New South Wales Educational Edumacation Standards Authority

2019 **Higher School Certificate Examination**

Physics

General Instructions

- Reading time – 5 minutes
- Writing time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- NESA approved calculators may be used
- A data sheet, formulae sheet and Periodic Table are provided at the back of this paper
- For questions in Section II, show all relevant working in questions involving calculations

Total Marks: 100

Section I – 20 marks (pages 2 - 12)

- Attempt Questions 1–20
- Allow about 35 minutes for this section

Section II – 80 marks (pages 14 - 28)

- Attempt Questions 21–35
- Allow about 2 hours and 25 minutes for this section

Section I

20 marks

Attempt Questions 1–20

Allow about 35 minutes for this section

Use the multiple-choice answer sheet for Questions 1–20.

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1 What evidence led Hubble to discover the expansion of the Universe?

A. The presence of a "cosmological constant" in Einstein's general theory of relativity.
B. Observations that light from distant galaxies is red shifted.
C. Observations that light from distant galaxies is blue shifted.
D. Observations that matter is not uniformly distributed throughout the universe.

2 An $820\ Kg$ satellite makes a complete circular orbit of Earth once every $3.00\ days$ at a distance of $823\ Km$ above Earth's surface.

What is the satellite's angular velocity?

A. $1.21 \times 10^{-6}\ rad/s$
B. $3.86 \times 10^{-6}\ rad/s$
C. $2.42 \times 10^{-5}\ rad/s$
D. $1.99 \times 10^{2}\ rad/s$

3 A UFO is observed travelling towards Area 51 at a velocity of $90\ 000\ Km/s$. After landing, its mass is measured as $1050\ Kg$.

What was the UFO's momentum whilst it was travelling?

A. $9.45 \times 10^{7}\ Kg.m/s$
B. $9.91 \times 10^{7}\ Kg.m/s$
C. $9.45 \times 10^{10}\ Kg.m/s$
D. $9.91 \times 10^{10}\ Kg.m/s$

4 A cricket ball was hit at $50.0m/s$ from negligible height, at an angle θ to the horizontal, where $\theta > 45°$. If it first bounced 85.0m from the batsman $10.1\ s$ after it was hit, what was the angle of projection?

A. 9.73°
B. 70.5°
C. 80.3°
D. 86.66°

5 Which of the following lists ONLY contains fundamental particles according to the Standard Model of matter?

A. Tau-neutrino, Strange Quark, Gluon, Electron
B. Electron, Proton, Top Quark, Muon
C. Muon, Gluon, Neutron, Higgs Boson
D. Atom, Photon, Higgs Boson, Muon

6 In a transformer, the primary coil has 350 turns, and the secondary coil has 420 turns. If the power in the primary circuit is $100\ W$, what is the power in the secondary circuit?

A. $83.3\ W$
B. $100\ W$
C. $120\ W$
D. $420\ W$

7 Two $60cm$ current-carrying wires are placed parallel, $10cm$ apart from each other. A current of $10A$ is passed through the first wire, and a current of $5.0A$ is passed through the second in the opposite direction.

What is the force between these wires?

A. $1.9 \times 10^{-7}\ N$ attracting
B. $1.9 \times 10^{-7}\ N$ repelling
C. $6.0 \times 10^{-7}\ N$ attracting
D. $6.0 \times 10^{-7}\ N$ repelling

8 An astronomer discovers a dwarf planet orbiting the sun with an average distance to the Sun 13 times that of Earth. Determine its orbital period.

A. $2.35\ years$
B. $3.61\ years$
C. $13\ years$
D. $169\ years$

9 ${}^{0}_{+1}e + {}^{0}_{-1}e \rightarrow \gamma + \gamma$

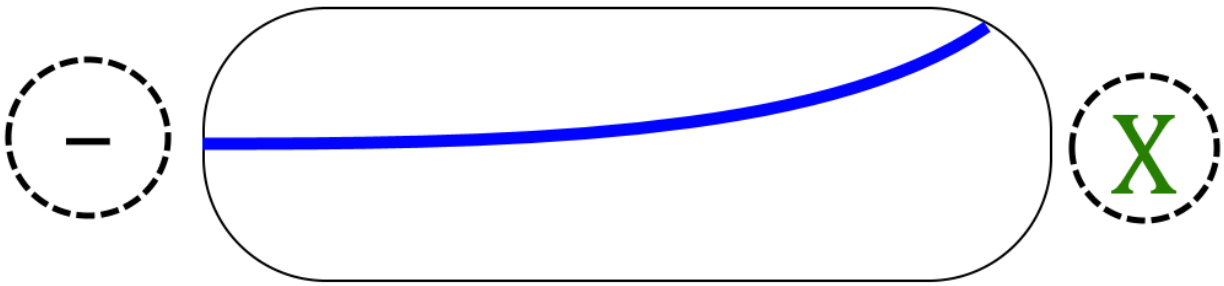
Considering the order of particles listed, what is described in the above equation?

A. The production of two gamma rays from two electrons in a nuclear reaction.
B. The annihilation of matter and antimatter forming gamma radiation.
C. The annihilation of antimatter and matter forming gamma radiation.
D. The production of energy from a proton-proton chain nuclear reaction in a star.

10 What is the escape velocity of an $800\ Kg$ object launched from Earth's surface?

A. $9.15 \times 10^{-8}\ m/s$
B. $1.29 \times 10^{-7}\ m/s$
C. $7.93 \times 10^{4}\ m/s$
D. $1.12 \times 10^{5}\ m/s$

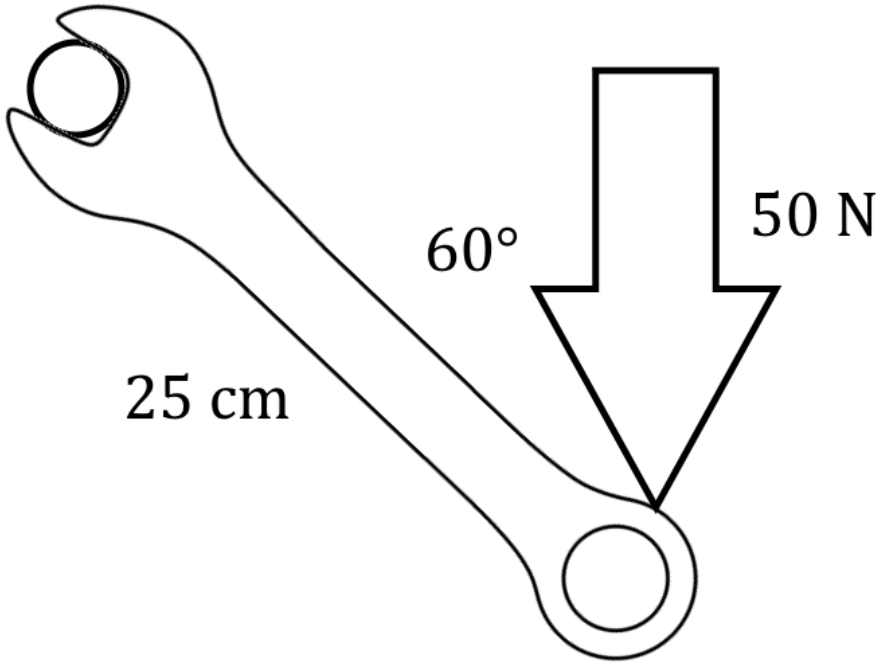
11



In the above diagram, a cathode-ray tube in a uniform magnetic field is depicted.
What is the direction of the magnetic field and what is the name of the component labelled X?

A. Into the page; Anode
B. Into the page; Cathode
C. Out of the page; Anode
D. Out of the page; Cathode

12



What is the torque being applied in this diagram?

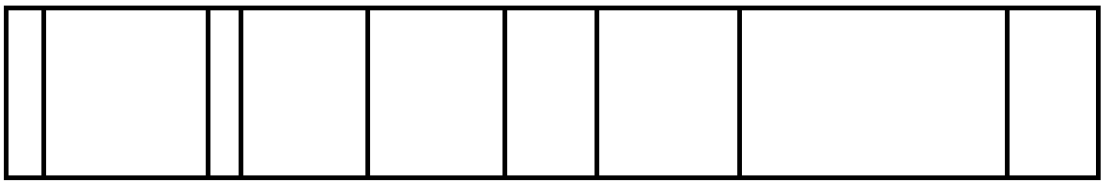
A. $10.8\ N.m$
B. $6.25\ N.m$
C. $21.7\ N.m$
D. $9.24\ N.m$

13 In order to identify compounds with a certain element in them, a scientist measured the emission spectra of the element as well as those of four samples. The emission spectrum of the element is shown in the diagram below.

Which of the following samples contains the element?

A.

B.



C.

D.

14 A group of students carried out an investigation to prove that the number of turns in a solenoid is directly proportional to the strength of the magnetic field generated by it.
Which experimental setup would gather the most reliable results?

A.

Current (A)	Number of turns
10	100
20	110
30	120
40	130
50	140

B.

Current (A)	Number of turns
10	50
10	100
10	150
10	200
10	250

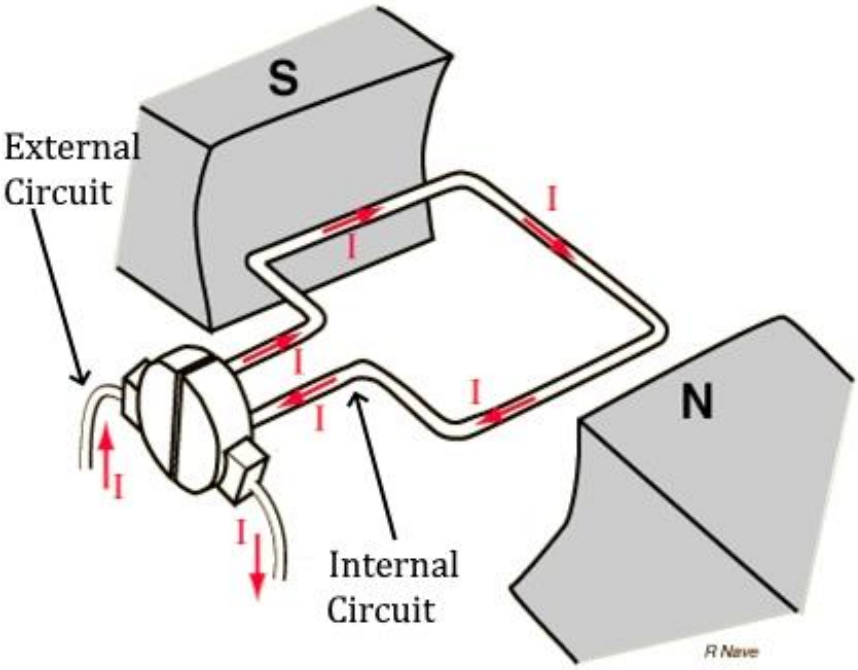
C.

Current (A)	Number of turns
10	100
20	100
30	100
40	100
50	100

D.

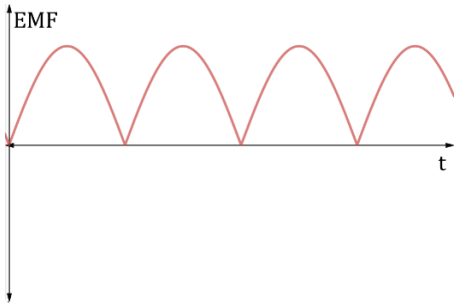
Current (A)	Number of turns
10	100
10	110
10	120
10	130
10	140

15

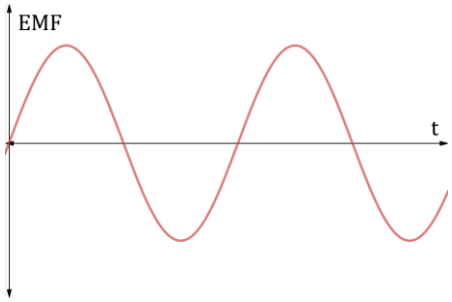


A DC generator is connected to an external circuit, as shown in the above diagram.

Graph 1: Internal EMF



Graph 2: External EMF



Which of the following is true?

A. Both graphs are correct.
B. Graph 1 is correct, and Graph 2 is incorrect.
C. Graph 1 is incorrect, and Graph 2 is correct.
D. Both graphs are incorrect.

16 If k is some constant, which of the following relations is NOT correct?

A. $F_C = k\,m$
B. $F_C = k\,v$
C. $F_C = k\frac{1}{r}$
D. $F_C = k\,a_c$

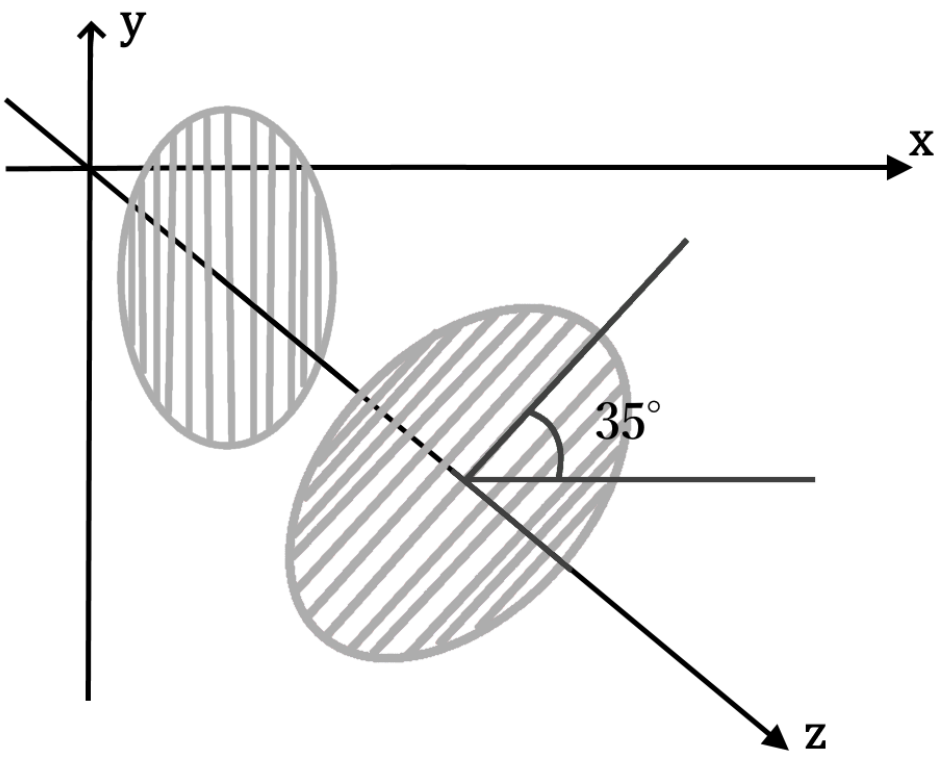
17 What was the main reason for the rejection of Newton's Corpuscular model of light?

A. It could not explain the phenomenon of refraction.
B. It required light to travel faster in denser mediums, which was observed not to be true.
C. The equations describing light are simpler when light is treated as a wave.
D. It could not explain the phenomenon of polarisation.

18 Which of these wavelengths is NOT part of the Balmer series in hydrogen?

A. 421 nm
B. 434 nm
C. 486 nm
D. 656 nm

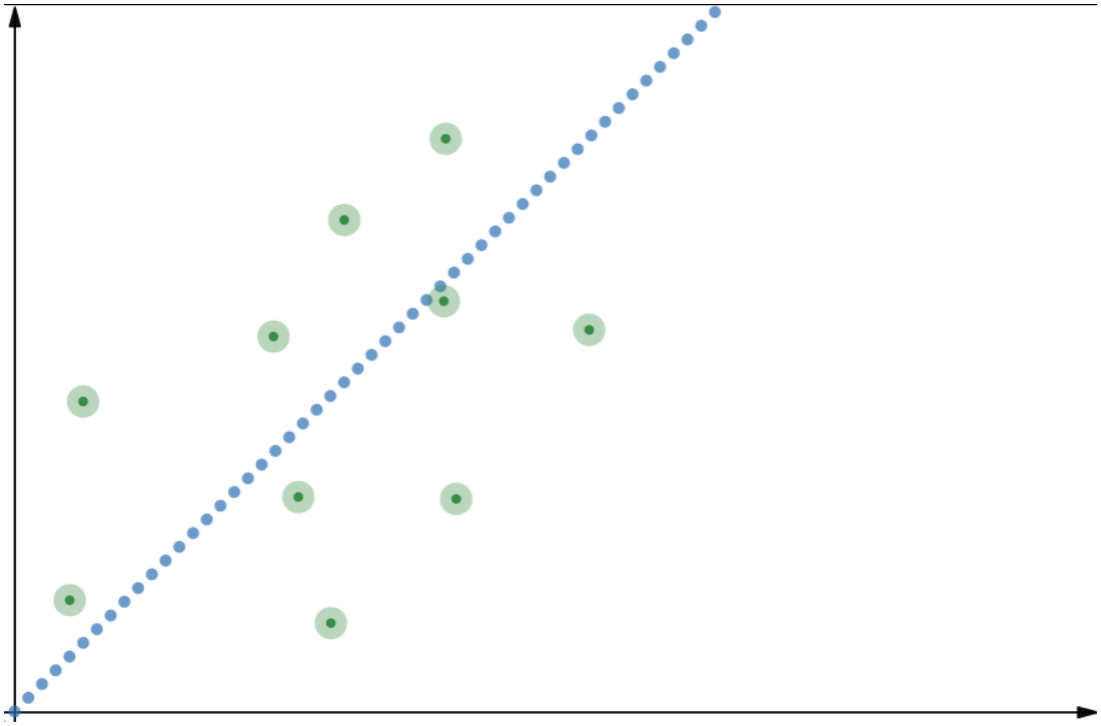
19 In the setup depicted below, light travels along the z-axis, passing through two polarising filter. The first filter's plane of polarisation is parallel to the y-axis, and the second's plane of polarisation makes an angle of $\theta = 35°$ with the x-axis.



When the second filter's plane of polarisation is at an angle of $\theta = 90°$ to the x-axis is $210\ lux$. What is the intensity of light when $\theta = 35°$ (as per the diagram)?

A. Not a number; impossible to calculate.
B. $69\ lux$
C. $140\ lux$
D. $172\ lux$

20



Referring to the above graph, what can be said about the data gathered?

A. The data is neither accurate, nor precise.
B. The data is accurate, but not precise.
C. The data is precise, but not accurate.
D. The data is both accurate and precise.

2019 **Higher School Certificate Examination**

Physics

Section II

Answer Booklet

80 marks

Attempt Questions 21–35

Allow about 2 hours and 25 minutes for this section

Instructions

- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Please turn over

Question 21 (4 marks)

Outline Galileo's analysis of projectile motion, using a labelled diagram to support your answer.

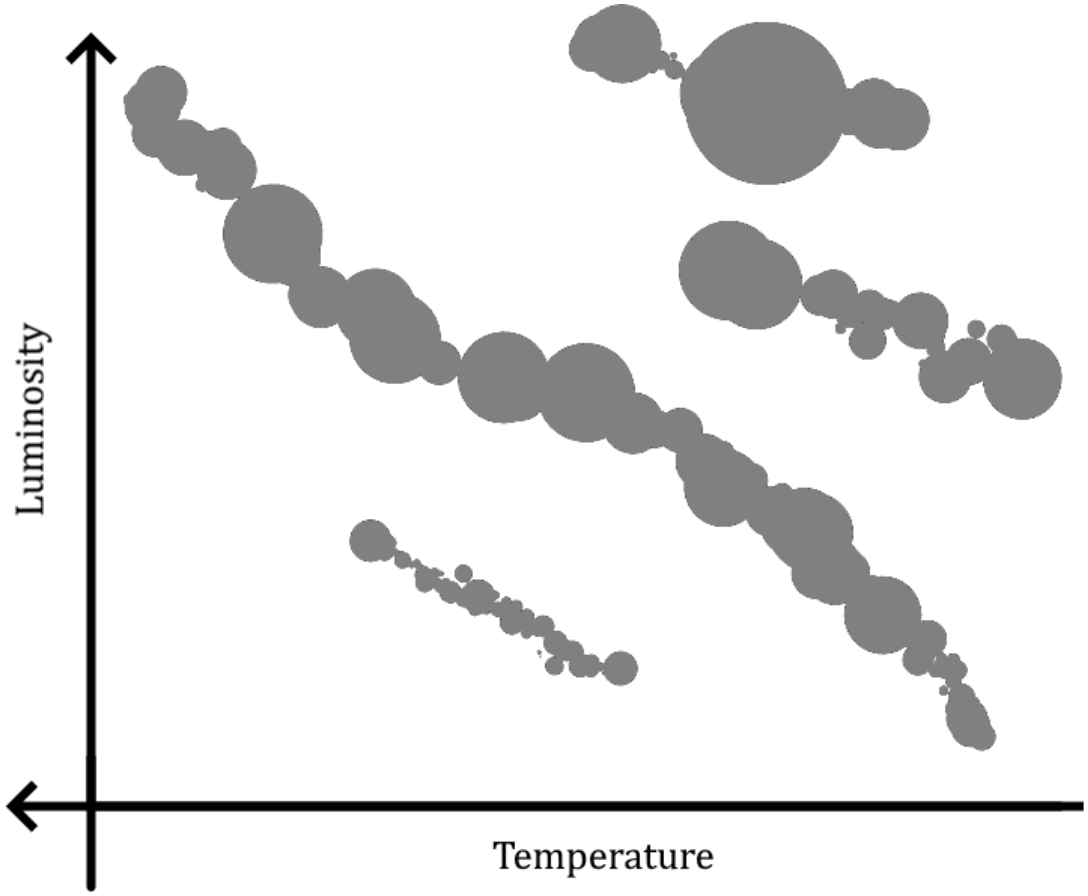
Question 22 (5 marks)

(a) A driver is approaching a horizontal corner of radius $30m$ in their $1.05\ tonne$ car. If they drive around the corner at $70\ Km/h$, and the maximum combined friction force their tyres can provide without slipping is $3800\ N$, determine whether they will crash their car. 2

(b) In order to improve road safety, the local council elects to turn the aforementioned corner into a banked corner. Calculate the angle of incline required for the driver to complete the turn at the same speed with no frictional force exerted on his car's tyres. 3

Question 23 (5 marks)

Use the following Hertzsprung-Russel diagram to answer Question 23.



(a) Label each of the four main groups of stars 2

(b) Outline the evolutionary process of a typical sun-like star by drawing arrows indicating how its position on this graph would change over time. 1

(c) Circle the groups of stars which produce their energy through the CNO cycle. 2

Question 24 (4 marks)

Describe Chadwick's experiment in which he discovered the neutron and explain how the properties of this particle were determined.

Question 25 (4 marks)

Describe how an EMF is generated in a solenoid in the vicinity of another solenoid through which AC current is passing, making detailed reference to Lenz's Law.

Question 26 (3 marks)

An archaeologist discovers a bone deep within the treacherous jungles of Madagascar. She knows that in a typical $10g$ sample of a bone, $0.10g$ of radioactive Carbon-14 atoms will be present. She determines that in a 10g sample of this bone, there is only $0.020g$ of Carbon-14 present. Given that the half-life of Carbon-14 is 5730 years, determine the age of this bone, correct to 3 significant figures.

Question 27 (6 marks)

(a) Two conductive wires from independent circuits run parallel for $5m$, at a distance of separation $15.0cm$. If the first is carrying a current of $25.0A$, and the second is at $5.00V$. If the force between the two wires is $6.65 \times 10^{11}\ N$ repelling, determine the magnitude of the power in the second wire. 3

(b) Explain how this force is induced between the wires. 3

Question 28 (3 marks)

Explain why the work done on an object undergoing circular motion is zero.

Question 29 (5 marks)

Compare the release of energy in a nuclear reactor to that of a power plant using traditional fuels, accounting for the conservation of energy.

Question 30 (7 marks)

Recall an investigation you carried out during your HSC physics course. Summarise the process of this investigation and explain the steps taken to ensure the accuracy and reliability of the results as well as those taken to ensure the safety of individuals conducting this investigation.

Question 31 (7 marks)

(a) Explain why gravitational potential energy is negative 3

(b) Derive an expression for escape velocity using the principle of the conservation of energy, given that at an infinite distance from the planet, the kinetic energy of an object launched from that planet will be zero. 3

(c) Calculate the escape velocity of a projectile launched from Earth's surface. 1

Question 32 (4 marks)

An electron is suspended directly above a stationary electric plate which is charged to $-2.952 \times 10^{-21}\ C$.

Regard the plate as a point charge.

By equating the downwards force due to gravity with the force between the two charges, determine the distance at which the proton is hovering above the plate.

Question 33 (6 marks)

Discuss the evidence supporting Einstein's theory of special relativity.

Question 34 (8 marks)

Analyse the current model of light, describing evidence for both the wave and particle models.

Question 35 (9 marks)

"If I have seen further than others, it is by standing upon the shoulder of giants"

- Isaac Newton

Our understanding of the world around us has developed over time as new evidence has been discovered.

Evaluate the accuracy of these statements with detailed reference to the development of the model of the atom.

END OF EXAM

This page was left blank intentionally by the publisher (NEESA), so that all you cheeky untrustworthy children wouldn't have the opportunity to peek at the last question, because that is the sort of thing that we think you millennials would do (my co-worker advises me that the children completing the HSC this year are actually a part of Gen-Z, but there is no difference in my opinion). Anyway, we needed to put this message here reminding you that this page was left blank intentionally because one time when we didn't do that, everyone thought it was a printing error and that there were actually more questions on this page. We got soooo many phone calls and it was really, really annoying, so we won't be making that mistake again. I mean if they were smart, they would have noticed that there was a huge, bold, caps-locked **END OF EXAM** at the end of the previous page, which means that obviously there aren't any more questions, but I guess we can't expect that kind of intelligence from kids these days. Of course, we still examine them like they're all child-prodigies, because that means we can ask really horribly mean questions like Question 35, which was actually inspired by the Studies of Religion exam and adapted to loosely fit the Physics syllabus, but still retain the same nastiness as a really malicious *evaluate* question. We really like putting nasty questions at the end of our exams; it helps the children know their place. Anyway, this message hopefully let you know that this page has been left blank by design. If I had my way, we wouldn't have this message here, but the executives at NEESA say that we have to so that the children doing the exam don't get confused, which they says is easily possible given the students' perceived unnecessarily high difficulty of our exams which contributes to their brains being fried and them having no motivation by the end of each one. Sadly, this message had to be here though, so here it is.

On second thoughts, this page isn't actually blank anymore.

The End.

New South Wales
Educational
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Standards
Authority

Physics

Fully worked solutions

Section I

1. **B**

   From the Universe to the Atom > Origins of the Elements >

   Investigate the evidence that led to the discovery of the expansion of the Universe by Hubble (ACSPH138)

2. **C**

   Advanced Mechanics > Circular Motion >

   Solve problems, model and make quantitative predictions about objects executing uniform circular motion in a variety of situations, using the following relationships: $\omega = \frac{\Delta\theta}{t}$

3. **D**

   The nature of Light > Light and Special Relativity >

   Describe the consequences and applications of relativistic momentum

4. **C**

   Advanced Mechanics > Projectile Motion >

   Apply the modelling of projectile motion to quantitatively derive the relationships between the following variables: launch angle, horizontal range of the projectile, time of flight

5. **A**

   From the universe to the atom > Deep inside the atom >

   Investigate the Standard Model of matter

6. **B**

   Electromagnetism > Electromagnetic Induction >

   Analyse quantitatively the operation of ideal transformers through the application of: $\frac{V_\mathrm{p}}{V_\mathrm{s}} = \frac{N_\mathrm{p}}{N_\mathrm{s}}$, $V_\mathrm{p} I_\mathrm{p} = V_\mathrm{s} I_\mathrm{s}$

7. **D**

   Electromagnetism > The Motor Effect >

   Analyse the interaction between two parallel current-carrying wires

8. **B**

   Advanced Mechanics > Motion in Gravitational Fields >

   Investigate the relationship of Kepler's Laws of Planetary Motion

9. C

The Nature of Light > Light and Special Relativity >

Particle–antiparticle interactions

10. D

Advanced Mechanics > Motion in Gravitational Fields >

The concept of escape velocity $v_{\text{esc}} = \sqrt{\frac{2GM}{r}}$

11. C

- Electromagnetism > Charged Particles, Conductors and Electric and Magnetic Fields >

  Analyse the interaction between charged particles and uniform magnetic fields
- From the Universe to the Atom > Structure of the Atom >

  Early experiments examining the nature of cathode rays

12. A

Advanced Mechanics > Circular Motion >

Investigate the relationship between the rotation of mechanical systems and the applied torque: $\tau = r_{\perp}F = rF\sin\theta$

13. C

The Nature of Light > Electromagnetic Spectrum >

Investigate how spectroscopy can be used to provide information about: the identification of elements

14. B

Working Scientifically > Analysing Data and Information >

Assess the reliability of primary and secondary data

15. D

Electromagnetism > Applications of the Motor Effect >

Investigate the operation of a simple DC motor to analyse: the functions of its components

16. B

Advanced Mechanics > Circular Motion >

explain and evaluate, for objects executing uniform circular motion, the relationships that exist between: centripetal force, mass, speed, radius

17. B

The Nature of Light > Light: Wave Model >

Analyse the experimental evidence that supported the models of light that were proposed by Newton and Huygens

18. A

From the Universe to the Atom > Quantum Mechanical Nature of the Atom >

Investigate the line emission spectra to examine the Balmer series in hydrogen

19. B

The Nature of Light > Light: Wave Model >

Conduct investigations quantitatively using the relationship of Malus' Law

$I = I_{\max} cos^2\theta$

20. B

Working Scientifically > Analysing Data and Information >

Assess the accuracy and validity of primary and secondary data

Section II

21.

Outline:

Marks	Criteria
2	States that the projectile follows a parabolic path, AND that its motion can be analysed by resolving it into independent components
1	States either that the projectile follows a parabolic path, OR that its motion can be analysed by resolving it into independent components

Diagram:

Marks	Criteria
2	Diagram contains accurate sketch of a parabolic path AND is labelled correctly with information stated in outline.
1	Diagram either contains accurate sketch of a parabolic path OR is labelled correctly with information stated in outline.

Advanced Mechanics > Projectile Motion

Solve problems, create models and make quantitative predictions by applying the equations of motion relationships for uniformly accelerated and constant rectilinear motion.

22.

(a)

Marks	Criteria
2	Correct calculation of centripetal force on car, and correct assessment that the car will crash.
1	Correct conversion to SI units, and correct substitution into the formula.

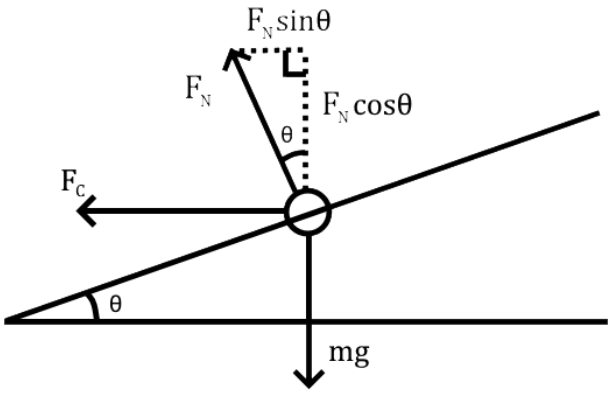
$$F_C = \frac{mv^2}{r}$$
$$m = 1.05\ T = 1050\ Kg$$
$$v = 70\ Km\ h^{-1} = 19.44\ldots m\ s^{-1}$$
$$r = 30m$$
$$\therefore F_C = \frac{1050 \times (19.44\ldots)^2}{30}$$
$$F_C = 13\,233.02\ldots\ N$$

This is greater than $3800\ N$, and therefore the car will crash.

evil laughter

(b)

Marks	Criteria
3	Correct calculation of answer.
2	Correct derivation of formula $\tan\theta = \frac{v^2}{gr}$ and substitution of variables into derived formula.
1	Correct resolution of forces two directions.



Resolving forces:

Vertically:

$$F_N\ cos\theta = mg$$
$$\therefore F_N = \frac{mg}{cos\theta}$$

Horizontally:

$$F_C = F_N \sin\theta = mg\frac{\sin\theta}{\cos\theta}$$

$$F_C = mg\tan\theta$$

$$\therefore \frac{mv^2}{r} = mg\tan\theta$$

Rearranging:

$$\tan\theta = \frac{v^2}{gr}$$

Substituting in values:

$$\tan\theta = \frac{(19.44\ldots)^2}{9.8 \times 30}$$

$$= 1.286\ldots$$

$$\therefore \theta = 52.1° \ (3SF)$$

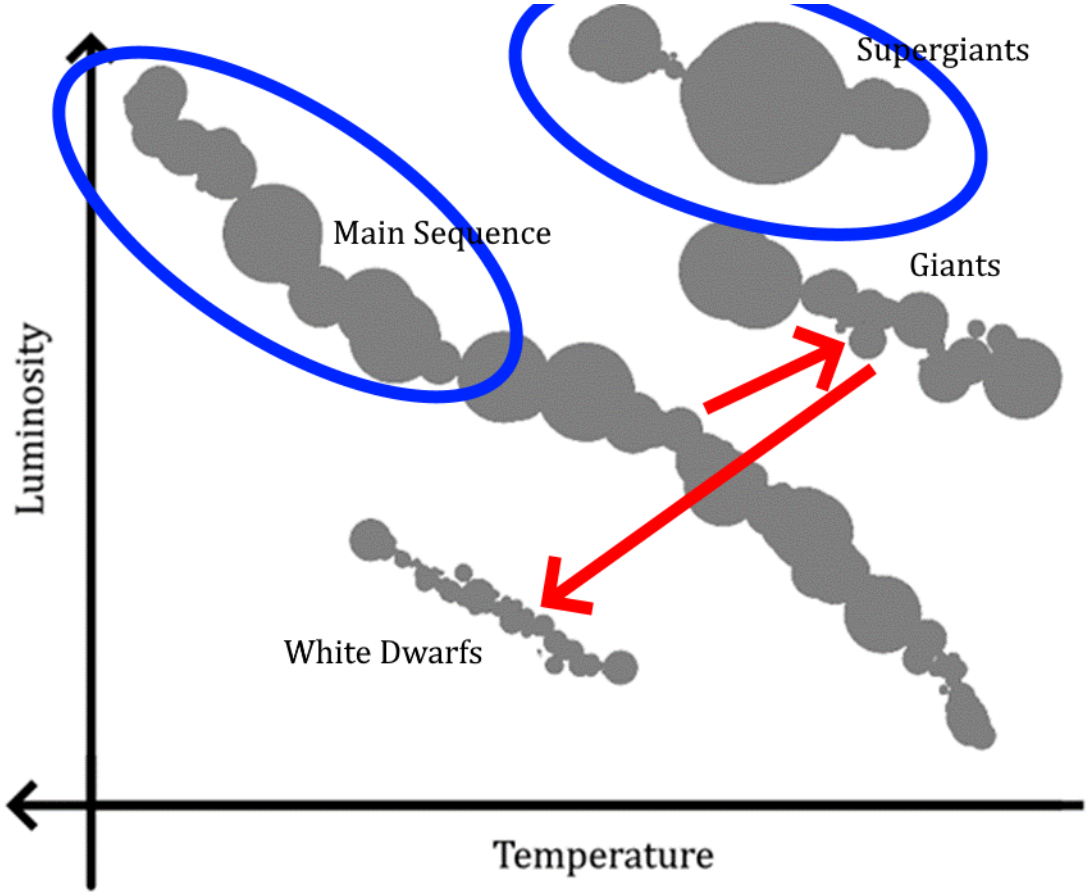
Advanced Mechanics > Circular Motion >

Analyse the forces acting on an object executing uniform circular motion in a variety of situations, for example: cars moving around horizontal circular bends, objects on banked tracks.

23. The solution to part a) is written in **BLACK**.

The solution to part b) is drawn in **RED**.

The solution to part c) is drawn in **BLUE**.



(a)

Marks	Criteria
2	Correct labelling of all 4 groups of stars.
1	Correct labelling of at least 2 groups of stars.

(b)

Marks	Criteria
1	Correctly drawn path from Main Sequence to Red Giant to White Dwarf

(c)

Marks	Criteria
2	Correct identification of two star groups that generate energy through the CNO-cycle.
1	Correct identification of one star group that generates energy through the CNO-cycle.

From the Universe to the Atom > Origins of the Elements >

- Investigate the Hertzsprung–Russell diagram and how it can be used to determine the following about a star: characteristics and evolutionary stage.
- Investigate the types of nucleosynthesis reactions involved in Main Sequence and Post-Main Sequence stars, including but not limited to: CNO (carbon–nitrogen–oxygen) cycle.

24.

From the Universe to the Atom > Structure of the Atom >

Investigate, assess and model the experimental evidence supporting the nuclear model of the atom, including: Chadwick's discovery of the neutron.

25.

Electromagnetism > Electromagnetic Induction >

The generation of an emf produced by the relative movement or changes in current in one solenoid in the vicinity of another solenoid.

26.

Marks	Criteria
3	Correct solution with correct rounding.
2	Correct solution with incorrect rounding, OR solution with one mistake with correct rounding.
1	Correct substitution of variables into formula.

$$N_t = N_0 e^{-\lambda t}, where\ \lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$

$$N_t = 0.020g$$
$$N_0 = 0.1g$$
$$t_{\frac{1}{2}} = 5730\ years$$

$$\therefore 0.020 = 0.1e^{-\left(\frac{\ln 2}{5730}\right)t}$$
$$0.2 = e^{-\left(\frac{\ln 2}{5730}\right)t}$$
$$-t\left(\frac{\ln 2}{5730}\right) = \ln 0.2$$
$$t = \frac{5730 \ln 0.2}{\ln 2}$$
$$t = 13304.64\ldots$$
$$t = 13300\ years\ (3SF)$$

From the Universe to the Atom > Properties of the nucleus >

Examine the model of half-life in radioactive decay and make quantitative predictions about the activity or amount of a radioactive sample using the following relationships:

- $N_t = N_0 e^{-\lambda t}$
- $\lambda = \frac{ln2}{t_{1/2}}$

27.

(a)

Marks	Criteria
3	Correct solution.
2	Correct calculation of current in second wire.
1	Correct substitution of variables into formula.

$$\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$$
$$F = 6.65 \times 10^{11}\ N$$
$$l = 5\ m$$
$$I_1 = 25\ A$$
$$r = 0.15\ m$$
$$\mu_0 = 4\pi \times 10^{-7}$$
$$\frac{6.65 \times 10^{11}}{5} = \frac{4\pi \times 10^{7}}{2\pi}\frac{25 \times I_2}{0.15}$$
$$\therefore I = \frac{6.65 \times 10^{11} \times 0.15}{5 \times 2 \times 25 \times 10^{-7}}$$
$$\text{But } P = IV$$
$$\therefore P = \frac{6.65 \times 10^{11} \times 0.15}{5 \times 2 \times 25 \times 10^{-7}} \times 5$$
$$P = 1.995 \times 10^{16}$$
$$P = 2.00 \times 10^{16}\ W\ (3SF)$$

Electromagnetism > The Motor Effect >

Analyse the interaction between two parallel current-carrying wires $\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$.

28.

Advanced Mechanics > Circular Motion >

Investigate the relationship between the total energy and work done on an object executing uniform circular motion.

29.

The Nature of Light > Light and Special Relativity >

Use Einstein's mass–energy equivalence relationship $E = mc^2$ to calculate the energy released by processes in which mass is converted to energy, for example: combustion of conventional fuel.

From the Universe to the Atom > Properties of the Nucleus >

Model and explain the process of nuclear fission, ⋯ and account for the release of energy in the process.

30.

Working Scientifically Skills > Planning Investigations >

Employ and evaluate safe work practices and manage risks.

Use appropriate technologies to ensure and evaluate accuracy.

31.

(b)

Marks	Criteria
3	Correct derivation of formula.
2	Derivation with one mistake.
1	Attempts to apply conservation of energy.

$$Applying\ conservation\ of\ energy:$$
$$E_i = E_f$$
$$\therefore (K+U)_i = (K+U)_f$$
$$\frac{1}{2}mv^2 + \frac{-GMm}{r} = 0 + 0$$
$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$
$$v^2 = \sqrt{\frac{2GM}{r}}$$

(c)

Marks	Criteria
1	Correct solution.

$$v = \sqrt{\frac{2 \times (6.67 \times 10^{-11}) \times (6.0 \times 10^{24})}{6.371 \times 10^{6}}}$$
$$v = 11208.55\ldots$$
$$v = 1.12 \times 10^{4}\ ms^{-1}\ (3SF)$$

Advanced Mechanics > Motion in Gravitational Fields >

Derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to a variety of situations, including but not limited to: the concept of escape velocity $v_{\text{esc}} = \sqrt{\frac{2GM}{r}}$.

32.

Marks	Criteria
4	Provides correct solution
3	Provides solution with one error (either in calculation, or in manipulation of equation)
2	Equates formulae and attempts to solve for r.
1	Correctly lists formulae and variables.

Given that:

$$F_g = mg \text{ and}$$

$$F_q = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Where:

$$m = 9.109 \times 10^{-31}$$
$$g = 9.8$$
$$q_1 = -1.602 \times 10^{-19}$$
$$q_2 = -2.952 \times 10^{-21}$$
$$\varepsilon_0 = 8.854 \times 10^{-12}$$

Equating:

$$mg = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$
$$r^2 = \frac{q_1 q_2}{4\, mg\, \pi\, \varepsilon_0}$$
$$r = \sqrt{\frac{q_1 q_2}{4\, mg\, \pi\, \varepsilon_0}}$$
$$= \sqrt{\frac{(-1.602 \times 10^{-19}) \times (-2.952 \times 10^{-21})}{4\,(9.109 \times 10^{-31}) \times 9.8 \times (8.854 \times 10^{-12}) \times \pi}}$$
$$= 0.69002 \ldots m$$
$$\therefore r = 0.690\, m\ (3SF)$$

Electromagnetism > Charged Particles, Conductors and Electric and Magnetic Fields > Investigate and quantitatively derive and analyse the interaction between charged particles and uniform electric fields.

33.

The Nature of Light > Light and Special Relativity >

- Analyse and evaluate the evidence confirming or denying Einstein's two postulates:
    - The speed of light in a vacuum is an absolute constant
    - All inertial frames of reference are equivalent
- investigate the evidence, from Einstein's thought experiments and subsequent experimental validation, for time dilation $t = t_0/\sqrt{\left(1 - \frac{v^2}{c^2}\right)}$ and length contraction $l = l_0\sqrt{\left(1 - \frac{v^2}{c^2}\right)}$, and analyse quantitatively situations in which these are observed, for example:
    - observations of cosmic-origin muons at the Earth's surface
    - atomic clocks (Hafele–Keating experiment)
    - evidence from particle accelerators
    - evidence from cosmological studies

34.

The Nature of Light > Light: Wave Model, Light: Quantum Model

35.

From the Universe to the Atom > Structure of the Atom, Quantum Mechanical Nature of the Atom