ASSESSMENT TWO

This assessment is a Semester Exam or end of unit test.

With thanks to Kaylyn Hennig for the covering artwork.

COVER SHEET AND RUBRIC

ASSESSMENT TWO: EXAM

Course:	Physics T
Unit:	Revolutions in Modern Physics
Year Group:	12
Assessment Conditions:	Exam conditions • Rulers, erasers, pencils, pens • Non programmable calculator • You may not use this equipment in reading time • Access to external information via means not specified above during the completion of this examination is forbidden.
Prior learning:	End of year summative exam
Key concepts:	• understand the consequences for space and time of the equivalence principle for inertial frames of reference • understand how the quantum theory of light and matter explains blackbody radiation, the photoelectric effect, and atomic emission and absorption spectra • understand how the Standard Model explains the nature of and interaction between the fundamental particles that form the building blocks of matter • understand how models and theories have developed over time, and the ways in which physical science knowledge and associated technologies interact with social, economic, cultural and ethical considerations • use science inquiry skills to design, conduct, analyse and evaluate investigations into frames of reference, diffraction, black body and atomic emission spectra, the photoelectric effect, and photonic devices, and to communicate methods and findings • use algebraic and graphical models to solve problems and make predictions related to the theory and applications of special relativity, quantum theory and the Standard Model • evaluate the experimental evidence that supports the theory of relativity, wave-particle duality, the Bohr model of the atom, the Standard Model, and the Big Bang theory • communicate physics understanding using qualitative and quantitative representations in appropriate modes and genres.
Key ideas:	SCIENCE INQUIRY SKILLS • identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes • design investigations, including the procedure to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics • conduct investigations, including use of simulations and manipulation of spectral devices, safely, competently and methodically for the collection of valid and reliable data

- represent data in meaningful and useful ways, including using appropriate si units, symbols and significant figures; organise and analyse data to identify trends, patterns and relationships; identify sources of uncertainty and techniques to minimise these uncertainties; utilise uncertainty and percentage uncertainty to determine the cumulative uncertainty resulting from calculations, and evaluate the impact of measurement uncertainty on experimental results; and select, synthesise and use evidence to make and justify conclusions
- interpret a range of scientific and media texts, and evaluate processes, claims and conclusions by considering the quality of available evidence; and use reasoning to construct scientific arguments
- select, construct and use appropriate representations, including text and graphic representations of empirical and theoretical relationships, simulations, simple reaction diagrams and atomic energy level diagrams, to communicate conceptual understanding, solve problems and make predictions
- select, use and interpret appropriate mathematical representations, including linear and non-linear graphs and algebraic relationships representing physical systems, to solve problems and make predictions
- communicate to specific audiences and for specific purposes using appropriate language, nomenclature, genres and modes, including scientific reports

SCIENCE AS A HUMAN ENDEAVOUR

- ICT and other technologies have dramatically increased the size, accuracy and geographic and temporal scope of datasets with which scientists work
- models and theories are contested and refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory power
- the acceptance of science understanding can be influenced by the social, economic and cultural context in which it is considered
- people can use scientific knowledge to inform the monitoring, assessment and evaluation of risk
- science can be limited in its ability to provide definitive answers to public debate; there may be insufficient reliable data available, or interpretation of the data may be open to question
- international collaboration is often required when investing in large-scale science projects or addressing issues for the Asia-Pacific region
- scientific knowledge can be used to develop and evaluate projected economic, social and environmental impacts and to design action for sustainability

SCIENCE UNDERSTANDING

SPECIAL RELATIVITY

- observations of objects travelling at very high speeds cannot be explained by Newtonian physics (for example, the dilated half-life of high-speed muons created in the upper atmosphere, and the momentum of high speed particles in particle accelerators)
- Einstein's special theory of relativity predicts significantly different results to those of Newtonian physics for velocities approaching the speed of light

	• the special theory of relativity is based on two postulates: that the speed of light in a vacuum is an absolute constant, and that all inertial reference frames are equivalent • motion can only be measured relative to an observer; length and time are relative quantities that depend on the observer's frame of reference • relativistic momentum increases at high relative speed and prevents an object from reaching the speed of light • the concept of mass-energy equivalence emerged from the special theory of relativity and explains the source of the energy produced in nuclear reactions
Cross-curriculum priorities:	Sustainability
General Capabilities:	Literacy, Critical and Creative Thinking, Numeracy

EXAMINATION INSTRUCTIONS:

- Your mark for the examination component will be added to your take home component mark to give your total Task 4 mark.
- This examination contains 3 booklets:
- Multiple choice question booklet.
- Answer booklet. Includes Multiple Choice answer sheet (part A), and parts B, C & D.
- Data booklet.
- **All answers must be written in the spaces provided in this answer booklet.**
- Marks will not be deducted for incorrect answers.
- All questions must be attempted.
- Questions are not equally weighted, please consider the allocation of marks when structuring your response and allocating time.
- Write all solutions in the spaces provided.
- Written answers to be in blue or black pen only.
- Graphs and diagrams to be in pencil.
- Marks are allocated for both correct answers and the required working.
- All responses must be legible.
- Check all work before submitting your paper.

Part A – Multiple Choice (15 marks)

Instructions:

Each question is worth 1 mark.

Record your answers on the multiple choice answer sheet.

Question 1

What is the energy of a 630 nm photon of electromagnetic radiation?

CMA1 C level question

Explains fundamental properties

a. 1.97 eV
b. 3.15 eV
c. 1.97×10^{-19} J
d. 3.15 J

Question 2

Which of the following is a correct statement about how the Bohr model of the atom was an improvement on the Rutherford model?

a. It stated that electrons exist in 3D orbitals with wave patterns that are described their probability density, which explained how wave particle duality was applied to atoms.
b. It stated than atoms have small, dense, positive nucleus, which explained why a small number of alpha particles fired at gold foil could be rebounded.
c. It stated that electrons have quantised orbits with fixed radius and angular momentum, which explained why electrons didn't decay into the nucleus by emitting electromagnetic radiation.
d. It stated that atoms have separate positive charge and negative electrons, which explained the production of cathode ray beams that could deflected by electric and magnetic fields.

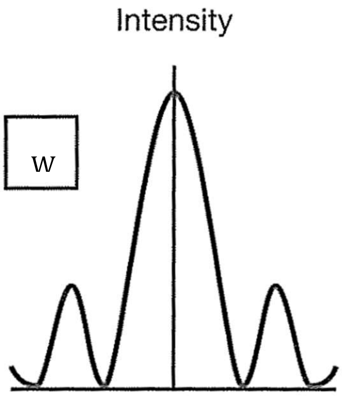
CMA2 C level question

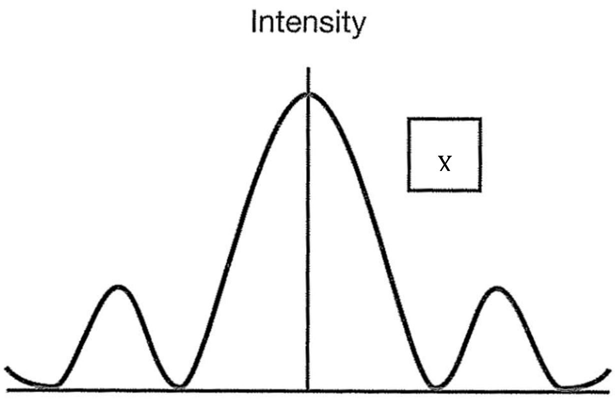
Explains nature, limitations and applications of theories and models

Question 3

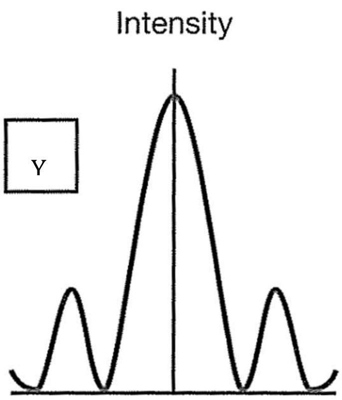
The diagrams below show four different interference patterns obtained from double slit experiments as observed on screens equidistant from the slits.

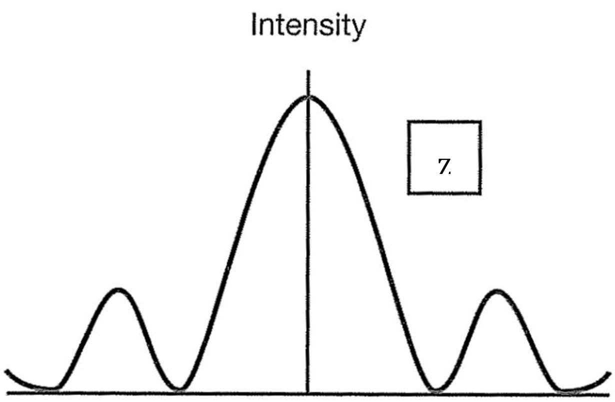
Experiment 1 – Same distance between slits. One pattern formed using blue light, the other using red light.





Experiment 2 – Same colour light used. One slit distance larger than the other.





Which of the following options below matches the observations from the two experiments?

	Experiment 1	Experiment 2
a.	Graph W – Red light Graph X – Blue light	Graph Y – Small slit distance Graph Z – Large slit distance
b.	Graph W – Blue light Graph X – Red light	Graph Y – Small slit distance Graph Z – Large slit distance
c.	Graph W – Red light Graph X – Blue light	Graph Y – Large slit distance Graph Z – Small slit distance
d.	Graph W – Blue light Graph X – Red light	Graph Y – Large slit distance Graph Z – Small slit distance

CMA3 B level question

Assesses evidence with reference to models and theories and develops conclusions

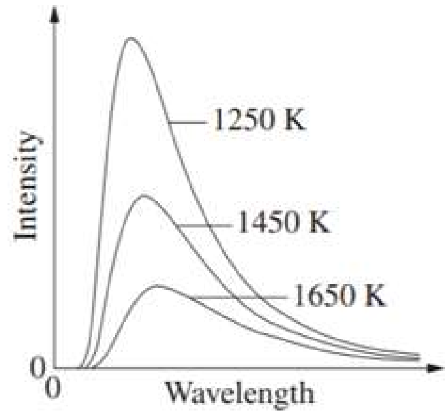
CMA2 D level question

Describes the nature of theories and models

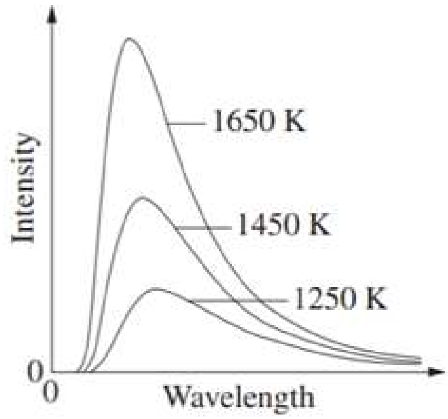
Question 4

Which graph below is consistent with predictions resulting from Planck's hypothesis regarding radiation from hot objects?

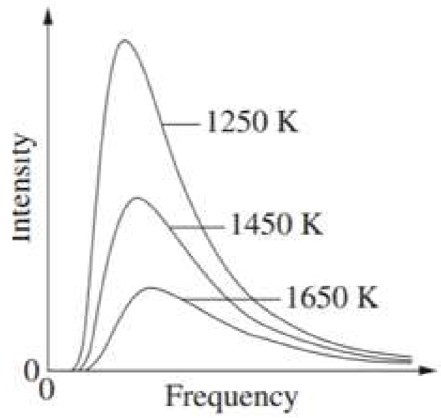
a.



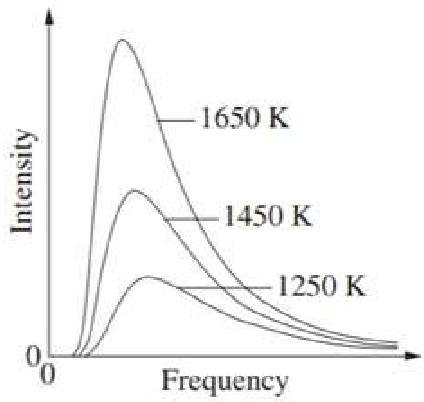
b.



c.



d.



Question 5

Atoms absorb and emit light at specific wavelengths that vary from element to element. What is the reason for this?

- **a.** Every element having a characteristic set of isotopes.
- **b.** Every element having a characteristic ionization energy.
- **c.** Every element emitting electrons with different kinetic energies.
- **d.** Every element having a characteristic set of electron energy levels.

CMA1 D level question

Describes fundamental properties

Why do the predictions of Special Relativity appear to us to be counterintuitive?

CMA2 D level question

Describes nature of theories

- **e.** They only apply to the behaviour of microscopic particles, like electrons.
- **f.** They apply only to inanimate objects like clocks and rods, and not to human beings.
- **g.** They are only noticeable at speeds much higher than we normally experience.
- **h.** Our intuition is based on experiences we have as infants, before we learn any physics.

Question 6

What is the main reason why the Michelson-Morley experiment is considered important?

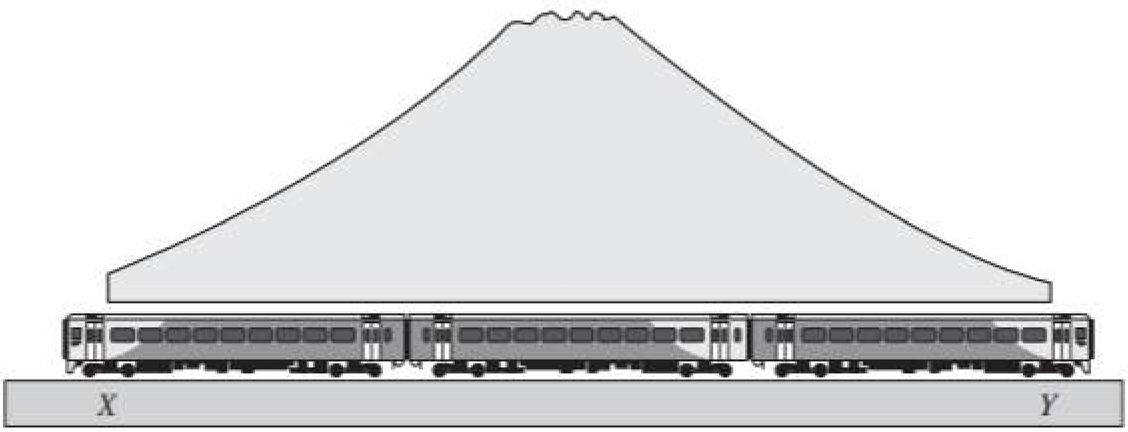
CMA2 E level question

Identifies nature and applications of theories and models

- **a.** It shows the existence of the aether.
- **b.** It suggests that light is an electromagnetic wave.
- **c.** It indicates that light can exhibit interference effects.
- **d.** It provides experimental support for the theory of relativity.

Question 7

When a train is at rest in a tunnel, the train is slightly longer than the tunnel, as shown below.



In a thought experiment, the train is travelling from left to right fast enough relative to the tunnel that its length contracts and it fits inside the tunnel.

An observer on the ground sets up two cameras, at X and Y, to take photos at exactly the same time. The photos show that both ends of the train are inside the tunnel.

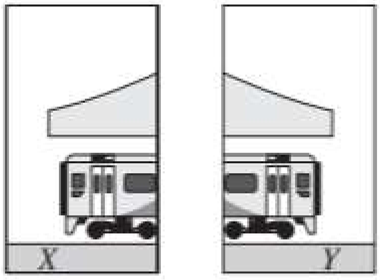


Photo 1 Photo 2

A passenger travelling on the train at its centre can see both ends of the tunnel and is later shown the photos.

From the point of view of the passenger, what is observed about the tunnel, and what can be deduced about the photos?

a. The tunnel's length contracts so the train does not fit, and photo 2 is taken before photo 1.
b. The tunnel's length contracts so the train does not fit, and photos 1 and 2 are taken at the same time.
c. The tunnel appears to expand due to the length contraction of the train, allowing it to fit in the tunnel, and photo 1 is taken before photo 2.
d. The tunnel appears to expand due to the length contraction of the train, allowing it to fit in the tunnel, and photos 1 and 2 are taken at the same time.

CMA2 B level question

Analyses the nature and application of theories

Question 8

A sealed container of gas is heated from a low temperature to a very high temperature. The particles of the gas have greatly increased their speed. Students are debating whether special relativity predicts that the mass of the gas will increase, remain constant or decrease.

Which one of the following statements is correct?

CMA2 C level question

Explains the nature function and applications of theories

a. The mass will increase.
b. The mass will decrease.
c. The mass will remain constant.
d. Special relativity does not apply to gas particles.

Question 9

A proton (mass 1.673×10^{-27} kg) ejected by a supernova attains a velocity of 0.9996c. What is the magnitude of the momentum of the proton?

CMA1 C level question

Explains properties of components and interactions

a. $1.41 \times 10^{-20}\ kgms^{-1}$
b. $5.02 \times 10^{-19}\ kgms^{-1}$
c. $1.77 \times 10^{-1}\ \ kgms^{-1}$
d. $2.51 \times 10^{-17}\ kgms^{-1}$

Question 10

What particles combine to form a meson?

CMA1 E level question

Identifies properties of components

a. Three quarks
b. Three anti-quarks
c. A quark anti-quark pair
d. An electron positron pair

Question 11

Which of the following particles is not a boson?

CMA1 E level question

Identifies properties of components

a. Photon
b. Muon
c. Gluon
d. Higgs particle

Question 12

What the force carrying particle for the strong nuclear force?

CMA1 E level question

Identifies properties of components

a. Gluon
b. Photon
c. Z boson
d. Higg's boson

Question 13

Which of the following interactions is not allowed?

CMA2 C level question

Explains applications of theories and models

a. $p \rightarrow n + e^{+} + \nu_e$
b. $n \rightarrow p + e^{-} + \overline{\nu}_e$
c. $p + \overline{p} \rightarrow \mu^{+} + \mu^{-}$
d. $\mu^{-} \rightarrow \tau^{-} + \overline{\nu}_\tau + \nu_\mu$

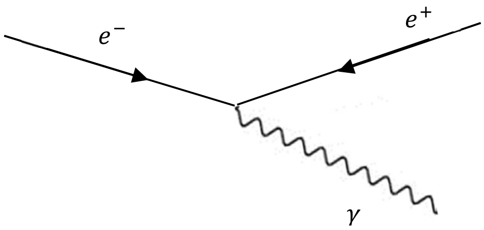
Question 14

Which of the following Feynman diagrams represents an allowed interaction?

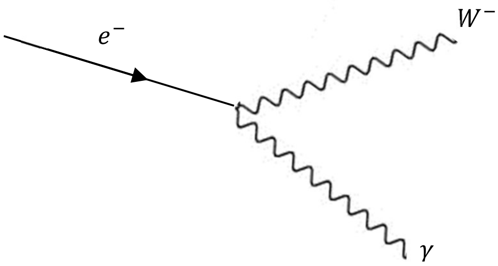
CMA2 C level question

Analyses applications and predictions of theories and models

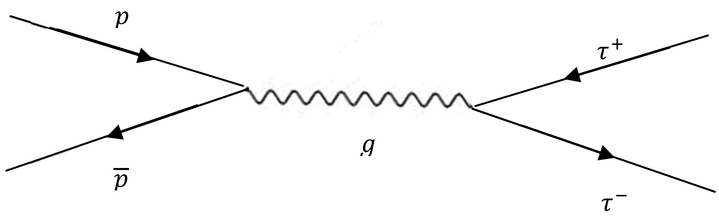
a.



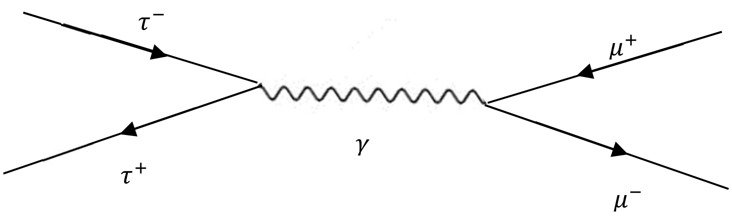
b.



c.



d.



Part B – Short Answer Questions (21 marks)

Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 15

In this course you have conducted a twin slit experiment with light.

CMA1 D level question

Describes processes and interactions

a. **Describe** what occurs when light is passed through twin slits. **(2 marks)**

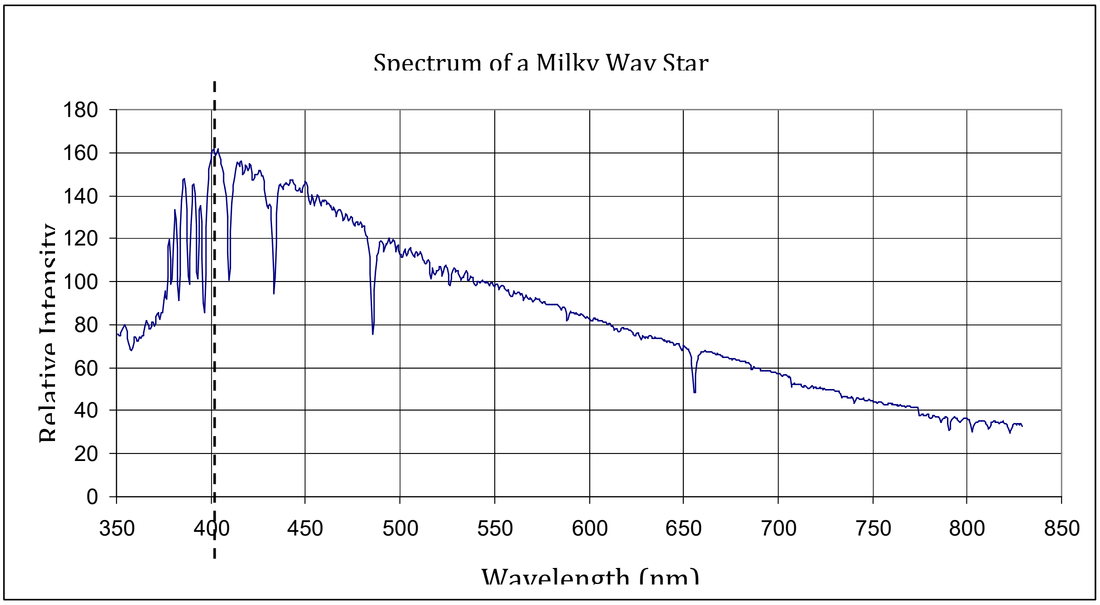
b. **Contrast** what the twin slit and photoelectric effect experiments reveal about the nature of light. **(3 marks)**

CMA1 C level question

Explains processes and interactions

Question 16

The spectrum of a star in the Milky Way is shown below. The wavelength of maximum intensity is marked with a dashed line.



Determine the temperature of the surface of the star. **(1 mark)**

CMA1 C level question

Explains fundamental properties

Question 17

The Bohr model of hydrogen was the first model of the atom that used the new quantum hypothesis, and is still used today in many fields. The predictions of the Bohr model are supported by de Broglie's matter wave proposal.

Explain how de Broglie's matter wave proposal supported the Bohr model of the atom. **(3 marks)**

CMA2 C level question

Explains nature and functions of theories and models

Question 18

a. **Define** an inertial reference frame. **(1 mark)**

CMA1 D level question

Describes fundamental properties

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b. **Identify** an example of a non-inertial reference frame. **(1 mark)**

CMA1 E level question

Identifies components, processes and interactions

Question 19

State the two (2) postulates of Einstein's special relativity. **(2 marks)**

CMA2 E level question

Identifies the nature and functions of theories and models

Question 20

Complete the table below which lists the fundamental matter particles of the standard model.

(3 marks)

Quarks		Leptons	
$+2/3$	$-1/3$	-1	0
Up	Down		
		Muon	
Top			

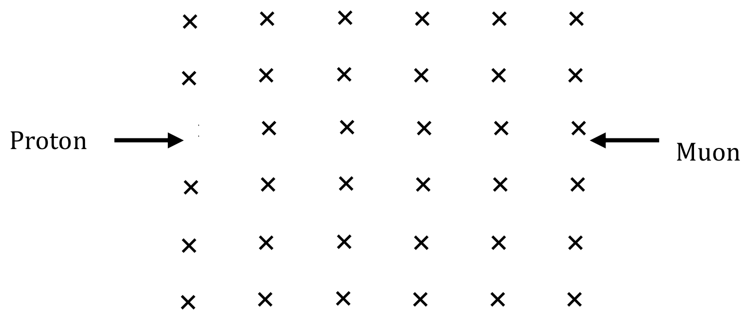
Gauge Boson
photon
W^+, W^-

CMA1 E level question

Identifies fundamental properties

Question 21

A proton and a muon are fired into a uniform magnetic field with the same speed from opposite sides as shown below. Their trajectories are initially perpendicular to the magnetic field.



CMA1 C level question

Explains processes and interactions

Explain one (1) similarity and one (1) difference in the trajectories of the proton and muon as the move in the magnetic field. **(3 marks)**

Part C –Data Analysis Questions (20 marks)

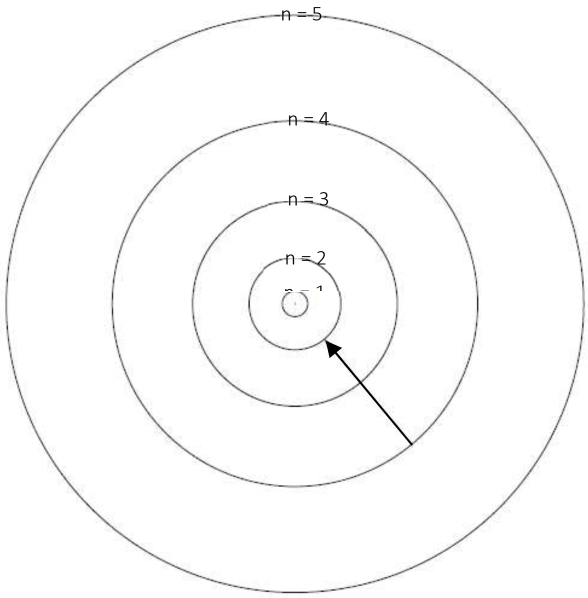
Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 22

The diagram below shows the first five circular Bohr orbits or 'stationary states' for the electron orbiting the nucleus of the hydrogen atom.



CMA1 C level question

Explains processes, interactions, and effects

a. For the electron transition shown on the diagram, **calculate** the wavelength of the emitted photon. **(3 marks)**

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b. **Identify** the part of the electromagnetic spectrum in which the emitted photon be found.

(1 mark)

CMA1 E level question

Identifies fundamental properties

Question 23

One of the primary functions of the OPAL nuclear reactor at ANSTO is to produce neutrons that can be used to probe the structures of different materials.

a. **Calculate** the de Broglie wavelength of a neutron travelling at 5.6 ms^{-1}.

(2 marks)

CMA1 C level question

Explains fundamental properties

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b. **Suggest** how the speed of the neutrons should be changed to make them more effective at probing the structure of ionic solids with atomic spacings of approximately 10^{-10} m. **(2 marks)**

CMA1 B level question
Analyses fundamental properties and interactions

Question 24

The table below lists the first generation of quarks and antiquarks.

Quarks			Antiquarks		
Name	*Symbol*	*Charge*	*Name*	*Symbol*	*Charge*
Up	u	$+\frac{2}{3}e$	Antiup	u	$-\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$	Antidown	d	$+\frac{1}{3}e$

The Standard Model of matter states that baryons, like protons and neutrons, are comprised of three quarks, while mesons, like the pions π^+ and π^- , are comprised of one quark and one antiquark.

a. Using the table above, **state** the quark composition of the following particles.

(i) Neutron **(1 mark)**

CMA1 D level question

Describes system components

(ii) Negative pion **(1 mark)**

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b. **State** the change that must take place among the quarks in one of the nucleons in the nucleus to allow beta decay to occur. **(1 mark)**

CMA1 C level question

Explains processes and interactions

Question 25

The equation below represents a muon decay.

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu}_e$$

a. Apply a symmetry to **transform** the above equation into a new interaction that will be allowed.

(1 mark)

CMA2 C level question

Explains application of theories

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b. **State** the symmetry that you used to construct your interaction. **(1 mark)**

CMA2 C level question

Explains application of theories

Part D – Practical Skills Questions (24 marks)

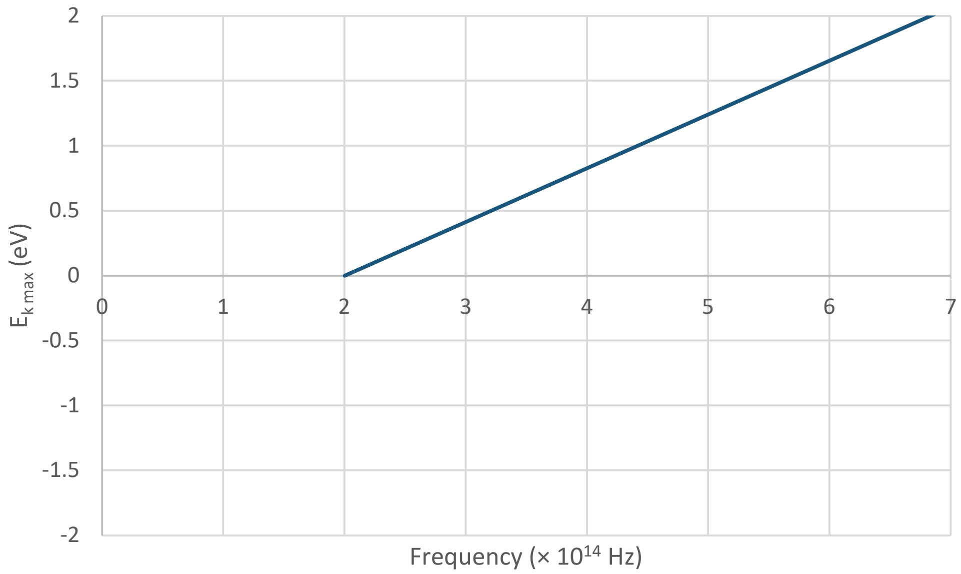
Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 26

The graph below shows the maximum kinetic energy of the photoelectrons ejected from a particular metal surface during a photoelectric effect experiment against the frequency of the incident light.



a. Use the information in the graph and Planck's constant ($4.14 \times 10^{-15}\ eVs$) to **calculate** the work function for the metal shown, in units of electron volts. **(2 marks)**

CMA3 C level question

Develops evidence-based conclusions

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b. **Draw** another line ***on the graph above*** for a different metal that has a work function twice that of the metal shown. **(2 marks)**

CMA3 C level question

Develops evidence-based conclusions

c. The experiment was repeated using light of a greater intensity.

(i) **Describe** the effect on the graph that this would have. **(1 marks)**

CMA3 C level question

Explains with reference to theories

(ii) **Explain** how Einstein's proposal about the nature of light accounts for your answer. **(2 marks)**

Question 27

The Large Hadron collider accelerates protons to very high speeds, reaching speeds of 0.999999991*c*, before two proton streams collide. As the protons increase in speed, the mass of the protons as measured in the laboratory frame increases according to the rules of special relativity.

Particle physicists commonly measure masses in units of MeV/c^2.

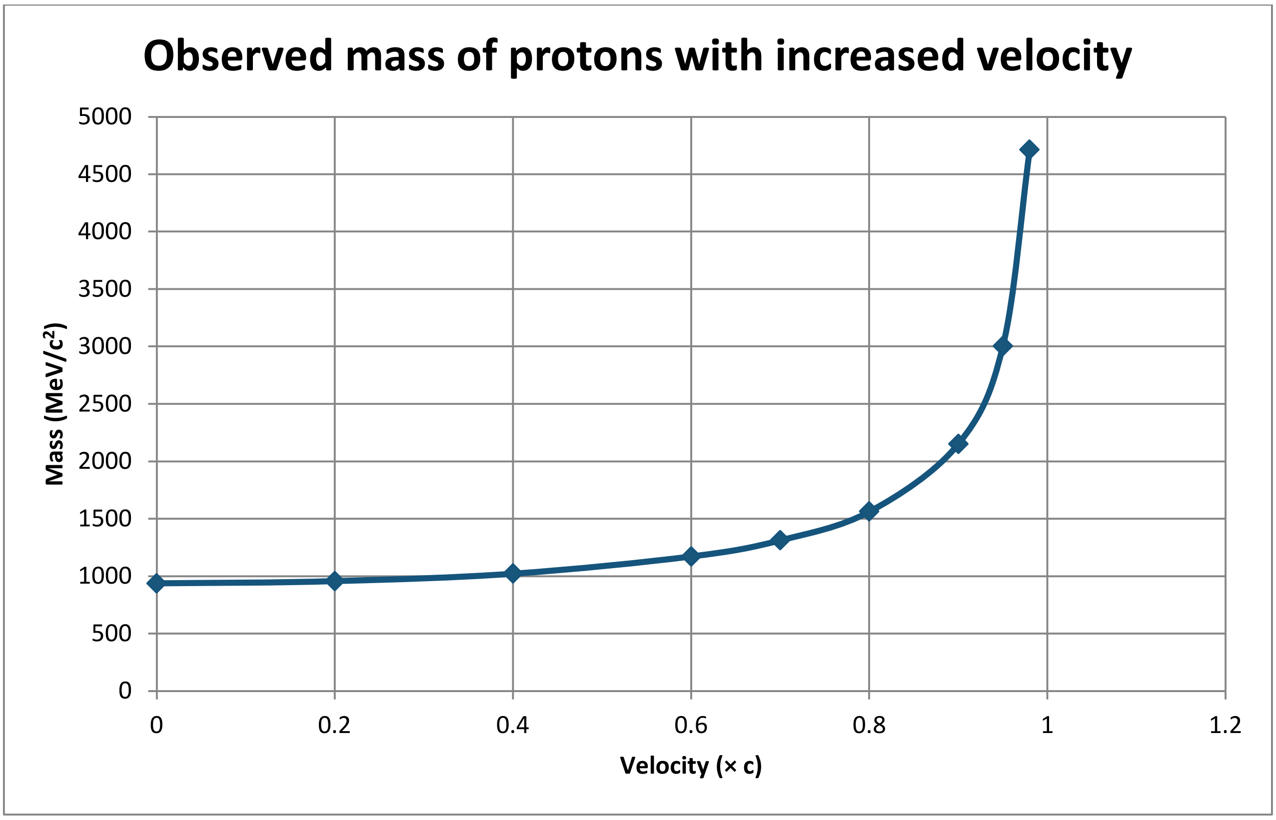
a. A table of the observed mass of a proton at different velocities is shown below. **Complete** the table by filling in the two (2) missing values. **(2 marks)**

Velocity ($\times c$)	Observed proton mass (MeV/c^2)
0.00	938
0.20	957
0.40	
0.60	1172
0.70	1313
0.80	1563
0.90	2152
0.95	
0.98	4714

CMA1 C level question

Explains processes and the effects of factors

The graph below shows the observed mass of the protons as a function of velocity.



b. **Explain** how the graph shows that there is maximum speed limit for all particles with mass.

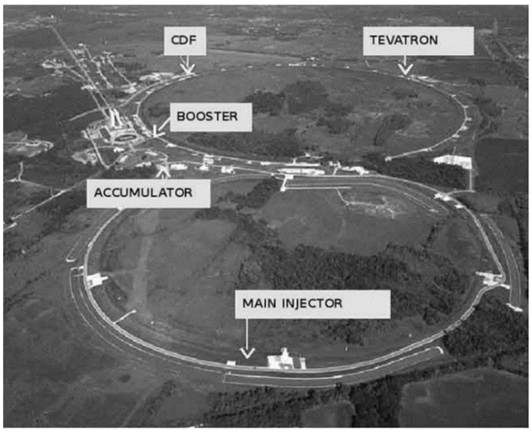
(3 marks)

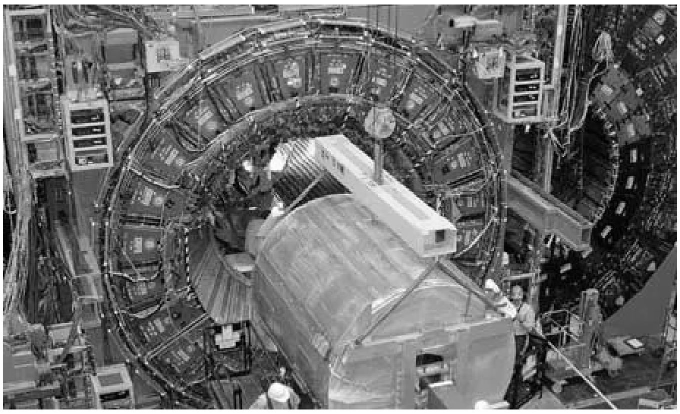
IS2 C level question

Explains relationships

Question 28

The Tetravon was a particle accelerator built at Fermilab in the USA that accelerated and collided protons and antiprotons to speeds of 99.999954% the speed of light. During its life time particle physicists used the Tetravon to experimentally discover the top quark in 1995 and the tau neutrino in 2000.





The Tetravon accelerator tunnel at Fermilab and CDF detector

The Tetravon was shut down in 2011 after the Large Hadron Collider (LHC) was built at CERN in Switzerland. The LHC cost $4.75 billion to make, and accelerates protons to a speed of 99.999999% the speed of light.

a. **Calculate** the kinetic energy of protons in LHC, in units of TeV **(3 marks)**
Note: *tera* = 10^{12}

CMA1 C level question

Explains processes and effects of factors

One criticism of the LHC is that it isn't worth spending the money to build it when it only gives a small increase in speed to protons compared the already successful Tetravon accelerator.

b. Use the information above and the concepts learned in this course to **evaluate** if it was worth replacing the Tetravon accelerator with the LHC. **(5 marks)**

C2 A level question

Evaluates influence of social and economic factors

Question 29

Brian is a particle physicist working for CERN at the Large Hadron Collider (LHC) is Switzerland.

In the detectors at the LHC two beams of protons are collided with each other at high energies, which then produce particle 'showers' as many new particles are created, many of which have more mass than the original two protons.

In 2012, CERN announced that they discovered a new heavy particle, the Higgs boson, that had been predicted to exist in 1964 by several scientists, including Peter Higgs. The discovery of the particle involved analysing millions of collisions in the LHC detectors. The discovery was made separately by two independent experiments, ATLAS and CMS.

a. **Outline** two (2) reasons why millions of collisions were necessary before the scientists at CERN could reliably claim to have discovered the Higgs boson.

(2 marks)

CMA2 C level question

Explains applications of theories

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b. **Explain** why the discovery of the Higgs boson needed to be made using two independent experiments to be considered a valid scientific discovery. **(2 marks)**

C1 C level question

Explains epistemology and role of peer review in developing knowledge

Part E – Long Answer Questions (15 marks)

Question 30 **(8 marks)**

Imagine that you are a traffic engineer working in a world where the speed of light has suddenly changed to have a value of 50 ms^{-1} (180 kmh^{-1}). All other physics has remained the same.

CMA2 A level question

Evaluates predictions and limitations of theories

Assess the impact that this change will have on road travel, traffic, and road safety.

- You can consider impacts on travel at different speed limits, intersections, fuel needs, collisions and car safety, and any other relevant physics.
- You must make specific use of your knowledge of special relativity and how the impacts will give different predictions than Newton's Laws.
- Your answer must include specific examples to support your impacts.
- Make sure your answer addresses all aspects of the relevant physics.

Question 30 Marking Rubric

A grade (8)	B grade (6-7)	C grade (4-5)	D grade (2-3)	E grade (0-1)
Evaluates predictions and limitations of special relativity and Newton's laws to create insightful solutions, with evidence, to the given problem.	Analyses predictions and limitations of special relativity and Newton's laws to create solutions, with evidence, to the given problem.	Explains predictions and limitations of special relativity and Newton's laws that relate to the given problem.	Describes predictions or limitations of special relativity and Newton's laws that relate to the given problem.	Identifies predictions or limitations of special relativity and Newton's laws that relate to the given problem.

CMA2 A level question Evaluates applications of theories using evidence in unfamiliar contexts

Question 31 **(7 marks)**

Imagine a future where scientists have developed the technology to reliably produce matter and antimatter leptons of all three families, and store them in containers where their decay into smaller particles can be prevented. Once released from their containers, the regular decay rates of each lepton occur.

One scientist, Annabelle, reads about an electron-positron annihilation reaction that produces D^+ and D^- mesons. She proposes that a new spaceship engine can be built using this annihilation reaction to provide thrust.

A different scientist, Belinda, proposes that a better engine design would use Tau leptons as the fuel source, and use their decays into electrons or muons once they are released from their container as the thrust source (decays into electrons and muons each account for about 17% of Tau decays).

Critically analyse the two engine proposals and **evaluate** which will be the most effective engine.

In your answer you need to include the following points, and any other relevant physics:

- **Describe** the particle reaction for each engine, including a reaction diagram of the reaction.
- **Explain** how an engine using each reaction could generate thrust, and where the energy comes from.
- **Evaluate** the effectiveness of the decay as a fuel source.

Question 31 Marking Rubric

A grade (7)	B grade (6)	C grade (4-5)	D grade (2-3)	E grade (0-1)
Evaluates applications and predictions of particle physics models to evaluate the effectiveness of the proposed engines.	Analyses applications and predictions of particle physics models to judge the effectiveness of the proposed engines.	Explains applications and predictions of particle physics models when determining the effectiveness of the proposed engines.	Describes applications or predictions of particle physics models that relate to the given problem.	Identifies applications or predictions of particle physics models that relate to the given problem.

End of exam

SUMMARY OF STUDENT ACHIEVEMENT BY ACHIEVEMENT STANDARD

Achievement Criteria Assessed	Standard	Marks Awarded	Total Available
Concepts Models and Applications 1	B		2
Concepts Models and Applications 1	C		20
Concepts Models and Applications 1	D		7
Concepts Models and Applications 1	E		8
Concepts Models and Applications 2	A		15
Concepts Models and Applications 2	B		1
Concepts Models and Applications 2	C		11
Concepts Models and Applications 2	D		1
Concepts Models and Applications 2	E		3
Concepts Models and Applications 3	B		1
Concepts Models and Applications 3	C		7
Contexts 1	C		2
Contexts 2	A		5
Inquiry Skills 2	C		3

SUMMARY OF STUDENT ACHIEVEMENT BY QUESTION GRADE LEVEL

Grade	Marks Awarded	Total available
A		20
B		4
C		43
D		8
E		11

ASSESSMENT TWO: ANALYSIS OF THE TASK USING QUALITY ASSESSMENT GUIDELINES

High	Coverage of BSSS Accredited Courses
Outstanding	Reliability
Outstanding	Bias Awareness
High	Levels of Thinking
Outstanding	Student Engagement
Outstanding	Academic Integrity

1. COVERAGE OF BSSS ACCREDITED COURSES

High Coverage of BSSS Accredited Courses - Assessment tasks are thoughtfully planned. Assessments are not too big: assessing irrelevant criteria; nor too small: missing important criteria.

COMMENTS

The task provides high coverage of unit goals and assessment criteria in Concepts Models and Applications, with some coverage of Contexts and Inquiry Skills.

2. RELIABILITY

Outstanding Reliability - Assessment tasks and marking are strategically designed to remove all sources of non-relevant variation in measurements.

COMMENTS

Instructions and conditions are clear and unambiguous. The exam marking guide is very clear and would enable a marker to clearly distinguish between levels of student achievement. The long answer questions in Part E have a brief rubric which clarifies expectations to students and allows the marker to distinguish between levels of student achievement.

3. BIAS AWARENESS

Outstanding Bias Awareness – The assessment task is strategically designed to be sensitive and empowering for all students, catering for the diverse needs of gender, socio-economic status, disabilities and/or cultures, and that do not marginalise or favour a student or group of students, or advantage or disadvantage certain background knowledge or ways of thinking.

COMMENTS

There are no identifiable sources of bias in the task. The task is accessible to students from a wide range of backgrounds and has no special requirements that would favour one group of students over another. The task is clearly focussed on the key ideas of the unit, in particular providing opportunities for students to demonstrate their achievement on Concepts, Models and Applications from the Achievement Standards.

4. LEVELS OF THINKING

High Levels of Thinking – Clear assessment tasks are designed that allow students to engage at progressively higher cognitive demands. The suite of assessments demonstrates that there are expectations for all learners at all levels of learning and opportunities for extending all learners are planned for. Assessment tasks are flexible and varied, covering a range of assessment modes.

COMMENTS

Opportunities exist for students to demonstrate a range of thinking levels in the task. The task puts a heavy weight on C level question but provides adequate opportunity at the D and E standard for students at that level to demonstrate what they know. Opportunities exist for A level students to extend themselves, most notably in the long answer section of the exam. These questions also allow students to demonstrate across a range of thinking levels.

5. STUDENT ENGAGEMENT

Outstanding Student Engagement – Assessment tasks are strategically planned to engage students. Assessment tasks are explicitly and purposefully connected to contemporary issues or student lived experiences, interests, or prior knowledge. The suite of assessment tasks clearly supports student ownership.

COMMENTS

Task is clear and unambiguous. Students are asked to respond to a range of different question types and styles, including questions that connect to more recent discoveries in particle physics and that require students to use their knowledge of the contents of the unit to draw conclusions in a wider societal context. These questions facilitate students thinking like an expert.

6. ACADEMIC INTEGRITY

Outstanding Academic Integrity - Students are required to engage in genuine deep learning at a level of challenge appropriate to the student and tasks make provision for sense making or knowledge construction. Assessment is designed to ensure authenticity from students and requires individualised responses.

COMMENTS

Assessment conditions dictate a high level of academic integrity. These conditions are clear and unambiguous in the task instructions.

ANNOTATED STUDENT WORK : A GRADE

PART A – MULTIPLE CHOICE (15 MARKS)

Instructions:

Each question is worth 1 mark.

Record your answers on the multiple choice answer sheet.

Question 1

What is the energy of a 630 nm photon of electromagnetic radiation?

CMA1 C level question
Explains fundamental properties

Correct response

- **a.** 1.97 eV
- **b.** 3.15 eV
- **c.** 1.97×10^{-19} J
- **d.** 3.15 J

Question 2

Which of the following is a correct statement about how the Bohr model of the atom was an improvement on the Rutherford model?

CMA2 C level question
Explains nature, limitations and applications of theories and models

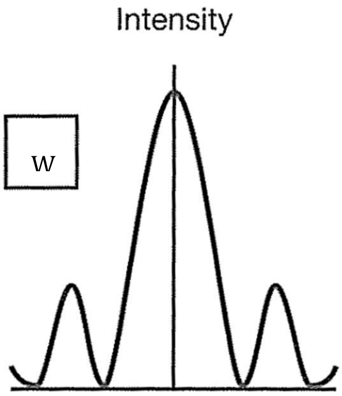
Correct response

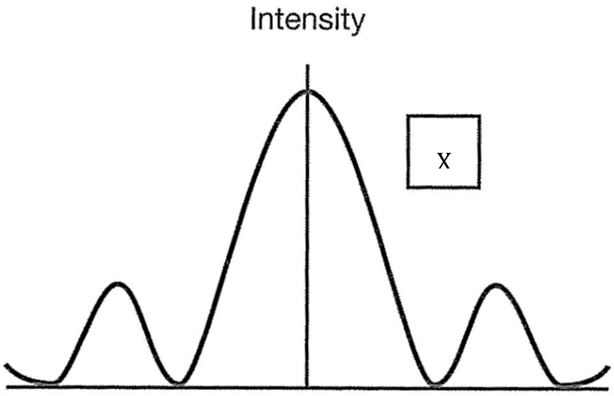
- **a.** It stated that electrons exist in 3D orbitals with wave patterns that are described their probability density, which explained how wave particle duality was applied to atoms.
- **b.** It stated than atoms have small, dense, positive nucleus, which explained why a small number of alpha particles fired at gold foil could be rebounded.
- **c.** It stated that electrons have quantised orbits with fixed radius and angular momentum, which explained why electrons didn't decay into the nucleus by emitting electromagnetic radiation.
- **d.** It stated that atoms have separate positive charge and negative electrons, which explained the production of cathode ray beams that could deflected by electric and magnetic fields.

Question 3

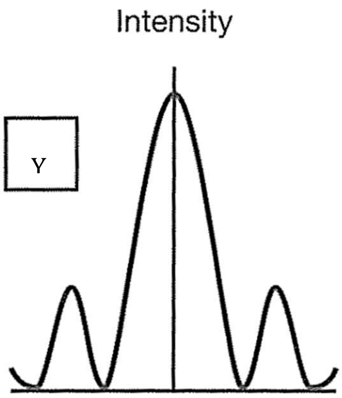
The diagrams below show four different interference patterns obtained from double slit experiments as observed on screens equidistant from the slits.

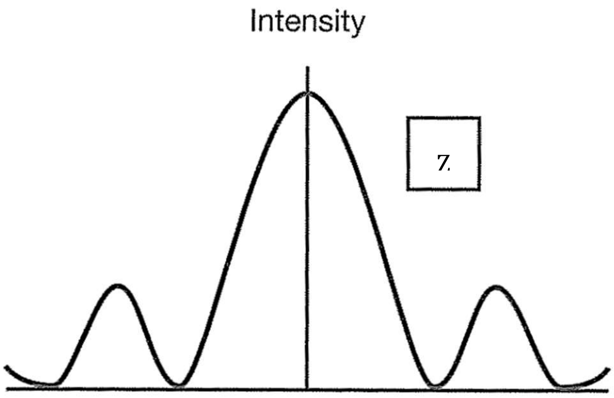
Experiment 1 – Same distance between slits. One pattern formed using blue light, the other using red light.





Experiment 2 – Same colour light used. One slit distance larger than the other.





Which of the following options below matches the observations from the two experiments?

CMA3 B level question
Assesses evidence with reference to models and theories and develops conclusions

Correct response

	Experiment 1	Experiment 2
a.	Graph W – Red light Graph X – Blue light	Graph Y – Small slit distance Graph Z – Large slit distance
b.	Graph W – Blue light Graph X – Red light	Graph Y – Small slit distance Graph Z – Large slit distance

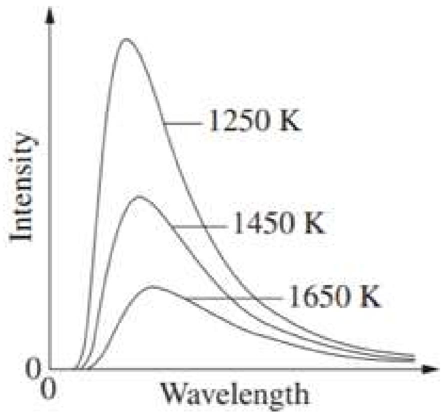
c.	Graph W – Red light Graph X – Blue light	Graph Y – Large slit distance Graph Z – Small slit distance
d.	Graph W – Blue light Graph X – Red light	Graph Y – Large slit distance Graph Z – Small slit distance

Which graph below is consistent with predictions resulting from Planck's hypothesis regarding radiation from hot objects?

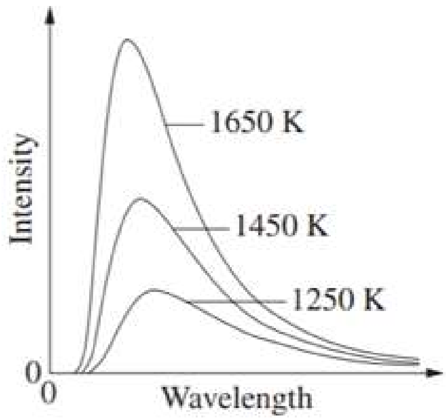
CMA2 D level question
Describes the nature of theories and models

Correct response

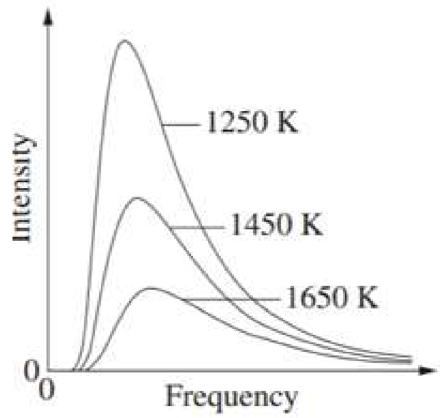
a.



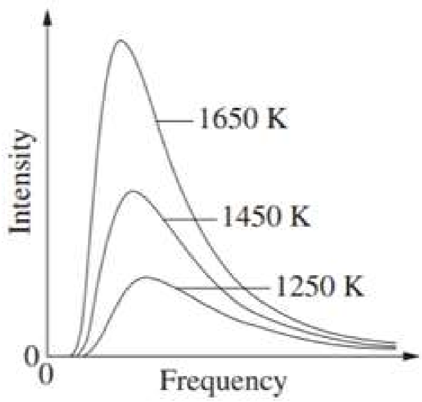
b.



c.



d.



Question 4

Atoms absorb and emit light at specific wavelengths that vary from element to element. What is the reason for this?

- **a.** Every element having a characteristic set of isotopes.
- **b.** Every element having a characteristic ionization energy.
- **c.** Every element emitting electrons with different kinetic energies.
- **d.** Every element having a characteristic set of electron energy levels.

CMA1 D level question
Describes fundamental properties

Correct response

Question 5

Why do the predictions of Special Relativity appear to us to be counterintuitive?

CMA2 D level question
Describes nature of theories

Correct response

- **a.** They only apply to the behaviour of microscopic particles, like electrons.
- **b.** They apply only to inanimate objects like clocks and rods, and not to human beings.
- **c.** They are only noticeable at speeds much higher than we normally experience.
- **d.** Our intuition is based on experiences we have as infants, before we learn any physics.

Question 6

What is the main reason why the Michelson-Morley experiment is considered important?

CMA2 E level question
Identifies nature and applications of theories and models

Correct response

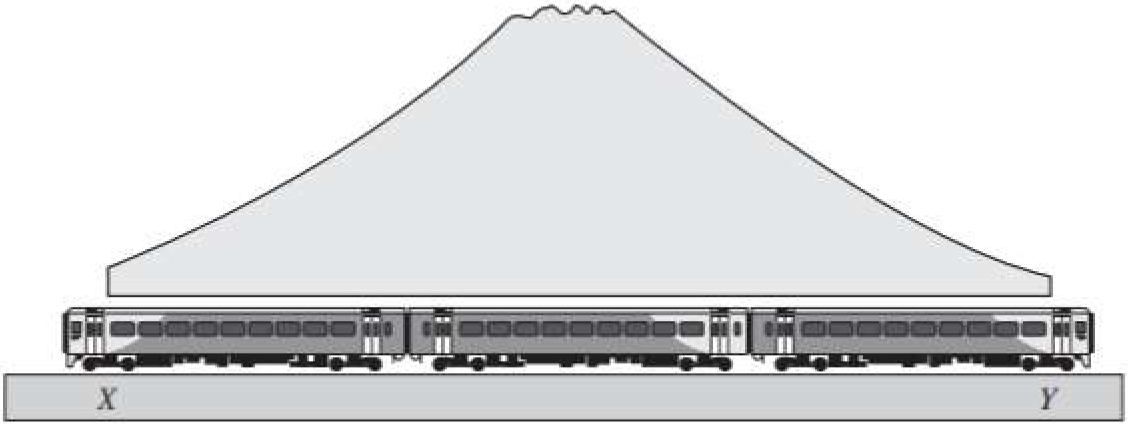
- **a.** It shows the existence of the aether.
- **b.** It suggests that light is an electromagnetic wave.
- **c.** It indicates that light can exhibit interference effects.
- **d.** It provides experimental support for the theory of relativity.

CMA2 B level question
Analyses the nature and application of theories

Correct response

Question 7

When a train is at rest in a tunnel, the train is slightly longer than the tunnel, as shown below.



In a thought experiment, the train is travelling from left to right fast enough relative to the tunnel that its length contracts and it fits inside the tunnel.

An observer on the ground sets up two cameras, at X and Y, to take photos at exactly the same time. The photos show that both ends of the train are inside the tunnel.

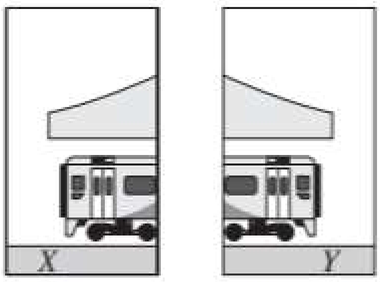


Photo 1 Photo 2

A passenger travelling on the train at its centre can see both ends of the tunnel and is later shown the photos.

From the point of view of the passenger, what is observed about the tunnel, and what can be deduced about the photos?

a. The tunnel's length contracts so the train does not fit, and photo 2 is taken before photo 1.

b. The tunnel's length contracts so the train does not fit, and photos 1 and 2 are taken at the same time.
c. The tunnel appears to expand due to the length contraction of the train, allowing it to fit in the tunnel, and photo 1 is taken before photo 2.
d. The tunnel appears to expand due to the length contraction of the train, allowing it to fit in the tunnel, and photos 1 and 2 are taken at the same time.

Question 8

A sealed container of gas is heated from a low temperature to a very high temperature. The particles of the gas have greatly increased their speed. Students are debating whether special relativity predicts that the mass of the gas will increase, remain constant or decrease.

Which one of the following statements is correct?

CMA2 C level question
Explains the nature function and applications of theories

Correct response

a. The mass will increase.
b. The mass will decrease.
c. The mass will remain constant.
d. Special relativity does not apply to gas particles.

Question 9

A proton (mass 1.673 × 10^{-27} kg) ejected by a supernova attains a velocity of 0.9996c. What is the magnitude of the momentum of the proton?

CMA1 C level question
Explains properties of components and interactions

Correct response

a. $1.41 \times 10^{-20}\ kgms^{-1}$
b. $5.02 \times 10^{-19}\ kgms^{-1}$
c. $1.77 \times 10^{-1}\ \ kgms^{-1}$
d. $2.51 \times 10^{-17}\ kgms^{-1}$

Question 10

What particles combine to form a meson?

CMA1 E level question
Identifies properties of components

Correct response

a. Three quarks
b. Three anti-quarks
c. A quark anti-quark pair
d. An electron positron pair

Question 11

Which of the following particles is not a boson?

CMA1 E level question
Identifies properties of components

Correct response

a. Photon
b. Muon
c. Gluon
d. Higgs particle

Question 12

What the force carrying particle for the strong nuclear force?

CMA1 E level question
Identifies properties of components

Correct response

a. Gluon
b. Photon
c. Z boson
d. Higg's boson

Question 13

Which of the following interactions is not allowed?

CMA2 C level question
Explains applications of theories and models

Correct response

a. $p \rightarrow n + e^{+} + \nu_{e}$
b. $n \rightarrow p + e^{-} + \overline{\nu}_{e}$
c. $p + \overline{p} \rightarrow \mu^{+} + \mu^{-}$
d. $\mu^{-} \rightarrow \tau^{-} + \overline{\nu}_{\tau} + \nu_{\mu}$

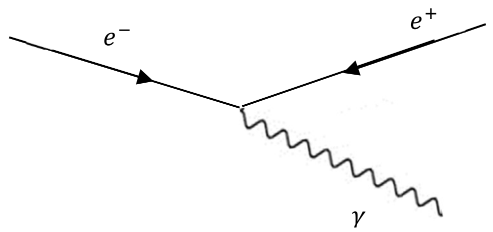
Question 14

Which of the following Feynman diagrams represents an allowed interaction?

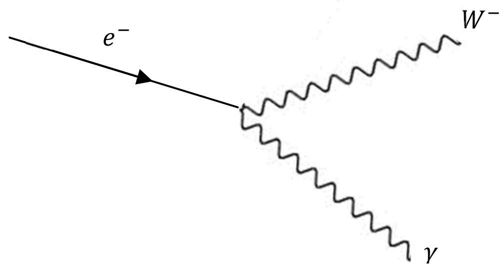
CMA2 C level question
Analyses applications and predictions of theories and models

Correct response

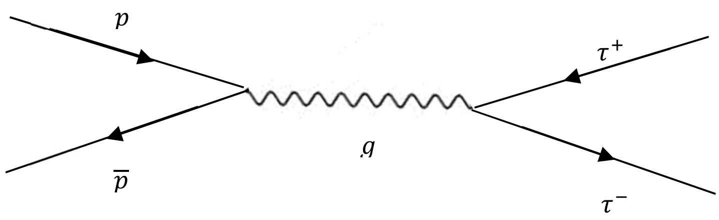
a.



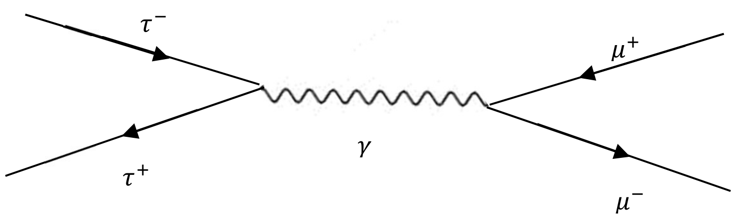
b.



c.



d.



Part B – Short Answer Questions (19 marks)

Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 15

In this course you have conducted a twin slit experiment with light.

a. **Describe** what occurs when light is passed through twin slits. **(2 marks)**

It produces an interference pattern where a path difference of 1λ gives constructive interference, forming bright spots and $\frac{1}{2}\lambda$ gives destructive interference, forming darker spots thus producing an alternating pattern of light and dark

CMA1 D level question
Student correctly describes a physical process and interaction

2/2

b. **Contrast** what the twin slit and photoelectric effect experiments reveal about the nature of light. **(3 marks)**

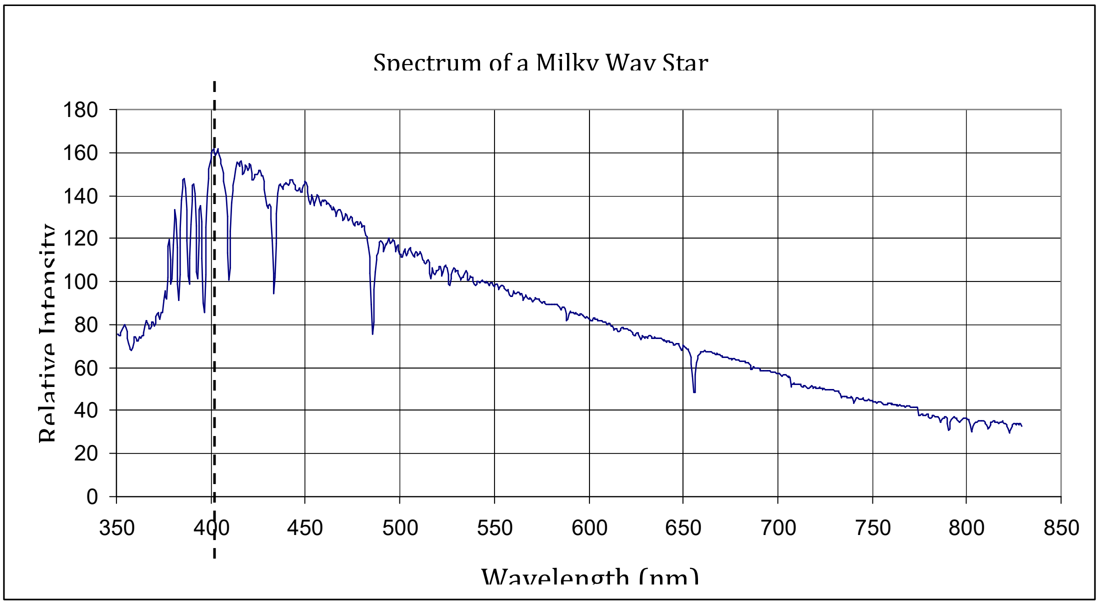
Only waves undergo interference patterns, therefore light is a wave, while photoelectric effect experiments demonstrate that only some energies of light can ionise an electron, showing that light is a particle, transferring discrete packets of energy that depend on its frequency. This differs with waves which would be able to ionise eventually no matter the frequency.

CMA1 C level question
Student explains processes and interactions

3/3

Question 16

The spectrum of a star in the Milky Way is shown below. The wavelength of maximum intensity is marked with a dashed line.



Determine the temperature of the surface of the star.**(1 mark)**

CMA1 C level question
Student correctly identifies peak wavelength and uses this to explain how to determine the temperature

1/1

$$T = \frac{b}{\lambda} = \frac{2.898\times10^{-3}}{405\times10^{-9}} = 7160\ K$$

Question 17

The Bohr model of hydrogen was the first model of the atom that used the new quantum hypothesis, and is still used today in many fields. The predictions of the Bohr model are supported by de Broglie's matter wave proposal.

Explain how de Broglie's matter wave proposal supported the Bohr model of the atom.

(3 marks)

CMA2 C level question
Student correctly explains nature and functions of theories and models

3/3

De Broglie's proposal suggested that electrons are waves. We can model these as standing waves, and only standing waves with particular wavelengths fit around the nucleus. This model predicts the fixed orbits of Bohr's model.

Question 18

a. **Define** an inertial reference frame.
(1 mark)

A reference frame with no acceleration

CMA1 D level question
Student describes fundamental properties
1/1

b. **Identify** an example of a non-inertial reference frame. **(1 mark)**

A rocket ship taking off from Earth

CMA1 E level question
Student identifies components, processes and interactions
1/1

Question 19

State the two (2) postulates of Einstein's special relativity. **(2 marks)**

CMA2 E level question
Student identifies the nature and functions of theories and models
2/2

1. The speed of light is constant in all reference frames
2. The laws of physics are the same in all inertial reference frames

CMA1 E level question
Student identifies fundamental properties
3/3

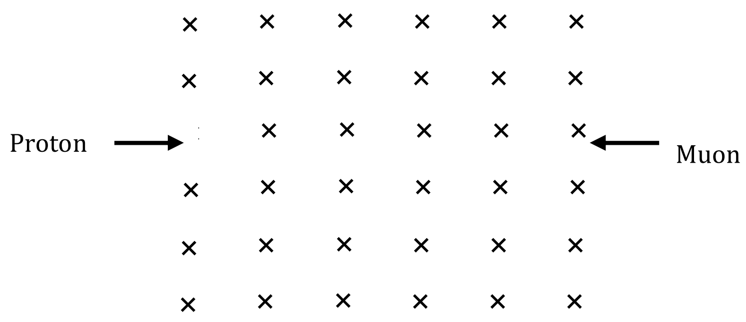
Question 20

Complete the table below which lists the fundamental matter particles of the standard model. **(3 marks)**

Quarks		Leptons		Gauge Boson
+2/3	**−1/3**	**−1**	**0**	photon
Up	Down	electron	electron neutrino	gluon
Charm	Strange	Muon	Muon neutrino	W^+, W^-
Top	Bottom	Tau	Tau neutrino	Z^0

Question 21

A proton and a muon are fired into a uniform magnetic field with the same speed from opposite sides as shown below. Their trajectories are initially perpendicular to the magnetic field.



Explain one (1) similarity and one (1) difference in the trajectories of the proton and muon as the move in the magnetic field. **(3 marks)**

They both have opposite charges so will deflect in different directions, but one is coming from a different direction and thus will curve in the same way. The proton has a higher mass than the Muon and will therefore curve less than the muon.

CMA1 C level question
Student explains processes and interactions

3/3

Part C –Data Analysis Questions (13 marks)

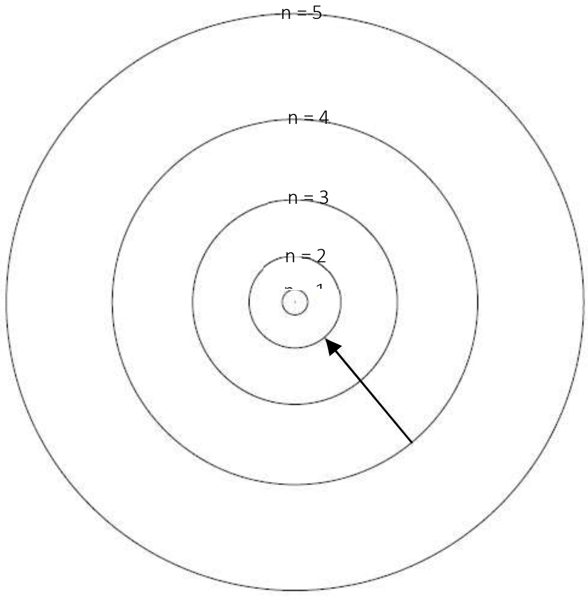
Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 22

The diagram below shows the first five circular Bohr orbits or 'stationary states' for the electron orbiting the nucleus of the hydrogen atom.



a. For the electron transition shown on the diagram, **calculate** the wavelength of the emitted photon. **(3 marks)**

$$\lambda = \frac{1}{R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)} = \frac{1}{1.097 \times 10^{-7} \times \left(\frac{1}{2^2} - \frac{1}{4^2}\right)} = 4.86 \times 10^{-7} m$$

CMA1 C level question
Student explains processes, interactions, and effects

3/3

b. **Identify** the part of the electromagnetic spectrum in which the emitted photon be found. **(1 mark)**

visible

CMA1 E level question
Student identifies fundamental properties

1/1

Question 23

One of the primary functions of the OPAL nuclear reactor at ANSTO is to produce neutrons that can be used to probe the structures of different materials.

a. **Calculate** the de Broglie wavelength of a neutron travelling at 5.6 ms^{-1}.
(2 marks)

$$\lambda = 6.626 \times \frac{10^{-34}}{1.675 \times 10^{-27} \times 5.6} = 7.1 \times 10^{-8} m$$

CMA1 C level question
Student explains fundamental properties

2/2

b. **Suggest** how the speed of the neutrons should be changed to make them more effective at probing the structure of ionic solids with atomic spacings of approximately 10^{-10} m. **(2 marks)**

They should speed up. Their wavelength is currently $7.1 \times 10^{-8} m$, and the wavelength should be decreased to better match the atomic spacings.

CMA1 B level question
Student analyses fundamental properties and interactions

2/2

Question 24

The table below lists the first generation of quarks and antiquarks.

Quarks		
Name	*Symbol*	*Charge*
Up	u	$+\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$

Antiquarks		
Name	*Symbol*	*Charge*
Antiup	u	$-\frac{2}{3}e$
Antidown	d	$+\frac{1}{3}e$

The Standard Model of matter states that baryons, like protons and neutrons, are comprised of three quarks, while mesons, like the pions π^+ and π^- , are comprised of one quark and one antiquark.

a. Using the table above, **state** the quark composition of the following particles.

CMA1 D level question
Student describes system components

2/2

(i) Neutron **(1 mark)**

udd

(ii) Negative pion **(1 mark)**

$d\bar{u}$

b. **State** the change that must take place among the quarks in one of the nucleons in the nucleus to allow beta decay to occur. **(1 mark)**

$down \rightarrow up$

CMA1 C level question
Student explains processes and interactions

1/1

Question 25

The equation below represents a muon decay.

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu_e}$$

a. Apply a symmetry to **transform** the above equation into a new interaction that will be allowed. **(1 mark)**

$\mu^- + e^+ \rightarrow \nu_\mu + \overline{\nu_e}$

CMA2 C level question
Student explains application of theories

1/1

b. **State** the symmetry that you used to construct your interaction. **(1 mark)**

Crossing symmetry

CMA2 C level question
Student explains application of theories

1/1

Part D – Practical Skills Questions (24 marks)

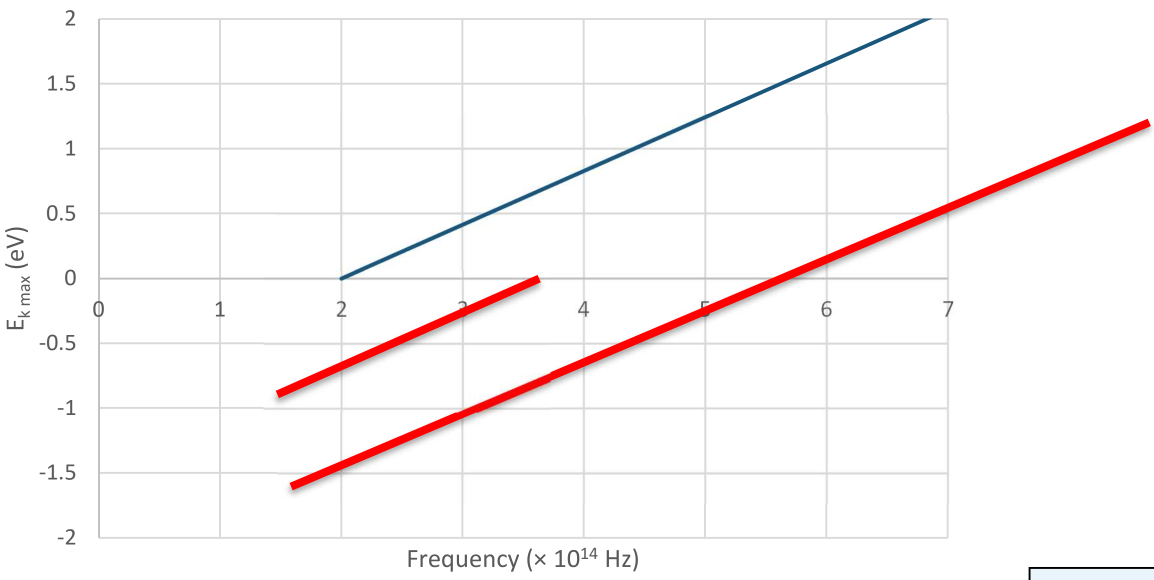
Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 26

The graph below shows the maximum kinetic energy of the photoelectrons ejected from a particular metal surface during a photoelectric effect experiment against the frequency of the incident light.



CMA3 C level question
Student develops evidence-based conclusions
2/2

a. Use the information in the graph and Planck's constant ($4.14 \times 10^{-15}\ eVs$) to **calculate** the work function for the metal shown, in units of electron volts. **(2 marks)**

$$W = hf_0 = (4.14 \times 10^{-1}\ )(2 \times 10^{14}) = 0.828\ eV$$

b. **Draw** another line ***on the graph above*** for a different metal that has a work function twice that of the metal shown. **(2 marks)**

CMA3 C level question
Student develops evidence-based conclusions
2/2

c. The experiment was repeated using light of a greater intensity.

(i) **Describe** the effect on the graph that this would have. **(1 marks)**

None

(ii) Explain how Einstein's proposal about the nature of light accounts for your answer. **(2 marks)**

Einstein proposes that light is a particle and that it only matters whether the energy of the particle is greater than the work function. If it is greater it will ionise and if not it won't. Greater intensity means that more electrons will be ionised, but will not add to the KE of the electrons.

CMA3 C level question
Student explains with reference to theories

3/3

Question 27

The Large Hadron collider accelerates protons to very high speeds, reaching speeds of 0.999999991*c*, before two proton streams collide. As the protons increase in speed, the mass of the protons as measured in the laboratory frame increases according to the rules of special relativity.

Particle physicists commonly measure masses in units of MeV/c^2.

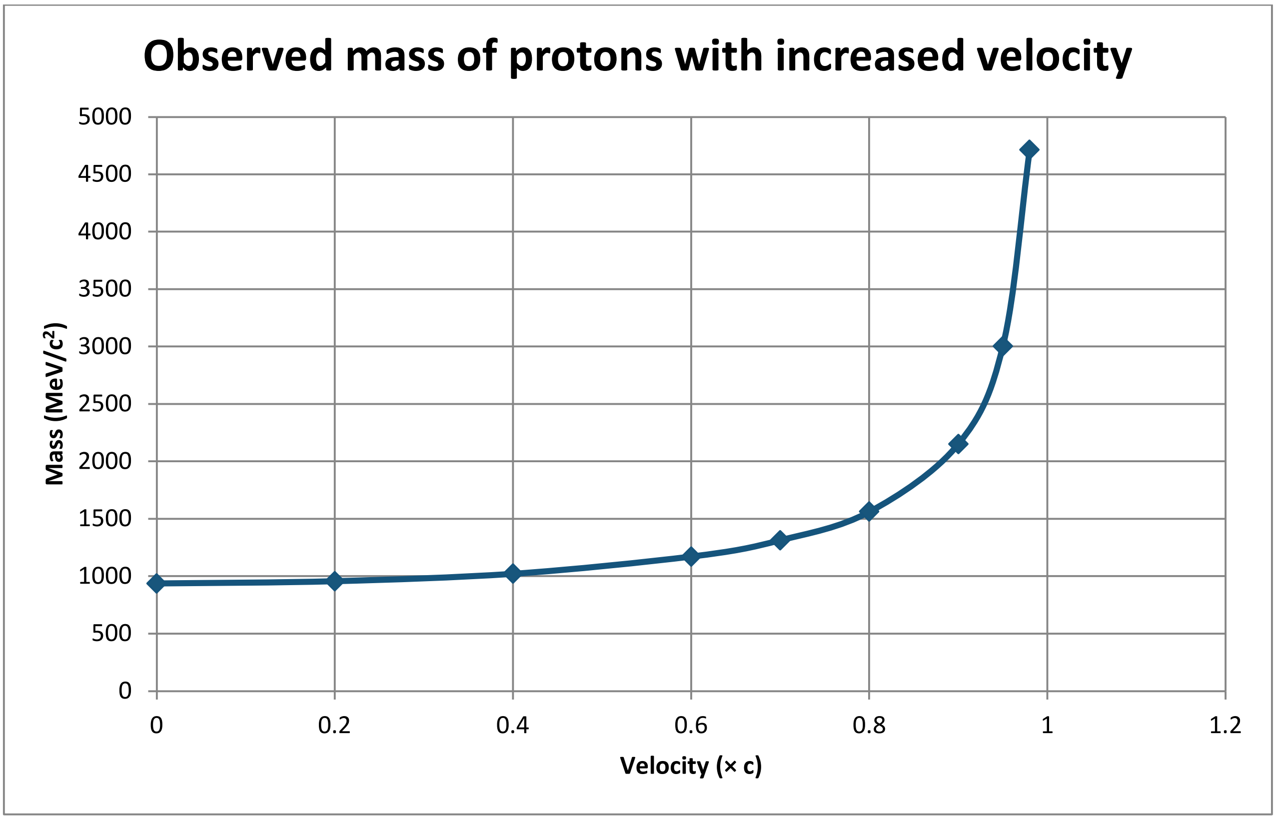
CMA1 C level question
Student explains processes and the effects of factors

2/2

a. A table of the observed mass of a proton at different velocities is shown below. **Complete** the table by filling in the two (2) missing values. **(2 marks)**

Velocity ($\times c$)	**Observed proton mass (MeV/c^2)**
0.00	938
0.20	957
0.40	1023
0.60	1172
0.70	1313
0.80	1563
0.90	2152
0.95	3004
0.98	4714

The graph below shows the observed mass of the protons as a function of velocity.



b. **Explain** how the graph shows that there is maximum speed limit for all particles with mass. **(3 marks)**

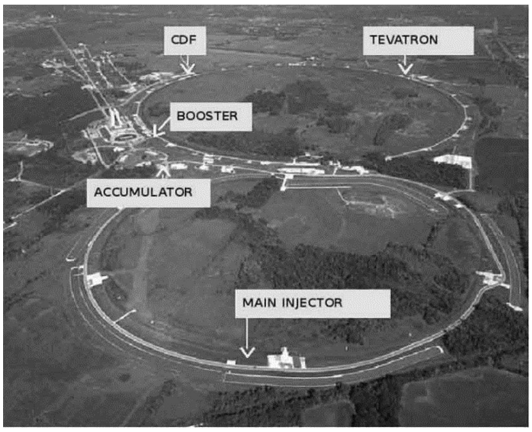
The asymptote of the graph is c, the speed of light. As an object approaches the speed of light, its mass increases quickly, requiring more energy to increase its speed further. In order to reach the speed of light, the mass would have to be infinite, which is not possible.

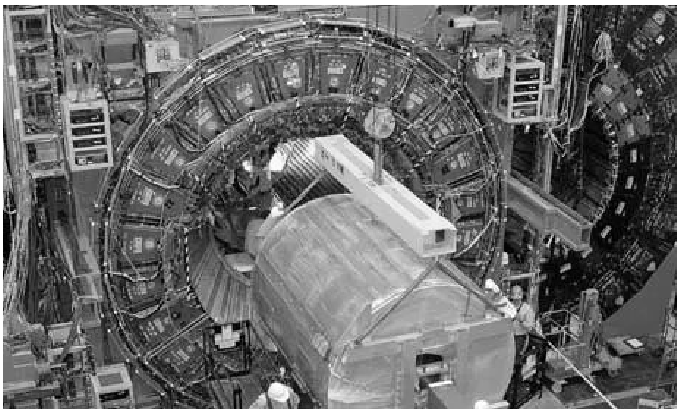
IS2 C level question
Student explains relationships

3/3

Question 28

The Tetravon was a particle accelerator built at Fermilab in the USA that accelerated and collided protons and antiprotons to speeds of 99.999954% the speed of light. During its life time particle physicists used the Tetravon to experimentally discover the top quark in 1995 and the tau neutrino in 2000.





The Tetravon accelerator tunnel at Fermilab and CDF detector

The Tetravon was shut down in 2011 after the Large Hadron Collider (LHC) was built at CERN in Switzerland. The LHC cost $4.75 billion to make, and accelerates protons to a speed of 99.999999% the speed of light.

CMA1 C level question
Student explains processes and effects of factors

3/3

a. **Calculate** the kinetic energy of protons in LHC, in units of TeV **(3 marks)**
Note: *tera* = 10^{12}

$$E_k = \left(\frac{1}{\sqrt{1-0.99999999^2}} - 1\right)(1.673\times10^{-27})(3.00\times10^{8})^2$$

$$E_k = (7071.1 - 1)(1.673\times10^{-2}\ )(3.00\times10^{8})^2$$

$$E_k = 1.065\times\frac{10^{-6}J}{1.602\times10^{-19}J/eV} = 6.645\ TeV$$

One criticism of the LHC is that it isn't worth spending the money to build it when it only gives a small increase in speed to protons compared the already successful Tetravon accelerator.

b. Use the information above and the concepts learned in this course to **evaluate** if it was worth replacing the Tetravon accelerator with the LHC. **(5 marks)**

Yes it was, it is much much harder to get protons to go just a tiny bit closer to the speed of light because the relativistic effects become insanely increased, such as the mass which makes it harder to accelerate. This small increase comparted to the Tetravon gives a Lorentz factor of 7071 compared to only 1041. This makes for a lot more energy that can be used to explore and create new particles that require such energies, as energy is converted to mass by $m = \frac{E}{c^2}$.

C2 A level question
Student evaluates influence of factors relating to impact on science but does not consider wider social and economic factors

4/5

Question 29

Brian is a particle physicist working for CERN at the Large Hadron Collider (LHC) is Switzerland.

In the detectors at the LHC two beams of protons are collided with each other at high energies, which then produce particle 'showers' as many new particles are created, many of which have more mass than the original two protons.

In 2012, CERN announced that they discovered a new heavy particle, the Higgs boson, that had been predicted to exist in 1964 by several scientists, including Peter Higgs. The discovery of the particle involved analysing millions of collisions in the LHC detectors. The discovery was made separately by two independent experiments, ATLAS and CMS.

c. **Outline** two (2) reasons why millions of collisions were necessary before the scientists at CERN could reliably claim to have discovered the Higgs boson.
(2 marks)

(1) Very very small possibility that particle showers happen in the right sequence to show Higgs boson.
(2) Millions of particles are created each time, so it is hard to track every one of them so you have to wait until a boson event happens and is noticed.

CMA2 C level question
Student explains applications of theories

2/2

d. **Explain** why the discovery of the Higgs boson needed to be made using two independent experiments to be considered a valid scientific discovery. **(2 marks)**

Science requires repeatability as one result could be produced by a systematic error, that is produced at one facility. Doing it at two significantly increases confidence in the validity as for error to be happening twice at two separate facilities is near impossible. So doing it at two confirms there was no systematic error.

C1 C level question
Student explains epistemology and role of peer review in developing knowledge

2/2

Part E – Long Answer Questions (15 marks)

Question 30 **(8 marks)**

CMA2 A level question

Imagine that you are a traffic engineer working in a world where the speed of light has suddenly changed to have a value of 50 ms^{-1} (180 kmh^{-1}). All other physics has remained the same.

Assess the impact that this change will have on road travel, traffic, and road safety.

- You can consider impacts on travel at different speed limits, intersections, fuel needs, collisions and car safety, and any other relevant physics.
- You must make specific use of your knowledge of special relativity and how the impacts will give different predictions than Newton's Laws.
- Your answer must include specific examples to support your impacts.
- Make sure your answer addresses all aspects of the relevant physics.

Question 30 Marking Rubric

Student evaluates predictions and limitations of special relativity and Newton's laws

8/8

A grade (8)	B grade (6-7)	C grade (4-5)	D grade (2-3)	E grade (0-1)
Evaluates predictions and limitations of special relativity and Newton's laws to create insightful solutions, with evidence, to the given problem.	Analyses predictions and limitations of special relativity and Newton's laws to create solutions, with evidence, to the given problem.	Explains predictions and limitations of special relativity and Newton's laws that relate to the given problem.	Describes predictions or limitations of special relativity and Newton's laws that relate to the given problem.	Identifies predictions or limitations of special relativity and Newton's laws that relate to the given problem.

If the speed of light were to change to a value of 50m/s (180km/h), it would have a massive change to on-road travel, traffic, fuel needs and road safety. The Lorentz factor can provide a significant change to properties at 10% of the speed of light, this value would be at only 5m/s or 18km/h in this scenario, meaning that all travel in a car will encounter relativistic effects and will have to account to this.

Lorentz factor @80km/h:

$$\gamma = \frac{1}{\sqrt{1 - \frac{22.2^2}{50^2}}} = 1.116$$

How mass would change in the 1500 kg car:

$$m = \gamma m_0 = (1.116)(1500) = 1674\ kg$$

Increased weight would require more fuel and affect performance.

Evaluates the impact of a mass dilation on fuel use and performance

How 80km would be shorter to travel:

$$l = \frac{l_0}{\gamma} = \frac{80}{1.116} = 71.68\ km$$

This would save almost 9km to travel and therefore save on fuel and time, offsetting the mass's negative impact on fuel efficiency, but not its performance.

Example of impact of time dilation:

Evaluates impact of length contraction

Event 1 hour, 170kms away. Speed of 170km/hour.

Using Newtonian physics, they would need to leave 1 hour early for the event 170kms away.

Using special relativity, length contracts:

$$\gamma = \frac{1}{\sqrt{1 - \frac{170^2}{180^2}}} = 3.04$$

$$l = \frac{l_0}{\gamma} = \frac{170}{3.04} = 55.92\ km$$

Thus the trip will take: (to the people in the car)

$$\frac{55.92}{170} = 0.329\ hours$$

Therefore they suggest they leave in ~40mins (0.671 hours) as the travel time is 20 mins (0.329hours).

When turning up at the event, they find out they were late! They forgot to take into account their motion relative to the event guests.

To people at the event, they would observe time to dilate for the people in the car:

$$t = \gamma t_0 = (3.04)(0.329) = 1\ hour$$

This means it actually took them an hour and therefore they were 40mins late even though the people in the car only experienced 20 mins. Therefore, in this world special relativity would have to be taken into account carefully when going to timed events, as speed with special relativity can significantly affect the time it takes.

Evaluates the impact of time dilation

Collisions would be much more violent. Impact of a 1500 kg car colliding at 40 kph:

Newtonian:

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(1500)\left(\frac{40}{3.6}\right)^2 = 92500\ J$$

$$p = mv = (1500)\left(\frac{40}{3.6}\right) = 16600\ kg\ m/s$$

Special relativity:

$$\gamma = \frac{1}{\sqrt{1 - \frac{40^2}{180^2}}} = 1.03$$

$$KE = (\gamma - 1)m_0c^2 = (1.03 - 1)(1500)(50)^2 = 112500\ J$$

$$p = \gamma mv = (1.03)(1500)\left(\frac{40}{3.6}\right) = 17200\ kg\ m/s$$

This difference in energy and momentum means that car collisions are much more dangerous in this slow speed of light world. In this reality, all speed limits would have to be reduced according to special relativity to increase car safety back to 'normal'.

Evaluates impact of lower speed of light on vehicle safety in collisions

Traffic lights would not work at intersections, as colours would change relative to cars and continue to change as their speed differentiates. As cars go faster, red's wavelength would shorten, possibly even to green which would have disastrous consequences. In this world, onboard displays of traffic lights would have to be installed in cars that are synchronised with intersections by mobile communication. The colour would not shift because they would be in the same reference frame as the car and therefore the driver. Alternatively, dynamic traffic lights would have to be installed that account for special relativity by tracking cars speed and showing colours to the car that would update to their speed.

Evaluates impact on some safety devices, but suggests a solution based on an oversight, missing that mobile communication would also be affected by the slower speed of light.

CMA2 A level question

Evaluates applications of theories using evidence in unfamiliar contexts

Question 31
(7 marks)

Imagine a future where scientists have developed the technology to reliably produce matter and antimatter leptons of all three families, and store them in containers where their decay into smaller particles can be prevented. Once released from their containers, the regular decay rates of each lepton occur.

One scientist, Annabelle, reads about an electron-positron annihilation reaction that produces D^+ and D^- mesons. She proposes that a new spaceship engine can be built using this annihilation reaction to provide thrust.

A different scientist, Belinda, proposes that a better engine design would use Tau leptons as the fuel source, and use their decays into electrons or muons once they are released from their container as the thrust source (decays into electrons and muons each account for about 17% of Tau decays).

Critically analyse the two engine proposals and **evaluate** which will be the most effective engine.

In your answer you need to include the following points, and any other relevant physics:

- **Describe** the particle reaction for each engine, including a reaction diagram of the reaction.
- **Explain** how an engine using each reaction could generate thrust, and where the energy comes from.
- **Evaluate** the effectiveness of the decay as a fuel source.

Question 31 Marking Rubric

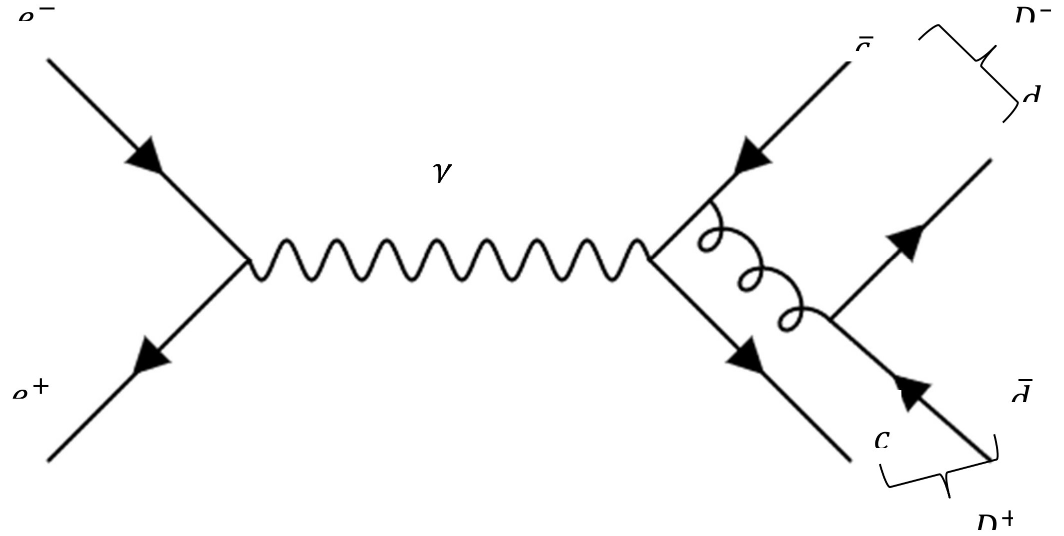
Student correctly explains the reactions and determines some issues relevant to the effectiveness of the proposed engines, but does not correctly evaluate their effectiveness as they do not identify the source of thrust and explore the ability of the proposed reactions to generate it.

5/7

A grade (7)	B grade (6)	C grade (4-5)	D grade (2-3)	E grade (0-1)
Critically analyses applications and predictions of particle physics models to evaluate the effectiveness of the proposed engines.	Analyses applications and predictions of particle physics models to judge the effectiveness of the proposed engines.	Explains applications and predictions of particle physics models when determining the effectiveness of the proposed engines.	Describes applications or predictions of particle physics models that relate to the given problem.	Identifies applications or predictions of particle physics models that relate to the given problem.

Electron/positron annihilation

Describes the reaction in detail and explains mass discrepancy



	e^-	e^+	$\bar{c}$	c	$\bar{d}$	d
Charge	-1	+1	-2/3	+2/3	+1/3	-1/3
Baryon	0	0	-1	+1	-1	+1
$Lepton_e$	+1	-1	0	0	0	0

0 = 0

0 = 0

0 = 0

γ interacted with charged particles, g interacted with quarks only

Mass: (0.511 MeV + 0.511 MeV) – (1.27 GeV + 1.27 GeV + 4.8 MeV + 4.8 MeV) = -2548.78 MeV

Explains application of conservation rules

An electron and positron annihilate into a photon. Photon then decays into a charm and anti-charm quark pair with a lot of energy. The pair starts moving apart, increasing energy by stretching the gluon field. From the gluon interaction, a down anti down quark is created. The anti-charm and down quark pair up to form a D- meson, while the charm and anti-down quark pair up to form a D+ meson.

This interaction follows all the conservation rules and uses the right force-carrying bosons is therefore possible. It however is unlikely to occur, as it requires two particles to collide, making it more unreliable. The particles also require a lot of kinetic energy for this reaction to happen, this compounds the previous issue as it will limit the number of reactions happening and make problems if the required energy is not met.

Explains energy requirements for the reaction but does not evaluate in the context of an engine, its design and efficiency

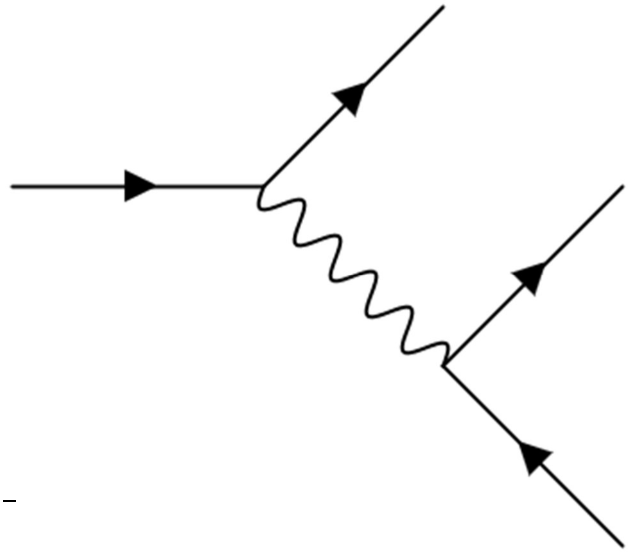
This reaction won't be an effective fuel source and could not generate sufficient thrust – if any. This is because particle reactions require a mass discrepancy to generate energy as according to E=mc^2 they can be converted into each other. This reaction produces a negative mass discrepancy, meaning it turns energy into mass more than the other way around that would be required to produce thrust from the energy.

Explains mass deficit, but does not identify source of thrust and evaluate

The negative mass discrepancy is why the electron/positrons must be given enough kinetic energy. With enough energy, the reaction could produce positive discrepancy and therefore a thrust. But it will have a net loss in energy because the ship or earth would have to provide the extra energy at the start to the electron/positrons. Even with this net loss, the energy produced would be very small and hence not provide sufficient thrust.

Tau Lepton decay

Describes the reaction in detail and explains mass discrepancy



e^-, μ^-

$\bar{\nu}_e, \bar{\nu}_\mu$

	τ^-	ν_τ	μ^-, e^-	$\bar{\nu}_\mu, \bar{\nu}_e$
Charge	-1	0	-1	0
$Lepton_\tau$	+1	+1	0	0
$Lepton_e$	0	0	+1	-1
$Lepton_\mu$	0	0	+1	-1

-1 = -1

+1 = +1

0 = 0

0 = 0

Mass (e event): 1.777 GeV – (15.5 MeV + 0.511 MeV + 2.2 MeV) = 1758.789 MeV

Mass (μ event): 1.777 GeV – (15.5 MeV + 105.7 MeV + 2.2 MeV) = 1655.63 MeV

A tau lepton decays into W- boson and a tau neutrino. The W- boson further decays into an electron and an anti-electron neutrino 17% of the time, or a muon and anti-muon neutrino 17% of the time.

This reaction follows all the conservation rules and uses the right charged weak nuclear force boson so is possible. It is likely to occur, as it only requires one particle for the reaction to occur. Taus are the heaviest leptons and hence are likely for this decay to happen.

In both events, there is a positive mass discrepancy and hence passively creates energy to provide thrust. The electron producing event is the most desirable as it produces the greatest discrepancy and therefore the most thrust. However, it is just as likely the muon event. It is completely up to chance and hence using taus as fuel will produce unpredictable amounts of thrust and take different times each journey. This will be hard to calibrate when landing and taking off from planets as the amount of thrust has to be specifically chosen to land safely, making it unreliable to use in this situation, so possibly another fuel source might have to be used.

Taus being hard energy would be harder to create than the readily available electrons (positrons being light would not be hard to create either). Positrons and electrons could be passively collected from natural nuclear decay and hence now energy would have to go into creating them and be a lot more efficient this way.

The tau decay however wins as the most effective fuel source as its reaction produces energy for thrust without any input energy while the electron annihilation does not.

Explains mass discrepancy, but does not identify the actual source of thrust and hence correctly evaluate this reaction's ability to generate it.

End of exam

SUMMARY OF STUDENT ACHIEVEMENT BY ACHIEVEMENT STANDARD

Achievement Criteria Assessed	Standard	Marks Awarded	Total Available
Concepts Models and Applications 1	B	2	2
Concepts Models and Applications 1	C	20	20
Concepts Models and Applications 1	D	7	7
Concepts Models and Applications 1	E	8	8
Concepts Models and Applications 2	A	13	15
Concepts Models and Applications 2	B	1	1
Concepts Models and Applications 2	C	11	11
Concepts Models and Applications 2	D	1	1
Concepts Models and Applications 2	E	3	3
Concepts Models and Applications 3	B	1	1
Concepts Models and Applications 3	C	7	7
Contexts 1	C	2	2
Contexts 2	A	4	5
Inquiry Skills 2	C	3	3

SUMMARY OF STUDENT ACHIEVEMENT BY QUESTION GRADE LEVEL

Grade	Marks Awarded	Total available
A	17	20
B	4	4
C	43	43
D	8	8
E	11	11

ANNOTATED STUDENT WORK: C GRADE

Part A – Multiple Choice (15 marks)

Instructions:

Each question is worth 1 mark.

Record your answers on the multiple choice answer sheet.

Question 1

What is the energy of a 630 nm photon of electromagnetic radiation?

- **a.** 1.97 eV
- **b.** 3.15 eV
- **c.** 1.97×10^{-19} J
- **d.** 3.15 J

CMA1 C level question
Explains fundamental properties

Correct response

Question 2

Which of the following is a correct statement about how the Bohr model of the atom was an improvement on the Rutherford model?

- **a.** It stated that electrons exist in 3D orbitals with wave patterns that are described their probability density, which explained how wave particle duality was applied to atoms.
- **b.** It stated than atoms have small, dense, positive nucleus, which explained why a small number of alpha particles fired at gold foil could be rebounded.
- **c.** It stated that electrons have quantised orbits with fixed radius and angular momentum, which explained why electrons didn't decay into the nucleus by emitting electromagnetic radiation.
- **d.** It stated that atoms have separate positive charge and negative electrons, which explained the production of cathode ray beams that could deflected by electric and ma

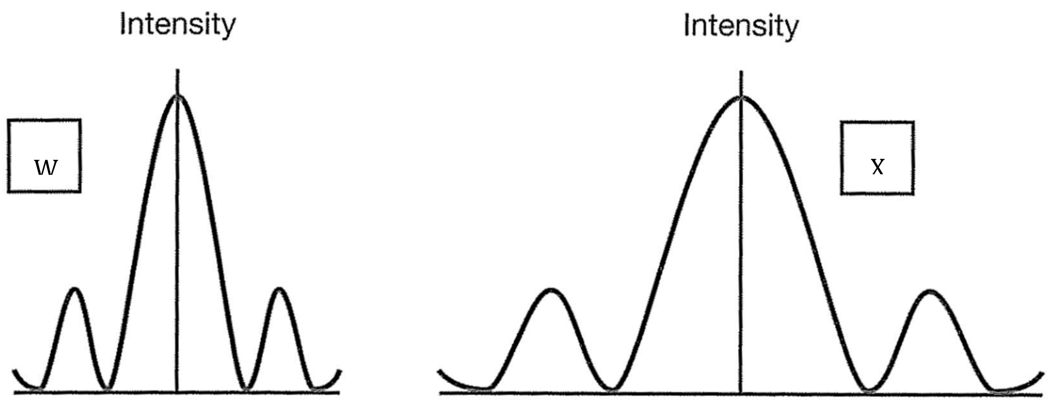
CMA2 C level question

Incorrect response

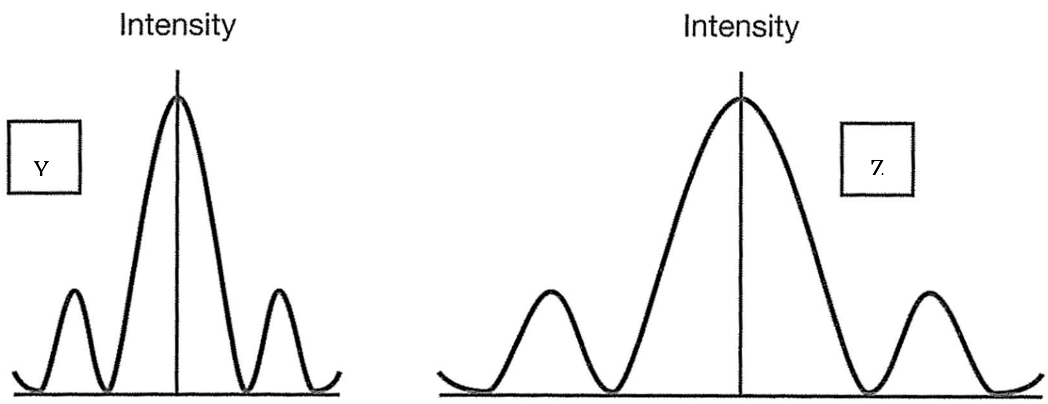
Question 3

The diagrams below show four different interference patterns obtained from double slit experiments as observed on screens equidistant from the slits.

Experiment 1 – Same distance between slits. One pattern formed using blue light, the other using red light.



Experiment 2 – Same colour light used. One slit distance larger than the other.



CMA3 B level question
Incorrect response

Which of the following options below matches the observations from the two experiments?

	Experiment 1	Experiment 2
a.	Graph W – Red light Graph X – Blue light	Graph Y – Small slit distance Graph Z – Large slit distance
b.	Graph W – Blue light Graph X – Red light	Graph Y – Small slit distance Graph Z – Large slit distance
c.	Graph W – Red light Graph X – Blue light	Graph Y – Large slit distance Graph Z – Small slit distance
d.	Graph W – Blue light Graph X – Red light	Graph Y – Large slit distance Graph Z – Small slit distance

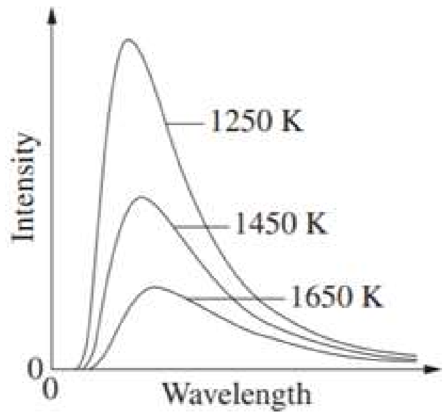
CMA2 D level question

Incorrect response

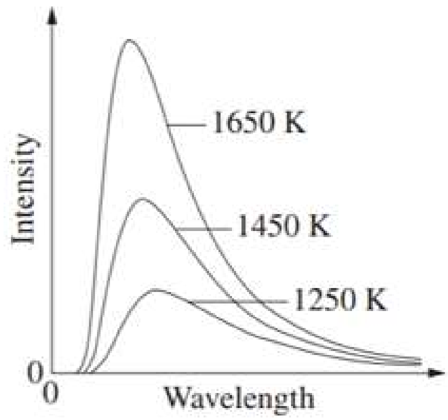
Question 4

Which graph below is consistent with predictions resulting from Planck's hypothesis regarding radiation from hot objects?

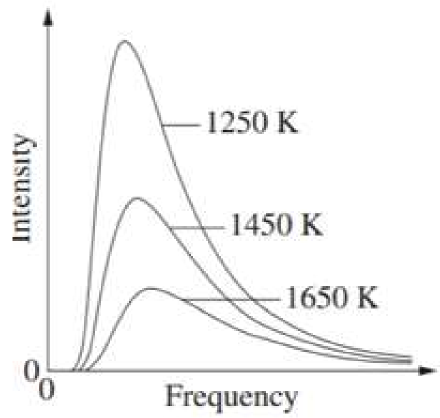
a.



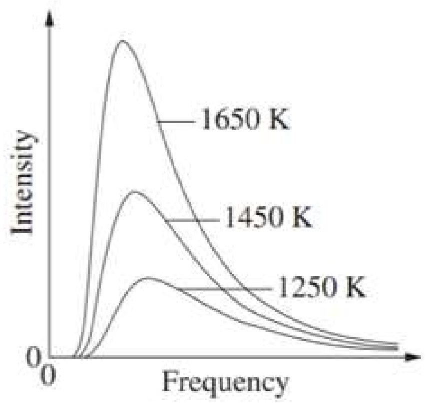
b.



c.



d.



Question 5

Atoms absorb and emit light at specific wavelengths that vary from element to element. What is the reason for this?

a. Every element having a characteristic set of isotopes.
b. Every element having a characteristic ionization energy.
c. Every element emitting electrons with different kinetic energies.
d. Every element having a characteristic set of electron energy levels.

CMA1 D level question
Describes fundamental properties

Correct response

Question 6

Why do the predictions of Special Relativity appear to us to be counterintuitive?

CMA2 D level question
Describes nature of theories

Correct response

a. They only apply to the behaviour of microscopic particles, like electrons.
b. They apply only to inanimate objects like clocks and rods, and not to human beings.
c. They are only noticeable at speeds much higher than we normally experience.
d. Our intuition is based on experiences we have as infants, before we learn any physics.

Question 7

What is the main reason why the Michelson-Morley experiment is considered important?

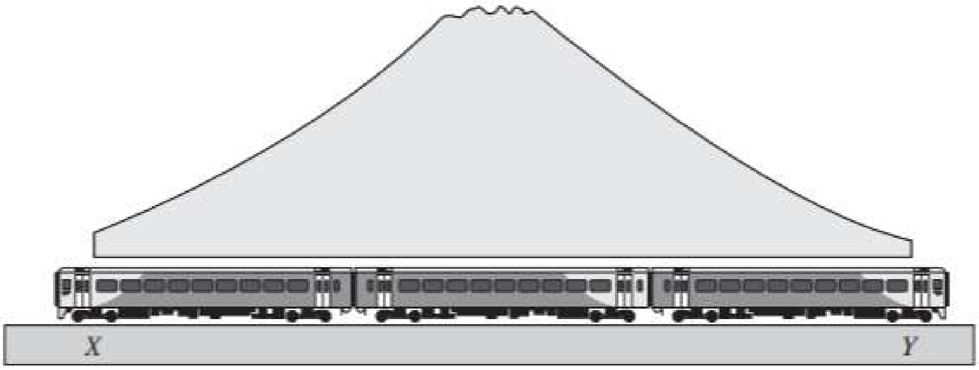
CMA2 E level question
Identifies nature and applications of theories and models

Correct response

a. It shows the existence of the aether.
b. It suggests that light is an electromagnetic wave.
c. It indicates that light can exhibit interference effects.
d. It provides experimental support for the theory of relativity.

Question 8

When a train is at rest in a tunnel, the train is slightly longer than the tunnel, as shown below.



In a thought experiment, the train is travelling from left to right fast enough relative to the tunnel that its length contracts and it fits inside the tunnel.

An observer on the ground sets up two cameras, at X and Y, to take photos at exactly the same time. The photos show that both ends of the train are inside the tunnel.

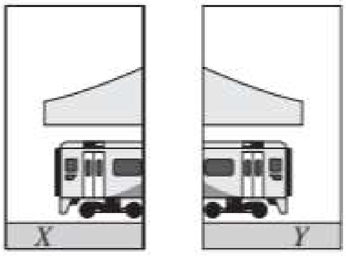


Photo 1 Photo 2

A passenger travelling on the train at its centre can see both ends of the tunnel and is later shown the photos.

From the point of view of the passenger, what is observed about the tunnel, and what can be deduced about the photos?

- **a.** The tunnel's length contracts so the train does not fit, and photo 2 is taken before photo 1.
- **b.** The tunnel's length contracts so the train does not fit, and photos 1 and 2 are taken at the same time.
- **c.** The tunnel appears to expand due to the length contraction of the train, allowing it to fit in the tunnel, and photo 1 is taken before photo 2.
- **d.** The tunnel appears to expand due to the length contraction of the train, allowing it to fit in the tunnel, and photos 1 and 2 are taken at the same time.

CMA2 B level question
Analyses the nature and application of theories

Incorrect response

Question 9

A sealed container of gas is heated from a low temperature to a very high temperature. The particles of the gas have greatly increased their speed. Students are debating whether special relativity predicts that the mass of the gas will increase, remain constant or decrease.

Which one of the following statements is correct?

CMA2 C level question
Explains the nature function and applications of theories

Correct response

a. The mass will increase.
b. The mass will decrease.
c. The mass will remain constant.
d. Special relativity does not apply to gas particles.

Question 10

A proton (mass 1.673×10^{-27} kg) ejected by a supernova attains a velocity of 0.9996c. What is the magnitude of the momentum of the proton?

a. $1.41 \times 10^{-20}\ kgms^{-1}$
b. $5.02 \times 10^{-19}\ kgms^{-1}$
c. $1.77 \times 10^{-17}\ kgms^{-1}$
d. $2.51 \times 10^{-17}\ kgms^{-1}$

CMA1 C level question
Explains properties of components and interactions
Incorrect response

Question 11

What particles combine to form a meson?

a. Three quarks
b. Three anti-quarks
c. A quark anti-quark pair
d. An electron positron pair

CMA1 E level question
Identifies properties of components

Incorrect response

Question 12

Which of the following particles is not a boson?

- **a.** Photon
- **b.** Muon
- **c.** Gluon
- **d.** Higgs particle

CMA1 E level question
Identifies properties of components
Correct response

Question 13

What the force carrying particle for the strong nuclear force?

- **a.** Gluon
- **b.** Photon
- **c.** Z boson
- **d.** Higg's boson

CMA1 E level question
Identifies properties of components
Correct response

Question 14

Which of the following interactions is not allowed?

- **a.** $p \rightarrow n + e^{+} + \nu_e$
- **b.** $n \rightarrow p + e^{-} + \overline{\nu}_e$
- **c.** $p + \overline{p} \rightarrow \mu^{+} + \mu^{-}$
- **d.** $\mu^{-} \rightarrow \tau^{-} + \overline{\nu}_\tau + \nu_\mu$

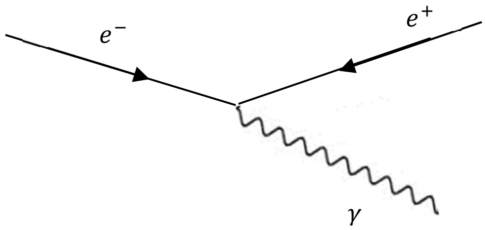
CMA2 C level question
Explains applications of theories and models

Incorrect response

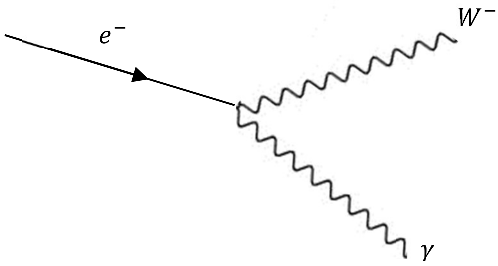
Question 15

Which of the following Feynman diagrams represents an allowed interaction?

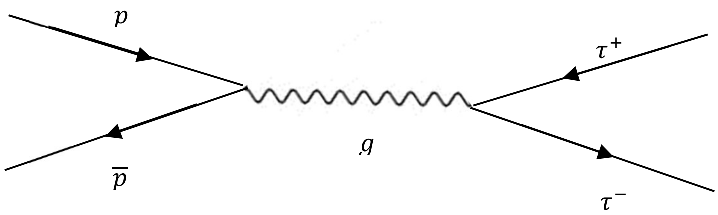
a.



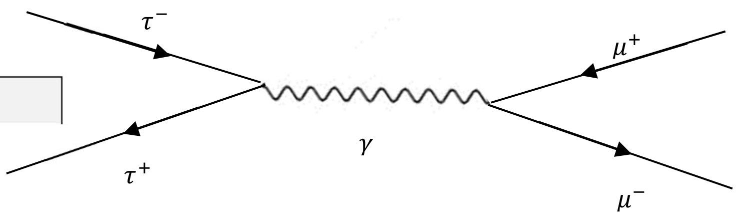
b.



c.



d.



CMA2 C level question
Analyses applications and predictions of theories and models

Correct response

Part B – Short Answer Questions (19 marks)

CMA1 D level question
Partially describes processes and interactions but does not describe the nature of the interference pattern

1/2

Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 16

In this course you have conducted a twin slit experiment with light.

a. **Describe** what occurs when light is passed through twin slits. **(2 marks)**

The light exhibits wave properties and forms a constructive-destructive wave interference pattern

b. **Contrast** what the twin slit and photoelectric effect experiments reveal about the nature of light. **(3 marks)**

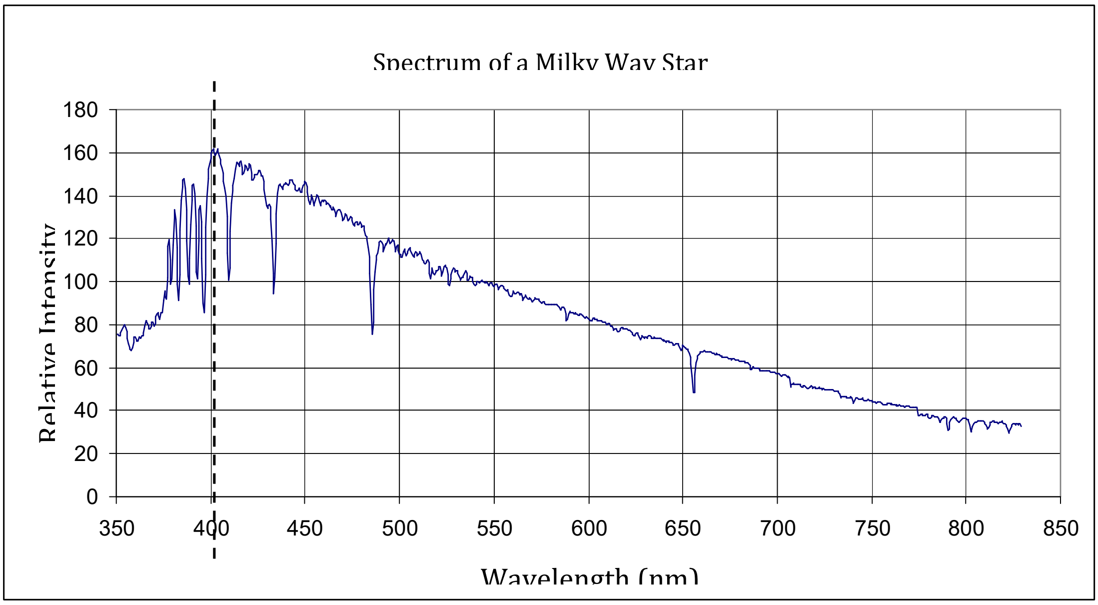
- The twin slit demonstrates the wave nature of light
- The photoelectric effect reveals the particle nature of light
- Together represent the particle-wave nature of light

CMA1 C level question
Describes but does not explain processes and interactions

1/3

Question 17

The spectrum of a star in the Milky Way is shown below. The wavelength of maximum intensity is marked with a dashed line.



Determine the temperature of the surface of the star. **(1 mark)**

$$T = \frac{b}{\lambda} = \frac{2.898 \times 10^{-3}}{4.00 \times 10^{-7}} = 7245\ K$$

CMA1 C level question
Explains fundamental properties

1/1

Question 18

The Bohr model of hydrogen was the first model of the atom that used the new quantum hypothesis, and is still used today in many fields. The predictions of the Bohr model are supported by de Broglie's matter wave proposal.

Explain how de Broglie's matter wave proposal supported the Bohr model of the atom. **(3 marks)**

The de Broglie wavelength of an electron is significant compared to its size. Therefore electrons are expected to exhibit both particle and wave like behaviours. The energy levels of electrons correspond with wavelengths.

CMA2 C level question
Student identifies some key ideas, but does not explain them correctly

1/3

Question 19

a. **Define** an inertial reference frame. **(1 mark)**

A reference frame not undergoing acceleration or no $\sum F$

CMA1 D level question
Describes fundamental properties
1/1

b. **Identify** an example of a non-inertial reference frame. **(1 mark)**

An accelerating car

CMA1 E level question
Identifies components, processes and interactions
1/1

Question 20

State the two (2) postulates of Einstein's special relativity. **(2 marks)**

- The laws of physics are the same in all inertial reference frames
- The speed of light is constant in all reference frames

CMA2 E level question
Identifies the nature and functions of theories and models
2/2

Question 21

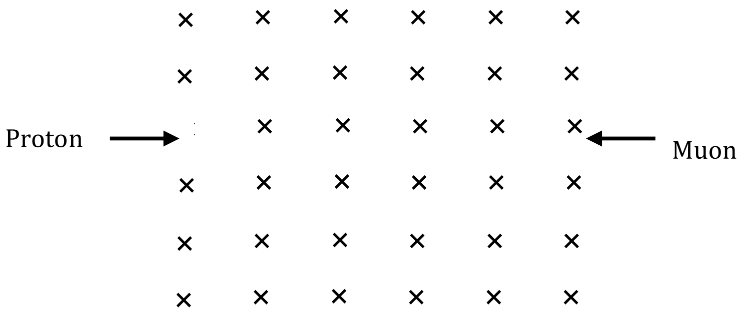
Complete the table below which lists the fundamental matter particles of the standard model. **(3 marks)**

Quarks		Leptons	
$+2/3$	**$-1/3$**	**-1**	**0**
Up	Down	electron	Electron neutrino
Strange	Charm	Muon	Muon neutrino
Top	Bottom	Tau	Tau neutrino

Gauge Boson
photon
gluon
W^+, W^-
Z

CMA1 E level question
Student identifies most fundamental properties of components correctly
2/3

A proton and a muon are fired into a uniform magnetic field with the same speed from opposite sides as shown below. Their trajectories are initially perpendicular to the magnetic field.



Explain one (1) similarity and one (1) difference in the trajectories of the proton and muon as the move in the magnetic field. **(3 marks)**

- Both particles will move in the same direction as they have opposite charges and are approaching from opposite sides in circular motion
- The proton will have a much larger radius for its circular motion, as it is much heavier than a muon, which is weightless and has momentum

CMA1 C level question
Explains processes and interactions

3/3

Part C –Data Analysis Questions (13 marks)

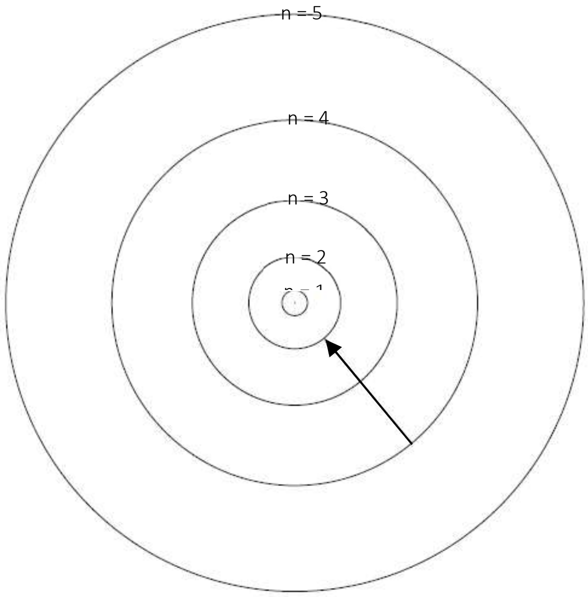
Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 22

The diagram below shows the first five circular Bohr orbits or 'stationary states' for the electron orbiting the nucleus of the hydrogen atom.



a. For the electron transition shown on the diagram, **calculate** the wavelength of the emitted photon. **(3 marks)**

CMA1 C level question
Explains processes, interactions, and effects, but with a reading error which means an incorrect conclusion is drawn

2/3

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\frac{1}{\lambda} = (1.097 \times 10^7)\left(\frac{1}{1^2} - \frac{1}{4^2}\right)$$

$$\frac{1}{\lambda} = (1.097 \times 10^7\left(\frac{15}{16}\right) = 1.028 \times 10^7$$

$$\lambda = \frac{1}{1.028 \times 10^7} = 9.723 \times 10^{-8}\ m = 97.23\ nm$$

b. **Identify** the part of the electromagnetic spectrum in which the emitted photon be found. **(1 mark)**

Gamma spectrum

CMA1 E level question
Incorrectly identifies fundamental properties

0/1

Question 23

One of the primary functions of the OPAL nuclear reactor at ANSTO is to produce neutrons that can be used to probe the structures of different materials.

a. **Calculate** the de Broglie wavelength of a neutron travelling at 5.6 ms^{-1}. **(2 marks)**

CMA1 C level question
Explains fundamental properties

2/2

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{5.6 \times 1.675 \times 10^{-27}} = 7.06 \times 10^{-8} m$$

$$\lambda = 71\ nm$$

b. **Suggest** how the speed of the neutrons should be changed to make them more effective at probing the structure of ionic solids with atomic spacings of approximately 10^{-10} m. **(2 marks)**

Increase the neutrons to relativistic speeds

CMA1 B level question
Reaches a correct conclusion that the speed needs to increase but does not provide evidence of analysis

1/2

Question 24

The table below lists the first generation of quarks and antiquarks.

Quarks		
Name	*Symbol*	*Charge*
Up	u	$+\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$

Antiquarks		
Name	*Symbol*	*Charge*
Antiup	u	$-\frac{2}{3}e$
Antidown	d	$+\frac{1}{3}e$

The Standard Model of matter states that baryons, like protons and neutrons, are comprised of three quarks, while mesons, like the pions π^+ and π^-, are comprised of one quark and one antiquark.

a. Using the table above, **state** the quark composition of the following particles.

(i) Neutron **(1 mark)**

u + d + d

CMA1 D level question
Describes one system component correctly and one incorrectly

1/2

(ii) Negative pion **(1 mark)**

ddd

b. **State** the change that must take place among the quarks in one of the nucleons in the nucleus to allow beta decay to occur. **(1 mark)**

Depending on B^+ or B^-, $udd \leftrightarrow uud$ $(n \leftrightarrow p)$

d changes to u or vice versa

CMA1 C level question
Explains processes and interactions

1/1

Question 25

The equation below represents a muon decay.

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu_e}$$

a. Apply a symmetry to **transform** the above equation into a new interaction that will be allowed. **(1 mark)**

$$\mu^- + \bar{\nu}_\mu \rightarrow e^- + \bar{\nu}_e$$

CMA2 C level question
Explains application of theories

1/1

b. **State** the symmetry that you used to construct your interaction. **(1 mark)**

Substitution

CMA2 C level question
Fails to explain application of theories 0/1

Part D – Practical Skills Questions (24 marks)

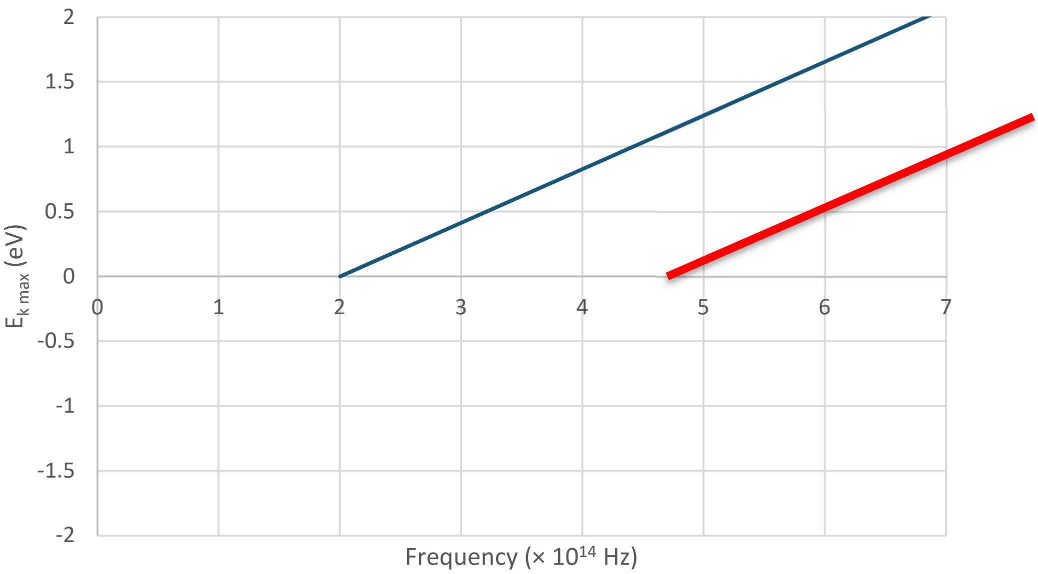
Instructions:

Answer all questions in the space provided.

Marks are allocated for each question as indicated.

Question 26

The graph below shows the maximum kinetic energy of the photoelectrons ejected from a particular metal surface during a photoelectric effect experiment against the frequency of the incident light.



a. Use the information in the graph and Planck's constant ($4.14 \times 10^{-15}\ eVs$) to **calculate** the work function for the metal shown, in units of electron volts.

(2 marks)

$$E_k = hf - W$$
$$W = hf - E_k$$
$$W = (4.136 \times 10^{-1}\ )(2 \times 10^{14}) - 0 = 2.068$$

CMA3 C level question
Reasoning to develop conclusions is sound, but incorrect conclusion is drawn
1/2

b. **Draw** another line ***on the graph above*** for a different metal that has a work function twice that of the metal shown.

(See line on graph)

CMA3 C level question
Develops evidence-based conclusions
2/2

(2 marks)

c. The experiment was repeated using light of a greater intensity.

(i) Describe the effect on the graph that this would have. **(1 marks)**

CMA3 C level question
Student draws an incorrect conclusion with partially correct explanation

1/3

More high energy photoelectrons

(ii) Explain how Einstein's proposal about the nature of light accounts for your answer. **(2 marks)**

The photon or light particle has to have enough energy to overcome the wf of the material. In wave theory, any λ would cause photoemission

Question 27

The Large Hadron collider accelerates protons to very high speeds, reaching speeds of 0.999999991*c*, before two proton streams collide. As the protons increase in speed, the mass of the protons as measured in the laboratory frame increases according to the rules of special relativity.

Particle physicists commonly measure masses in units of MeV/c^2.

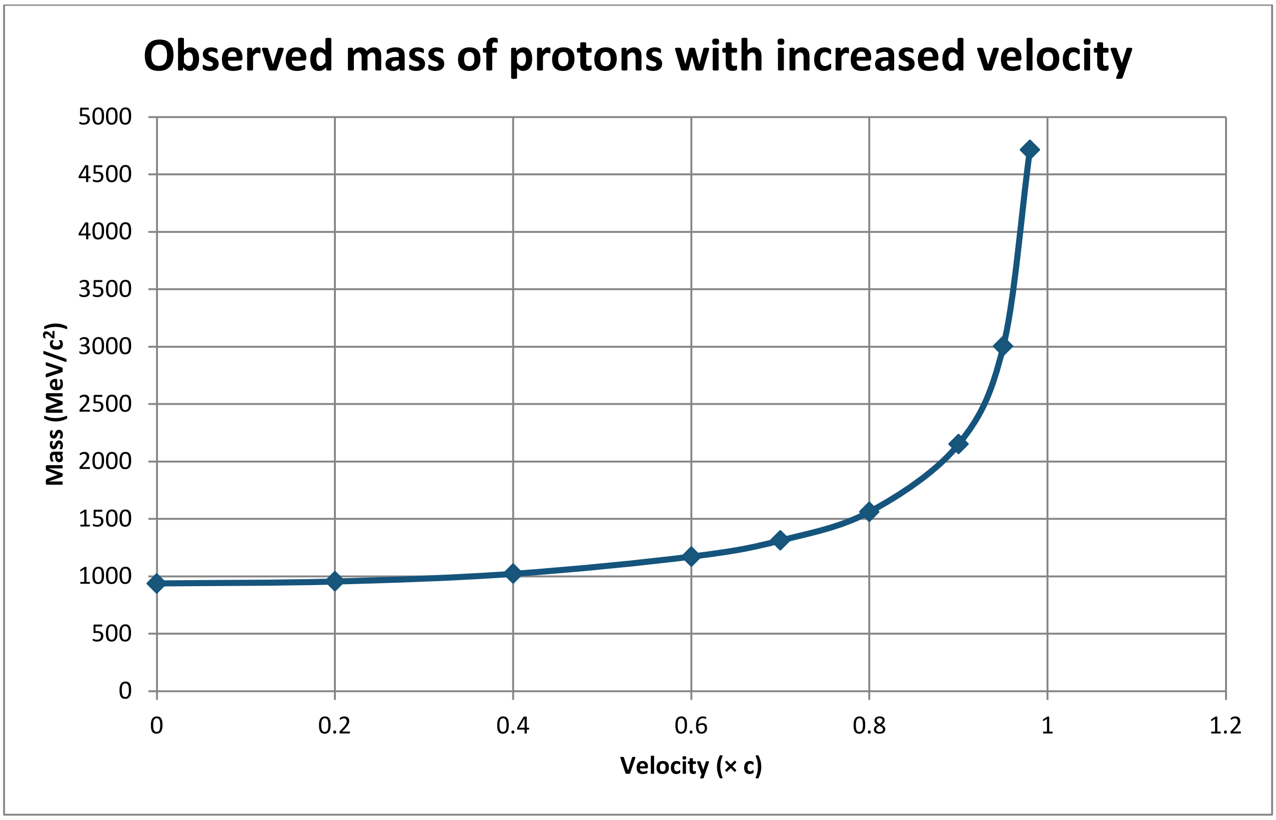
a. A table of the observed mass of a proton at different velocities is shown below. **Complete** the table by filling in the two (2) missing values. **(2 marks)**

Velocity ($\times c$)	Observed proton mass (MeV/c^2)
0.00	938
0.20	957
0.40	1023
0.60	1172
0.70	1313
0.80	1563
0.90	2152
0.95	3004
0.98	4714

CMA1 C level question
Explains processes and the effects of factors

2/2

The graph below shows the observed mass of the protons as a function of velocity.



b. **Explain** how the graph shows that there is maximum speed limit for all particles with mass.

(3

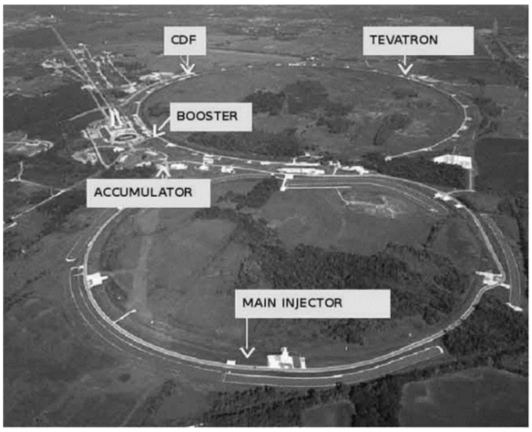
IS2 C level question
Explains relationships

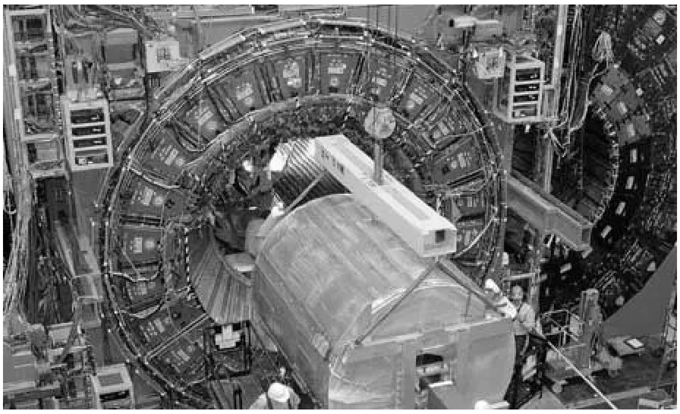
3/3

- The graph never reaches 1
- 1 is the asymptote of the exponential function
- The increase in m per increase in v increases as more energy becomes mass rather than v using $E = mc^2$

Question 28

The Tetravon was a particle accelerator built at Fermilab in the USA that accelerated and collided protons and antiprotons to speeds of 99.999954% the speed of light. During its life time particle physicists used the Tetravon to experimentally discover the top quark in 1995 and the tau neutrino in 2000.





The Tetravon accelerator tunnel at Fermilab and CDF detector

The Tetravon was shut down in 2011 after the Large Hadron Collider (LHC) was built at CERN in Switzerland. The LHC cost $4.75 billion to make, and accelerates protons to a speed of 99.999999% the speed of light.

a. **Calculate** the kinetic energy of protons in LHC, in units of TeV **(3 marks)**

Note: *tera* = 10^{12}

CMA1 C level question
Explains processes and effects of factors with errors
1/3

$$E_k = (\gamma - 1)m_0c^2$$

$$\gamma = \sqrt{1 - \frac{0.99999999^2}{1^2}} = 1.414214 \times 10^{-4}$$

$$E_k = (1.414214 \times 10^{-4})(1.673 \times 10^{-27})(3.00 \times 10^8)^2 = 2.12931 \times 10^{-6} eV$$

$$E_k = 2.129231 \times 10^{-18} TeV$$

One criticism of the LHC is that it isn't worth spending the money to build it when it only gives a small increase in speed to protons compared the already successful Tetravon accelerator.

b. Use the information above and the concepts learned in this course to **evaluate** if it was worth replacing the Tetravon accelerator with the LHC. **(5 marks)**

C2 A level question
Explains the impact of the small increase in speed to energy but does not explore the impact or evaluates the influence of social and economic factors
3/5

- Due to the exponential nature of relativistic speed, more and more energy is required for a % increase in speed
- Even with a small change (between Tetravon and LHC) the γ is different by nearly a factor of 10 which justifies the cost, for the purpose of scientific endeavour
- This is seen in recent discoveries with the LHC, notably the Higgs-Boson

Question 29

Brian is a particle physicist working for CERN at the Large Hadron Collider (LHC) is Switzerland.

In the detectors at the LHC two beams of protons are collided with each other at high energies, which then produce particle 'showers' as many new particles are created, many of which have more mass than the original two protons.

In 2012, CERN announced that they discovered a new heavy particle, the Higgs boson, that had been predicted to exist in 1964 by several scientists, including Peter Higgs. The discovery of the particle involved analysing millions of collisions in the LHC detectors. The discovery was made separately by two independent experiments, ATLAS and CMS.

e. **Outline** two (2) reasons why millions of collisions were necessary before the scientists at CERN could reliably claim to have discovered the Higgs boson. **(2 marks)**

- To ensure the results were accurately replicable and therefore reliable
- The millions of collisions increased the frequency of observing Higgs-bosons and ensured a good number of experimental repeats

CMA2 C level question
Explains some applications of theories
1/2

f. **Explain** why the discovery of the Higgs boson needed to be made using two independent experiments to be considered a valid scientific discovery. **(2 marks)**

To ensure that the discovery was not due to some flaw in the particle accelerator or detectors of one facility. This ensures reliable results.

C1 C level question
Describes epistemology and role of peer review in developing knowledge but does not explore validity
1/2

Part E – Long Answer Questions (15 marks)

Question 30 **(8 marks)**

Imagine that you are a traffic engineer working in a world where the speed of light has suddenly changed to have a value of 50 ms^{-1} (180 kmh^{-1}). All other physics has remained the same.

Assess the impact that this change will have on road travel, traffic, and road safety.

- You can consider impacts on travel at different speed limits, intersections, fuel needs, collisions and car safety, and any other relevant physics.
- You must make specific use of your knowledge of special relativity and how the impacts will give different predictions than Newton's Laws.
- Your answer must include specific examples to support your impacts.
- Make sure your answer addresses all aspects of the relevant physics.

Student explains predictions of special relativity and limitations of Newton's laws
5/8

Question 31 Marking Rubric

A grade (8)	B grade (6-7)	C grade (4-5)	D grade (2-3)	E grade (0-1)
Evaluates predictions and limitations of special relativity and Newton's laws to create insightful	Analyses predictions and limitations of special relativity and Newton's laws to create solutions, with	Explains predictions and limitations of special relativity and Newton's laws	Describes predictions or limitations of special relativity	Identifies predictions or limitations of special

solutions, with evidence, to the given problem.	evidence, to the given problem.	that relate to the given problem.	and Newton's laws that relate to the given problem.	relativity and Newton's laws that relate to the given problem.

Speed limits

All travel is now limited to less than 50m/s

Relativistic speeds are less than 0.1c, which is 5ms-1 or 18km/h. This means that walking pace is unaffected, but vehicular travel is much slower, due to it becoming exponentially harder to reach the speed of light.

Fuel requirements

Explains predictions of special relativity on fuel requirements

Fuel requirements would increase, due to higher engine load, as accelerating becomes harder the faster the vehicle is traveling

Vehicle collisions

Explains impact of special relativity on momentum and stopping distances.

The relativistic speed will add some energy to the collision due to relativistic momentum, which could result in worse collisions at high speeds, this relativistic momentum also increases stopping distance, increasing the number and impact velocity of collisions due to vehicles taking longer to reduce speed.

Intersections

Explains the impact of special relativity on the safety of intersections by identifying simultaneity as a key issue

Intersections would need to be redesigned due to issues surrounding simultaneity. For example, at relativistic speeds, if a driver were to observe a vehicle 100 metres away, traveling at 20m/s, the vehicle will be much closer to the observer than they perceive, as the time taken for information to travel, at 50m/s will be very significant. This could cause drivers to be unable to react to oncoming traffic in time to prevent a collision. This information delay would also apply to other important items, such as traffic lights and signs, as well as pedestrian activity, which could result in an increase in pedestrian-vehicle accidents.

Vehicle safety

A 50m/s speed of light also has potential ramifications for vehicle safety, airbags would deploy much slower, perhaps, not fast enough to prevent injury in the event of a crash, this could result in the need for passengers to utilise safety harnesses. On the other hand, reduced collision speeds would result in less forceful crashes, perhaps reducing passenger fatalities.

Identifies potential implications of lower speed of light for vehicle safety

Question 31 (
7 marks)

Imagine a future where scientists have developed the technology to reliably produce matter and antimatter leptons of all three families, and store them in containers where their decay into smaller particles can be prevented. Once released from their containers, the regular decay rates of each lepton occur.

One scientist, Annabelle, reads about an electron-positron annihilation reaction that produces D^+ and D^- mesons. She proposes that a new spaceship engine can be built using this annihilation reaction to provide thrust.

A different scientist, Belinda, proposes that a better engine design would use Tau leptons as the fuel source, and use their decays into electrons or muons once they are released from their container as the thrust source (decays into electrons and muons each account for about 17% of Tau decays).

Critically analyse the two engine proposals and **evaluate** which will be the most effective engine.

In your answer you need to include the following points, and any other relevant physics:

- **Describe** the particle reaction for each engine, including a reaction diagram of the reaction.
- **Explain** how an engine using each reaction could generate thrust, and where the energy comes from.
- **Evaluate** the effectiveness of the decay as a fuel source.

Student correctly describes the reactions and determines some issues relevant to the proposed engine. Student response lacks critical details to be able to support an evaluation of the effectiveness of the proposed engines.

Question 32 Marking Rubric

A grade (7)	B grade (6)	C grade (4-5)	D grade (2-3)	E grade (0-1)
Critically analyses applications and predictions of particle physics models to evaluate the effectiveness of the proposed engines.	Analyses applications and predictions of particle physics models to judge the effectiveness of the proposed engines.	Explains applications and predictions of particle physics models when determining the effectiveness of the proposed engines.	Describes applications or predictions of particle physics models that relate to the given problem.	Identifies applications or predictions of particle physics models that relate to the given problem.

Engine one - electron annihilation reaction

An electron and a positron with sufficient energy collide in a weak force interaction, via Z bosons or photons, a charm and an anti-charm are produced, which then decay into +/- D mesons, made up of a down quark and a charm quark.

Describes the reaction

Kinetic energy is converted into mass, then the mass decays into heavier mesons. Thrust comes from the process of kinetic energy being converted into mass, which is not 100% efficient

Describes the reaction

Engine two

Tau particles, which are unstable due to their high energy, decay. 17% decay into muon leptons, and 17% into electrons. This releases energy through mass-energy equivalence, as the Tau is ~3500 times more massive than an electron, and ~17 times more massive than a muon.

Engine two is likely better than engine one, due to the combined 34% chance of decay to electrons or muons as well as the single stage nature of the reaction. The largest factor is that the tau leptons do not need to be accelerated to induce the reaction, whereas the electron-positron annihilation requires a threshold kinetic energy to induce the reaction, and is therefore a worse fuel than tau leptons.

Attempts to evaluate the effectiveness of proposed engines, but with insufficient detail to support their argument.

End of exam

SUMMARY OF STUDENT ACHIEVEMENT BY ACHIEVEMENT STANDARD

Achievement Criteria Assessed	Standard	Marks Awarded	Total Available
Concepts Models and Applications 1	B	1	2
Concepts Models and Applications 1	C	14	20
Concepts Models and Applications 1	D	5	7
Concepts Models and Applications 1	E	6	8
Concepts Models and Applications 2	A	8	15
Concepts Models and Applications 2	B	0	1
Concepts Models and Applications 2	C	5	11
Concepts Models and Applications 2	D	0	1
Concepts Models and Applications 2	E	3	3
Concepts Models and Applications 3	B	0	1
Concepts Models and Applications 3	C	4	7
Contexts 1	C	1	2
Contexts 2	A	3	5
Inquiry Skills 2	C	3	3

SUMMARY OF STUDENT ACHIEVEMENT BY QUESTION GRADE LEVEL

Grade	Marks Awarded	Total available
A	11	20
B	1	4
C	27	43
D	5	8
E	9	11