold frequency	1
No photoelectrons are liberated, hence photo electric current drops to zero.	1
Total	4

Question 4 **(7 marks)**

An astronaut travels to a distant star 10.5 light years away, but to her surprise she finds that the journey only took her 8.98 years. She reasons that in order for this to be possible, she must have travelled faster than the speed of light.

(a) Explain why this reasoning is incorrect and explain the observations both from the perspective of an earthbound observer and the astronaut. (3 marks)

Description	Marks
The astronaut is moving relative to the distant star, hence the length to the star contracts in the direction of her motion, hence she must have travelled a distance less than 8.90 light years away.	1
From the earthbound observer's perspective, the astronaut's time will pass more slowly, hence from their perspective, the journey will take more than 10.5 years.	1
From either perspective, the astronaut did not travel faster than the speed of light	1
Total	3

(b) Prove that with a speed of 0.760 c, these observations are possible.

(4 marks)

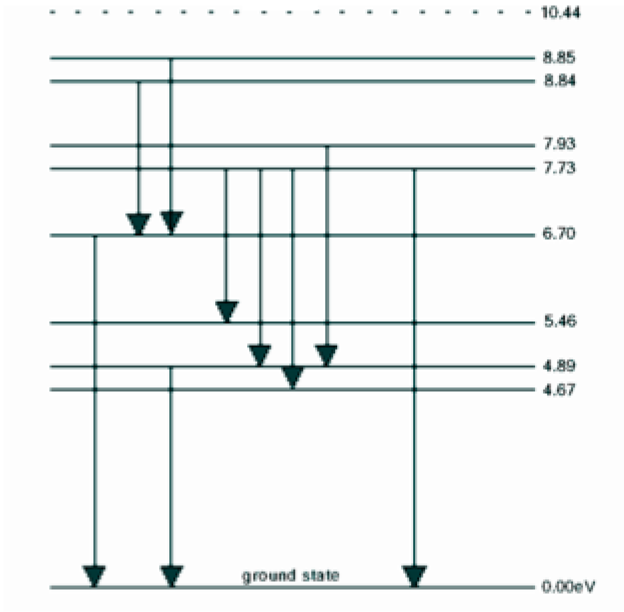
Description	Marks
$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $\gamma = \frac{1}{\sqrt{1 - 0.760^2}} = 1.54$	1
From astronaut's perspective, length is contracted $l = \frac{l_0}{\gamma}$ $l = \frac{10.5}{1.54} = 6.82\ ly$	1
Hence, her calculated speed is $v = \frac{s}{t} = \frac{6.82\ light\ years}{8.98\ years}$	1
$v = 0.759c$	1
Total	4

OR final three marks:

Description	Marks
From Earth's perspective, astronaut's time dilates: $t = \gamma t_0$ $t = 8.98(1.52) = 13.8\ years$	1
Hence, her calculated speed is $v = \frac{s}{t} = \frac{10.5\ light\ years}{13.8\ years}$	1
$v = 0.761c$	1
Total	3

Question 5 **(5 marks)**

The following diagram shows the allowed electron transitions for mercury.



(a) A ground state electron in a mercury atom is bombarded with electrons of kinetic energy 8.00 eV. Determine all possible scattered electron energies.

(2 marks)

Description	Marks
8.00 eV	0.5
8.00 - 7.73 = 0.270 eV	0.5
8.00 – 6.70 = 1.30 eV	0.5
8.00 – 4.89 = 3.11 eV	0.5
Total	2

(b) Determine which two energy levels are involved in the production of the violet line in mercury's emission spectrum, with a wavelength of 408 nm.

(3 marks)

Description	Marks
E (in eV) = hc/ $q\lambda$	1
E = (6.63 x 10^{-34})(3.00 x 10^{8}) / (1.6 x 10^{-19} x 408 x 10^{-9}) = 3.05 eV	1
n=7 to n=3 7.93 – 4.89 = 3.04 eV (Also accept n=6 to n=2 7.73-4.67 = 3.06 eV)	1
Total	3

Question 6 **(7 marks)**

(a) Explain how electromagnetic radiation is produced, and state which type(s) of radiation can be emitted due to the thermal motion of particles.

(3 marks)

Description	Marks
Photons / radiation is emitted from accelerating charged particles which produces a changing electric field	1
His induces changing magnetic field and vice versa which is propagated through space	1
Infrared, visible light and UV can be produced from thermal motion	1
Total	3

Classical physics considers electromagnetic radiation as a wave only, and this leads to the conclusion that even relatively low temperature objects should emit high energy radiation.

(b) Explain how experimental findings have altered our understanding and supported the particle model of light. You may support your explanation with a diagram.

(4 marks)

<table>
<tr><td>Description</td><td>Marks</td></tr>
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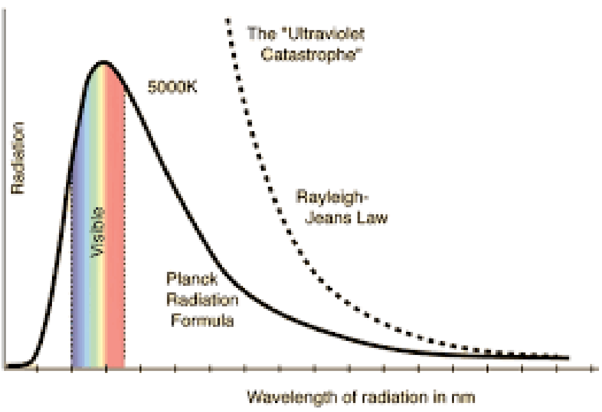
- Experimental results show that blackbodies radiate energy with an intensity curve as shown, where the peak varies according to temperature, but drops off at lower frequencies.



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- This cannot be explained with classical theory (UV catastrophe) hence a new model was required (not required on diagram)

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- Planck's quantisation of light theory, where E=nhf, was able to explain this shape

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- Leading to the idea that light has a particle nature.

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<tr><td>Total</td><td>4</td></tr>
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Question 7 **(8 marks)**

In a linear particle accelerator, an alpha particle of mass 6.64 x 10^{-27} kg is accelerated through an electric field to a final kinetic energy of 5.37 GeV.

(a) Calculate its final speed

(5 marks)

Description	Marks
$E_{TOTAL} = E_k + mc^2$ $= 5.37 \times 10^9 \times 1.6 \times 10^{-19} + (6.64 \times 10^{-27})(3.00 \times 10^8)^2$ $= 1.46 \times 10^{-19}$ J	1
$E_{TOTAL} = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}$	1
Let v be expressed in terms of c – algebraically solves for v $1.46 \times 10^{-19} = \frac{(6.64 \times 10^{-27})(3.00 \times 10^8)^2}{\sqrt{1-v^2}}$ $\sqrt{1-v^2} = \frac{(6.64 \times 10^{-27})(3.00 \times 10^8)^2}{1.46 \times 10^{-19}}$ = 0.409 $v = \sqrt{1-\left(\frac{(6.64 \times 10^{-27})(3.00 \times 10^8)^2}{1.46 \times 10^{-19}}\right)^2}$ = sqrt(1- 0.167)	2
v = 0.912 c (or 2.74 x 10^8 m s^{-1})	1
Total	5

(b) Calculate its final momentum. (If you failed to answer part (a), use a speed of 0.880c)

(3 marks)

Description	Marks
$p = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$	1
$p = \frac{6.64 \times 10^{-27}(0.912 \times 3.00 \times 10^8)}{\sqrt{1-0.912^2}}$	1
$p = 4.43 \times 10^{-18}\ kg\ m\ s^{-1}$ Alternative answer 3.69 x 10^{-18} kg m s^{-1}	1
Total	3

END OF TEST