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Examiners' report

PHYSICS B (ADVANCING PHYSICS)

H557
For first teaching in 2015

H557/01 Summer 2018 series

Version 1

Contents

Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates. The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report. A full copy of the question paper can be downloaded from OCR.

Paper H557/01 series overview

H557/01 'Fundamentals of Physics' component is worth 110 marks and assesses specification content from across all the teaching modules.

Section A consisted of thirty multiple choice questions, each worth one mark.

Section B included five structured short answer questions worth a total of 22 marks. Each question typically examined a single context. To do well on this section candidates needed to be comfortable answering questions that involved problem-solving and practical-based questions as well as performing calculations.

Section C, consisted of six questions worth 58 marks in total. In addition to some short answer questions there were two opportunities for extended writing (Questions 39a and 40b) worth 6 marks each. There was also a practical and data analysis based question involving the double slit experiment.

Candidate performance overview

Candidates who did well on this paper generally:

- Correctly calculated the power of the lens in Question 31a.
- Were able to explain the need to avoid aliasing in response to Question 32.
- Applied their knowledge in unfamiliar contexts, for example in Question 34.
- Used sound physics, covering both of the required strands, in a logical structure for the extended response questions 39a and 40b.
- Were able to find the number of hydrogen molecules per mole of particles with sufficient energy to reach the Earth's escape velocity in Question 39b(ii).

Candidates who did less well on this paper generally:

- Omitted some multiple choice questions in Section A, despite there being no penalty for incorrect responses.
- Found it difficult to present sound reasoning for questions that required explanation - for example in Qu 36a where they needed to provide evidence from the graphs given.
- Showed poor setting out of questions that required clear algebraic reasoning e.g. Questions 39b, 41b(i).
- Found it hard to manipulate algebraic expressions, for example in Question 37a(ii) and 37b(i).
- Covered just one of the required strands for the extended response questions 39a and 40b and lacked structure in their reasoning.

There was little evidence that any time constraints had led to a candidate underperforming, only a few did not reach the end of the paper although some candidates did not respond to the more challenging parts of questions but did not return to complete them.

Section A overview

This section consisted of thirty multiple choice questions, each worth one mark.

Question 2

2 Which of these ages is estimated correctly?

A The Earth is about 4 billion years old.

B The Sun is about 14 billion years old.

C The Milky Way Galaxy is about 20 billion years old.

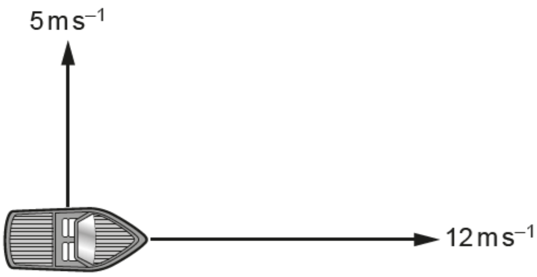
D The Universe is about 20 billion years old.

Your answer [1]

Whilst over half of the candidates recognised the correct estimate as that for the Earth's age, the range of other responses selected suggests that candidates are not familiar with the age of typical objects in the universe, as the specification requires.

Question 5

5 A boat travels eastwards with a velocity of $12\,\mathrm{m\,s^{-1}}$.
A current from the south pushes the boat northwards at a velocity of $5\,\mathrm{m\,s^{-1}}$.



What is the magnitude of the resultant velocity of the boat?

A $7\,\mathrm{m\,s^{-1}}$

B $13\,\mathrm{m\,s^{-1}}$

C $17\,\mathrm{m\,s^{-1}}$

D $169\,\mathrm{m\,s^{-1}}$

Your answer [1]

This elementary application of Pythagoras Theorem was correctly answered by almost every candidate.

Question 6

6 A weight of 20 N is suspended from a steel wire.

What is the extension of the wire?

Data: original length of wire = 2.5 m
cross-sectional area of wire = $7.0 \times 10^{-8}\,m^2$
Young Modulus of the wire material = $2.1 \times 10^{11}\,Pa$

A 0.0030 m

B 0.0034 m

C 0.030 m

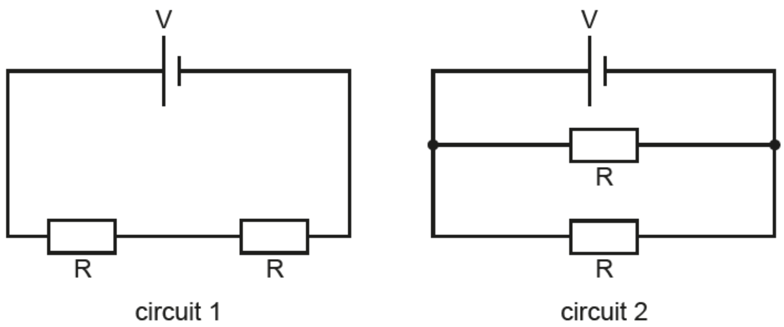
D 0.034 m

Your answer ☐ **[1]**

A common feature of responses from less able candidates was to make "power of ten" errors in the calculation and select response D (0.034m) rather than the correct answer B (0.0034m)

Question 7

7 These two circuits use identical components.
The cells have zero internal resistance.



What is the ratio $\frac{\text{power dissipated in circuit 1}}{\text{power dissipated in circuit 2}}$?

A $\frac{1}{4}$

B $\frac{1}{2}$

C 2

D 4

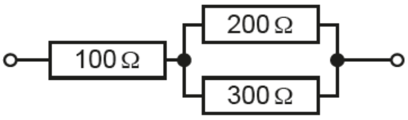
Your answer ☐ **[1]**

This question was based on the ratio of electrical powers in two circuits – one parallel, one series - containing identical resistors. A common incorrect response was to give the inverse of the correct ratio.

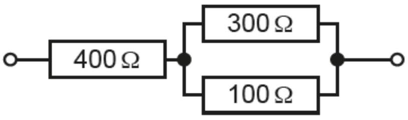
Question 8

8 Which combination of resistors gives the **lowest** total resistance?

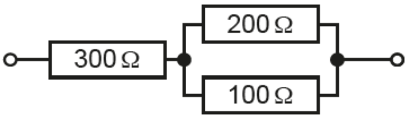
A



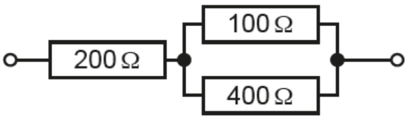
B



C



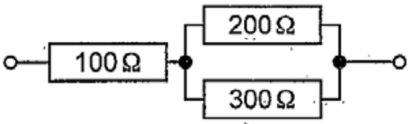
D



Your answer [ ] **[1]**

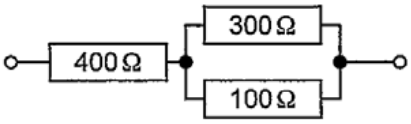
Exemplar 1

A



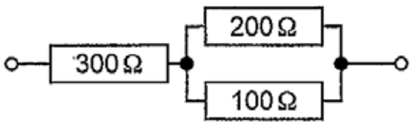
$100 + \frac{1}{\frac{1}{200} + \frac{1}{300}} = 220$

B



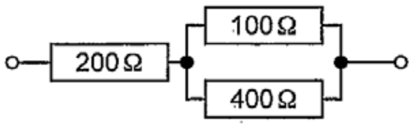
$400 + \frac{1}{\frac{1}{300} + \frac{1}{100}} = 475$

C



$300 + \frac{1}{\frac{1}{200} + \frac{1}{100}} = 366.7$

D



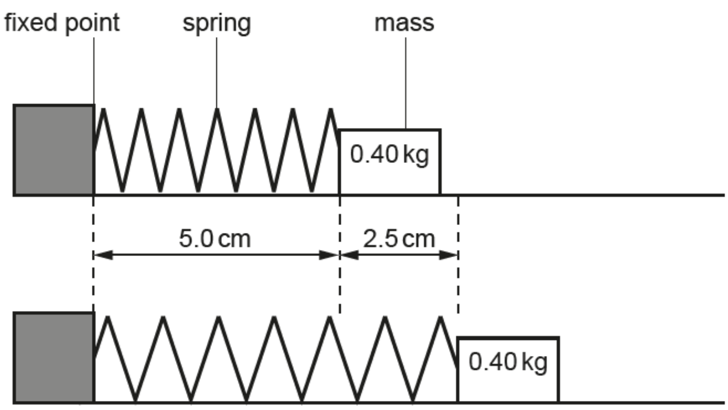
$200 + \frac{1}{\frac{1}{100} + \frac{1}{400}} = 280$

Your answer [A] **[1]**

Whilst working is not required or credited, successful candidates , as in this exemplar, often showed their working against each of the networks.

Question 10

10 The spring in this diagram has a spring constant of 20 N m^{-1}.
The mass is pulled away from the fixed point. The spring stretches by 2.5 cm.
The mass is then released.



What is the maximum speed reached by the mass?

A 0.18 m s^{-1}

B 0.53 m s^{-1}

C 1.25 m s^{-1}

D 3.75 m s^{-1}

Your answer [ ] **[1]**

Higher ability candidates realised that they had to apply an energy equation to a mass on a spring problem, kinetic energy gained = potential energy lost ($\frac{1}{2} m v^2 = \frac{1}{2} k x^2$) to find the maximum velocity reached.

Question 11

11 An electron is travelling at a speed of 3.1×10^5 m s^{-1}.

What is its kinetic energy in electronvolts?

A 4.4×10^{-20} eV

B 8.8×10^{-7} eV

C 0.27 eV

D 500 eV

Your answer [ ] **[1]**

The working shown by some candidates who did not gain credit suggested that they may not have been aware that the value of electron mass is given in the data booklet.

Question 14

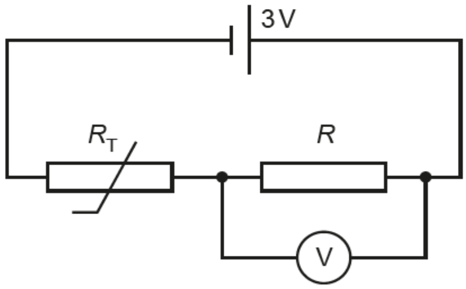
14 Which set of values **A** to **D** above, most closely represents the situation 3 seconds after the switch is closed?

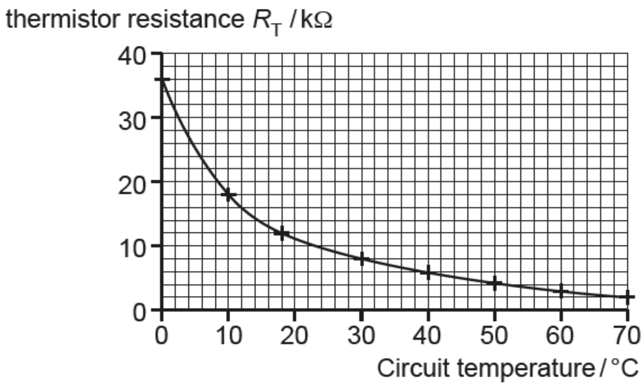
Your answer [1]

This pair of questions concerned a capacitor charging from a supply through a fixed resistance. Candidates were offered a variety of currents and voltage distributions and had to select the correct combinations for when the switch was just closed (Qu 13) and after 3 seconds when they could deduce the capacitor would be fully charged due to a low RC value << 3 seconds (Qu14). Most candidates selected the correct response (D) for Qu 13 fewer than half of candidates identifying A as the correct response for Qu14 where many thought the capacitor would be half charged rather than fully charged after the 3 seconds.

Question 16

16 A thermistor is used in a potential divider circuit.





When the circuit temperature is 10 °C the reading on the voltmeter is 1.0 V.
What is the resistance of the resistor *R*?

A 6 kΩ

B 9 kΩ

C 18 kΩ

D 36 kΩ

Your answer [1]

A majority of candidates were able to read the thermistor resistance from the graph and apply it within a potential divider equation to find the resistance of the fixed resistor at a given temperature.

Question 18

18 What is the best estimate for the rate of change of flux in the transformer core?

A $0.12\,\text{Wb}\,\text{s}^{-1}$

B $0.12\,\text{T}\,\text{m}^{-2}\,\text{s}^{-1}$

C $12\,\text{Wb}\,\text{s}^{-1}$

D $12\,\text{T}\,\text{m}^{-2}\,\text{s}^{-1}$

Your answer ☐ **[1]**

A common error for this question was to select the correct numerical value with incorrect units or vice-versa.

Question 20

The following information is for use in questions **20** and **21**.

A particle of charge *q* and mass *m* travels in a vacuum in a region of constant magnetic flux density *B*.
It moves at a constant speed *v* in a circle of radius *r*.

20 Which expression gives the time for the particle to complete one circle of its motion?

A $\frac{2\pi m}{Bqr}$

B $\frac{2\pi mr}{Bq}$

C $\frac{2\pi m}{Bq}$

D $\frac{Bq}{2\pi m}$

Your answer [ ] **[1]**

Exemplar 2

A $\frac{2\pi m}{Bqr}$

B $\frac{2\pi mr}{Bq}$

C $\frac{2\pi m}{Bq}$

D $\frac{Bq}{2\pi m}$

$Bqv = \frac{mv^2}{r}$ $\quad T = \frac{2\pi r}{v}$

$r = \frac{mv}{Bq}$ $\quad r = \frac{Tv}{2\pi}$

$\frac{Tv}{2\pi} = \frac{mv}{Bq}$

$T = \frac{2\pi m}{Bq}$

Your answer [C] **[1]**

Successful candidates, as in this exemplar, needed to undertake algebraic manipulation of t = 2π r / v and Bqv = m v ^{2} / R.

Question 22

22 This table shows the half-lives of three radioactive isotopes.

Isotope	^{60}cobalt	^{192}iridium	^{210}thallium
Half-life	5.3 years	74 days	1.8 minutes

Which statement can be deduced from the information given?

A The decay constant of thallium is smaller than that of iridium.

B Because of the difference in half-lives, the energy of the particles emitted from cobalt must be less than the energy of the particles emitted by thallium.

C The most active source will be thallium.

D If the number of atoms in the cobalt and iridium sources is initially equal, then the iridium source will have the greater initial activity.

Your answer ☐ **[1]**

A common error for this question was to select response C on the basis that thallium has the shortest half-life, without understanding that activity is also dependent on the number of nuclei present.

Section B overview

This section included five structured short answer questions worth a total of 22 marks.

Question 31(a)

31 The lens in a digital clock projects the time onto a wall 1.5 m away as shown in **Fig. 31**.

The digital display is 0.030 m from the lens.

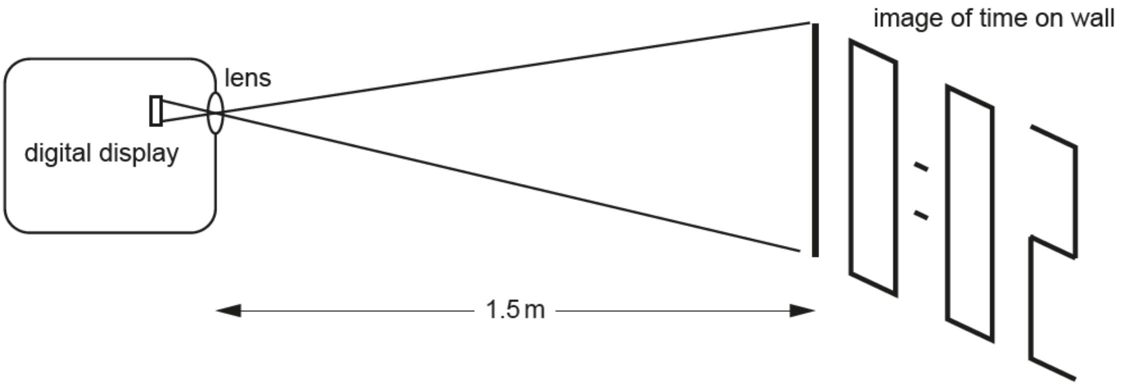


Fig. 31

(a) Calculate the power of the lens.

power of the lens = ... D **[3]**

Question 31(b)

(b) State the magnification of the lens in this example.

magnification = ... **[1]**

Exemplar 3

$$\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$$

$$\frac{1}{1.5} - \frac{1}{-0.03} = \frac{1}{f} = p = 34$$

power of the lens = ...34........... D **[3]**

Successful candidates could calculate the power of the projector lens in part (a) for the digital clock as 34 D. The course encourages the use of Cartesian sign convention, as per exemplar 3, but methods assuming the "real is positive" sign convention were given full credit.

Most candidates then were successful in correctly calculating the magnification as x50 for part (b).

Question 32(a)

32 A video file is downloaded at a rate of 24 Mbit s^{-1}.
The video file is 1.2 Gbytes in size.

(a) Show that the time taken for the file to download is greater than 6 minutes.

[2]

Exemplar 4

$$\frac{1.2 \times 10^9 \times 8}{24 \times 10^6} = 400$$

$$\frac{400}{60} = 6.67 \text{ minutes}$$

[2]

Successful candidates, as in exemplar 4, calculated the download time as 6.7 minutes for full credit.

Question 32(b)

(b) The video file contains a soundtrack sampled at 16.0 kHz.
State and explain the highest frequency of sound that can be recorded on the soundtrack.

highest frequency .... kHz

....

.... **[2]**

Successful candidates correctly calculated that the highest frequency of sound recorded was 8 kHz (half the sampling frequency) but less able candidates could not give an explanation that identified the need for two samples per cycle to pick up the variation, or the need to avoid aliasing. Some candidates stated or referred to the Nyquist theorem but this was not considered worthy of credit.

Question 34(a)

34 A solar panel is charging a rechargeable battery, with a resistor R in series.

The values of the internal resistances r, the external resistance R and the e.m.f.s ε at the start of the charging process are shown in **Fig. 34**.

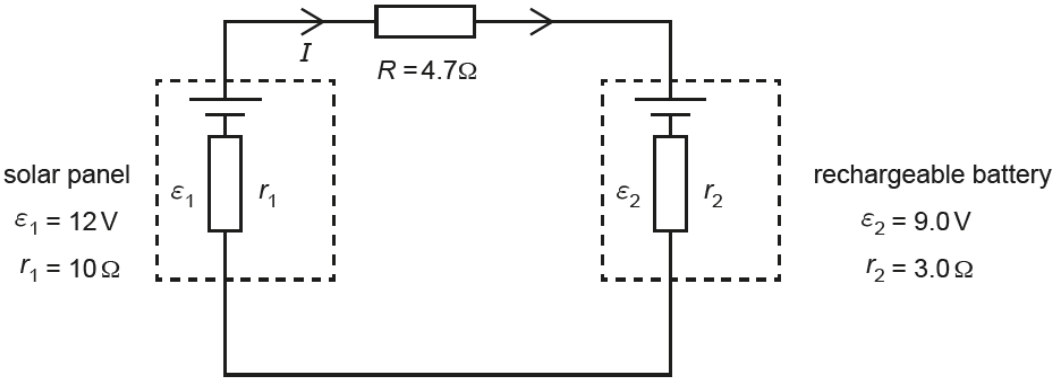


Fig. 34

(a) Show that the initial current charging the rechargeable battery I is less than 0.2A.

[2]

Question 34(b)

(b) When fully charged, the rechargeable battery has enough charge to deliver an average current of 500 mA for an hour before it is fully discharged.

Estimate the time needed to recharge the battery at the mean charging current of 0.12 A.

time = ... hours **[2]**

Exemplar 5

(a) Show that the initial current charging the rechargeable battery I is less than 0.2A.

Total resistance : $10 + 4.7 + 3 = 17.7\,\Omega$

$V = 12 - 9 = 3V$

$V = IR \therefore \frac{V}{R} = I = \frac{3}{17.7} = 0.17A$

[2]

(b) When fully charged, the rechargeable battery has enough charge to deliver an average current of 500 mA for an hour before it is fully discharged.

Estimate the time needed to recharge the battery at the mean charging current of 0.12 A.

$Q = It$

$Q = 500 \times 10^{-3} \times 60 \times 60$

$= 1800C$

$1800 = 0.12t$

$t = 15000s$

≈ 4 hours 10 minutes

time = ...4.2...... hours **[2]**

(2SF)

This question on the application of Kirchhoff's law was challenging. Although only a one loop circuit, the opposition of the charging solar cell and the rechargeable battery caused confusion; the most able candidates, as in exemplar 5, could show that the circuit current (0.17 A) was less than 0.2 A in part (a). Less able candidates were given credit for finding the sum of e.m.f.s around the circuit, the sum of the I R products or the total circuit resistance. In part (b) this candidate has successfully gone on to use Q = I t to find the time to recharge the battery as 4.2 hours.

Question 35(a)

35 This question is about a model of an atom with one electron.
The electron is trapped in a box as shown in **Fig. 35**.
Possible electron kinetic energy levels are plotted as shown.

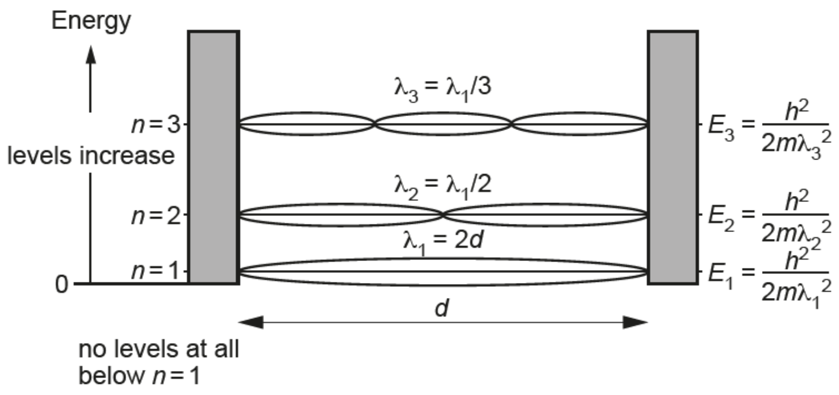


Fig. 35

(a) Explain how this model gives rise to discrete quantised energy levels for the atom.

....

....

....

.... **[2]**

This question asked for an explanation of the discrete energy levels in the "model atom". Successful responses explained the importance of λ/2 loops fitting into a fixed distance, or the need for nodes at the barriers, in setting up a standing wave. Less able candidates gained a mark for recognising that wavelength determines kinetic energy but some incorrectly used E=hc / λ.

Question 35(c)

(c) The distance *d* between the walls of the box is about atomic size ≈ 0.10 nm.

Calculate the frequency of the most energetic photon that this model atom could emit.

frequency = ... Hz **[3]**

This part of the question asked candidates to calculate the frequency of the most energetic photon this "atom" could emit. As this was designed for three stretch and challenge marks no hints about how to proceed were given. For those answers that did not arrive at the correct value of 7.3×10^{16} Hz, candidates could gain credit by selecting the correct energy levels E3 and E1, or by finding the energy difference ΔE between them (4.8×10^{-17} J). One mark was also allowed for the energy or frequency of a jump from L3 to an invented zero level. The most common misconception was to treat the electron matter wave as an electromagnetic wave of that wavelength and find the corresponding photon frequency, this gave 4.5×10^{16} Hz (a close answer) but earned no credit due to the error of Physics.

Section C overview

This section consisted of six questions worth 58 marks in total.

Question 36(a)(i)

36 This question considers some of the evidence for a Hot Big Bang start to our expanding universe.

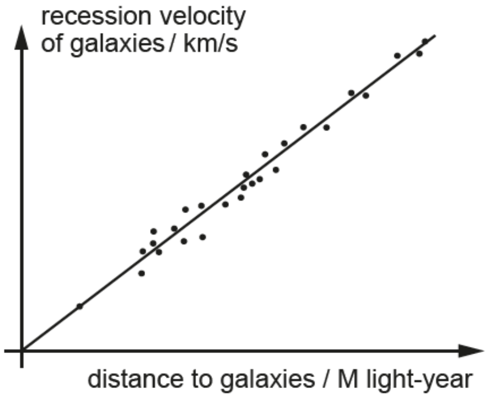


Fig. 36.1

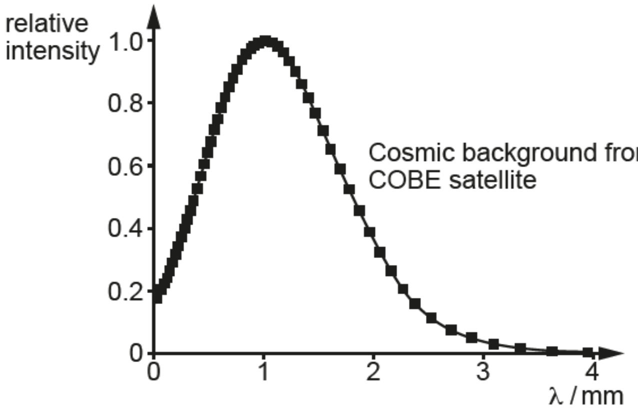


Fig. 36.2

(a) Explain how the graph(s) show evidence that the universe started from:

(i) a big bang expansion

....

....

....

.... **[2]**

Question 36(a)(ii)

(ii) a hot state.

....

....

....

.... **[2]**

This question asked candidates to give evidence from the two graphs presented (Hubble recession and the current CMBR spectrum) for our universe having a big bang expansion and for a hot starting state. For part a(i) less able candidates did not gain the mark as they only stated that "as distance from us increases so does the recession velocity of galaxies". For credit they needed to mention proportionality not just correlation. More able candidates were successful in gaining the second mark for arguing that at one time the matter in all galaxies would have a common origin.

For part a(ii) candidates gained credit for commenting that the radiation now is in the microwave region of the electromagnetic spectrum. The less able candidates correctly identified that the wavelength is longer now than previously, however they did not gain the second mark as they did not also identify that the wavelengths have been stretched by universal expansion or cosmological red-shift.

Exemplar 6

(i) a big bang expansion

The recession velocity graph (36.1) shows that a correlation that the further away galaxies are the greater their velocity (proportional relationship) Hence it suggests galaxies were once closer together and have moved apart, with the faster galaxies end at a greater distance, which suggests **[2]** an expansion from a single point as galaxies would once have been close together.

(ii) a hot state.

There is a high intensity of 1mm λ cosmic background radiation (relative intensity of 1.0 from graph (36.2)). This radiation is left over from the big bang. This suggests that as the universe has cooled and expanded the wavelength has stretched from gamma (high energy) to microwave **[2]** (lower energy). Hence this suggests universe started from a hot state when short wavelength high energy radiation was formed. This then cooled and forms uniform background (cosmic radiation) at microwave wavelengths.

This candidate has successfully identified the proportional relationship in part a(i) and gained the second mark for identifying that the big bang expansion came from a single point in space and time. Part (ii) also gains full credit as the candidate has recognised that the high intensity peak at 1mm means the wavelength now is in the microwave range and also that they have been stretched from gamma.

Question 36(b)

(b) The intensity spectrum of thermal radiation depends on temperature T. Photons at the **peak** of intensity have energy $\varepsilon \approx 5kT$.

Use this approximation and data from **Fig. 36.2** to estimate the temperature of the cosmic microwave background radiation (CMBR).

temperature = ... K **[4]**

This question was well-answered with candidates scoring the full marks four marks by using data read from the graph (peak intensity at λ = 1 mm) and applying the given approximation $\varepsilon \approx 5\ KT = h\ f = h\ c\ /\ \lambda$ to estimate the temperature of the CMBR as ≈ 2.8 K. Less able candidates gained one mark for identifying the peak wavelength from the graph.

Question 37(a)(i)

37 This question is about propulsion systems for spacecraft.

(a) A solar sail uses the momentum of photons in solar radiation for propulsion.

(not to scale)

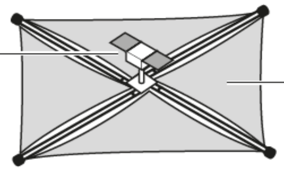


Fig. 37.1

Relativity shows that a photon of energy E has momentum $p = \frac{E}{c}$.

(i) Show that $\frac{E}{c}$ has the units of momentum.

[1]

The majority of candidates recognised that energy has unit of kg m^2 s^{-2}, speed has units of ms^{-1} and cancelled to give the unit of momentum as kg m s^{-1} for full credit. Credit was also given for the small number of candidates who used an alternative approach using J as the unit for energy leading to Ns for momentum.

Question 37(a)(ii)

(ii) The total photon power of the radiation received from the Sun on a 1.0 m^2 area of solar sail is P.

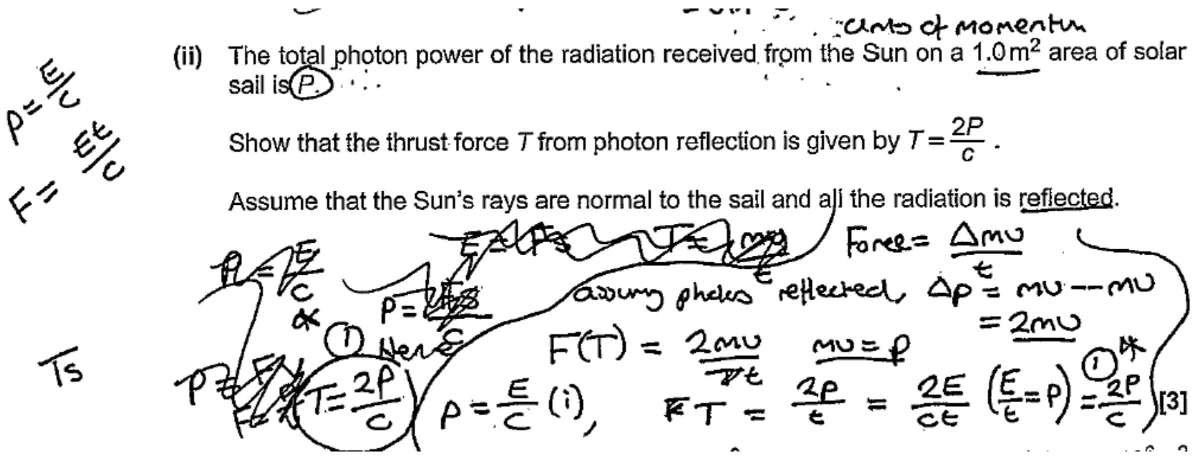
Show that the thrust force T from photon reflection is given by $T = \frac{2P}{c}$.

Assume that the Sun's rays are normal to the sail and all the radiation is reflected.

[3]

The most able candidates were able to manipulate algebraic expressions to show that the thrust from the solar sail T = 2 P / c where P is the total power density incident normally. They were then able to argue the momentum change per reflected photon is 2 E / c, and then relate the power of photon flux to the energy carried by n photons per m^2 s^{-1}. Other candidates got the first mark for stating that thrust was rate of change of momentum, but could not get much further. A common mistake was to confuse power, P, with the momentum symbol, p which led to confused and incorrect answers. Other errors were to introduce P = Fv or E = m c^2 which are not appropriate for photons or to omit the number of photons from the calculation.

Exemplar 7


(ii) The total photon power of the radiation received from the Sun on a 1.0 m^2 area of solar sail is *P*.

Show that the thrust force *T* from photon reflection is given by $T = \frac{2P}{c}$.

Assume that the Sun's rays are normal to the sail and all the radiation is reflected.

[3]

This candidate has correctly used F=Δmu / t and recognised that there is a change of 2mu on reflection to progress as far as T = "P /c but has omitted the number of photons from the final step.

Question 37(a)(iii)

(iii) The total photon power density is 1400 W m^{-2}. The 1.0 tonne spacecraft has a 10^6 m^2 solar sail.

Calculate the acceleration of the spacecraft.

acceleration = ... m s^{-2} **[2]**

This part of the question required candidates to use the equations given in part a(ii) to calculate the acceleration of a 1 tonne spacecraft using a 1 km^2 solar sail as 9.3 mm s^{-2}. Many candidates did this successfully even if they had not gained credit in part a(ii).

Question 37(b)(i)

(b) An ion drive uses the momentum of ions for propulsion. It ionises a gas and uses an accelerating field to accelerate the positive ions to a high velocity.

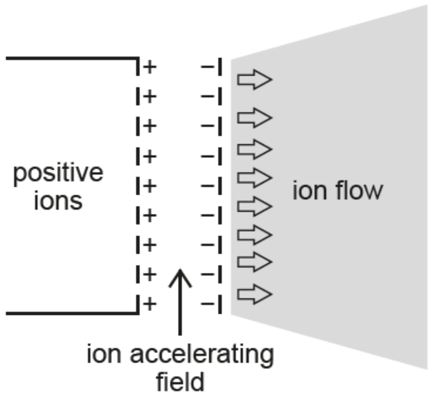


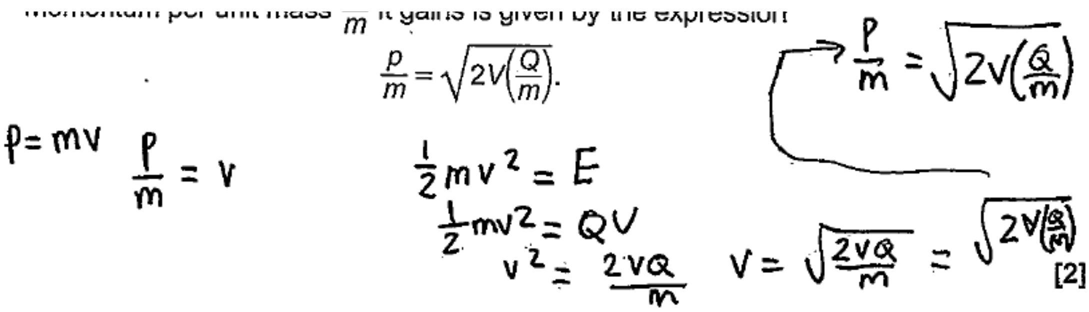
Fig. 37.2

(i) A positive ion of charge Q and mass m is accelerated through a p.d. V. Show that the momentum per unit mass $\frac{p}{m}$ it gains is given by the expression

$$\frac{p}{m} = \sqrt{2V\left(\frac{Q}{m}\right)}.$$

[2]

Exemplar 8



This part required algebraic reasoning and was often omitted by less able candidates. Those that were successful, as in exemplar 8, started from the equation for accelerated ions $QV = ½ m v^2$ and manipulated it to show that the momentum transfer per unit mass in the ion drive $p / m = \sqrt{(2 VQ / m)}$. Alternatively, some candidates realised that momentum per unit mass is in fact velocity for the ions and went on to derive v for full credit.

Question 37(b)(ii)

(ii) Discuss an advantage of using ions of hydrogen $^{1}H^{+}$ as propellant instead of xenon $^{130}Xe^{+}$.

....

....

.... **[2]**

Candidates were asked to compare the effectiveness of using $^{1}H^{+}$ and $^{130}Xe^{+}$ ions in the ion drive. Many gave trivial answers about availability and scored zero, but more able candidates gained full credit for arguing that $^{1}H^{+}$ has the largest charge mass ratio (Q / m) and hence the largest momentum transfer per unit mass.

Question 37(b)(iii)

(iii) An ion drive with accelerating p.d. $V = 2000\,V$ must produce a thrust of 0.24 N.

Show that the mass flow rate $\frac{\Delta m}{\Delta t}$ is less than $4 \times 10^{-7}\,kg\,s^{-1}$.

$\frac{Q}{m}$ for $^{1}H^{+}$ ions $= 9.6 \times 10^{7}\,C\,kg^{-1}$.

[2]

Successful candidates were able to recognise that thrust, T = Δp/ Δt and therefore T = Δp/ Δm x Δm/ Δt. They could then re-arrange this and use the equation p / m =√ (2 VQ / m) given in part b(i) to show that mass transfer rate was the thrust divided by momentum per unit mass, and hence that a 2000 V accelerator uses propellant at less than 4×10^{-7} kg s^{-1} to produce 0.24 N thrust.

Question 38(a)

38 A student performs Young's double slit experiment as shown in **Fig. 38.1**.

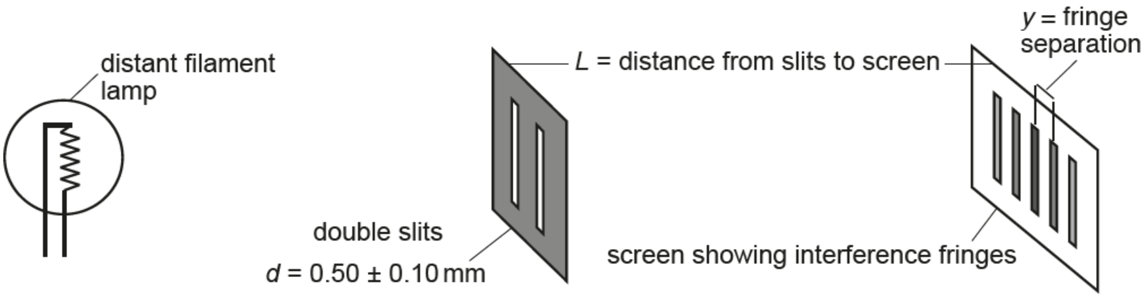


Fig. 38.1

The student investigates how the fringe spacing y varies with the distance L from slits to screen.
The student measures the slit separation $d = 0.5 \pm 0.1$ mm.
Fig. 38.2 shows the data obtained with uncertainties.

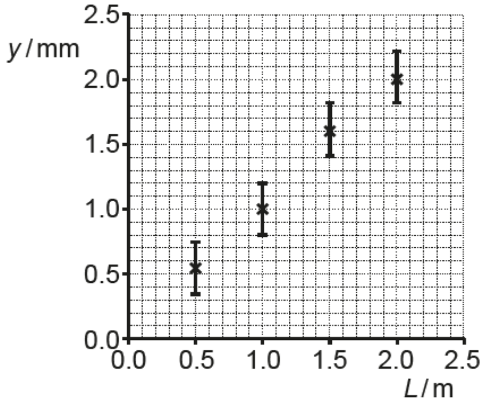


Fig. 38.2

(a) Suggest a reason why only uncertainties in the fringe spacing are shown on the graph.

....

.... **[1]**

Successful candidates recognised that percentage or relative uncertainty in L is much smaller than that in y. A common feature of weaker responses was to state that the uncertainty in the distance L is much less than the uncertainty in fringe spacing y; these responses did not gain credit since the uncertainty of both could be a similar size of ± 1 mm.

Question 38(b)

(b) Draw a line of best fit on the graph and measure its gradient with an uncertainty estimate.

gradient = ... ± .... **[3]**

Successful candidates gained the mark for a correct straight line of best fit and went on to calculate the gradient of their line and estimate the uncertainty from the error bars on the graph. Power of ten errors were common where candidates missed the "milli" multiplier on the mm axis. Candidates adopted a range of methods of estimating uncertainty and a wide range was accepted for credit to accommodate a variety of "worst fit" lines that could be drawn using the error bars.

Question 38(c)

(c) Use the gradient to estimate an average wavelength for the light together with an uncertainty estimate. Make your method clear.

wavelength = ... ± .... m **[3]**

Successful candidates were able to use the gradient calculated in (b) to find the wavelength of light, using $\lambda =$ d x gradient, in the range 450 to 600 nm. Examiners allowed errors in (b) to be carried forward without penalty. More able candidates went on to express the uncertainty in d, either as ±20% or ±0.2 and combine uncertainties to give an estimate; a wide range of ±150nm to ±360 was allowed for credit due to the range of gradients permissible in part (b) and several methods that may be used to estimate the uncertainty.

Question 38(d)

(d) State **one** way in which you could refine or develop this practical design or procedure to reduce uncertainty.

....

.... **[1]**

Candidates usually gained this mark by naming an item of equipment with better resolution – for example a travelling microscope or micrometer – but those candidates who just made a simple statement about measuring more precisely did not gain credit. More detailed responses that were accepted included repeating measurements to look for cluster giving greater precision, using a brighter light source, screening from background light and measuring multiple fringes.

Question 39(a)*

39 (a)* Boyle's Law states that at constant temperature, pressure is proportional to $\frac{1}{\text{volume}}$.

Explain how the random motion of particles gives rise to Boyle's law.

....

....

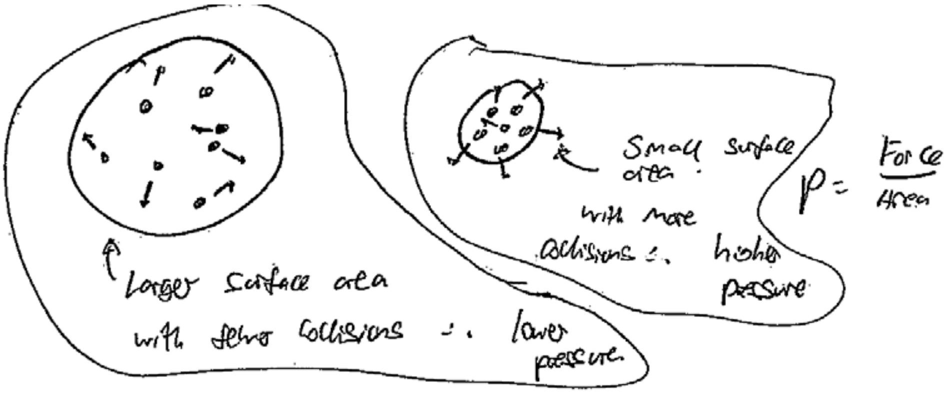
....

....

.... **[6]**

This question, worth six marks, asked candidates to explain how random motion of particles gives rise to Boyle's Law. For full credit candidates needed to include a clear explanation of two strands – random path motion & P proportional to 1/V – and to present the answer as a well-developed line of reasoning which is clear and logically structured. Those candidates that did this successfully used labelled diagrams and text that developed ideas about kinetic theory, the random walk of particles, the dynamics of rate of change of momentum and collision frequency, leading to impulse forces and pressure. Whilst it was not required, some even derived the complete kinetic theory equation $PV = 1/3\ N m c^2$. Weaker candidates gave ideas from only one strand or made many errors of physics. A very common mistake was to argue that if volume increases so does area, but that force remains the same so pressure ($P = F / A$) drops, and to miss out the crucial role of particle density and collision frequency.

Exemplar 9



• In a container, particles are constantly colliding with the container walls and each other – these collisions are random.

• The pressure on the container walls is caused by the force exerted by particles when they collide with the wall. Force is equal to rate of change of momentum, ~~so~~ so the change of momentum occurring when particles rebound.

• As $p \propto \frac{1}{V}$, as volume decreases, ~~pressure~~ pressure increases. This is illustrated above. ~~When~~ When the volume decreases, the random motion of the particles is retained and so they are more likely to collide with the container walls, increasing the rate of change of momentum and therefore the pressure.

• When the volume increases, pressure drops as there are fewer random collisions between the particles and the wall.

• Temperature must be kept constant, because increasing temperature can increase the pressure due to larger changes in particle momentum. **[6]**

This response was credited full marks. The candidate starts with a consideration of random motion and collisions then the argument is developed further by correctly linking rate of change of momentum, force and pressure. Pressure is also linked to volume so the candidate has used ideas from both the required strands of Physics. Since the answer contains a clear explanation of both those strands, it is judged to be a Level 3 response. It scores the higher mark within the level since the line of reasoning is well-developed, clear and logically structured.

Question 39(b)(i)

(b) Here are some data about trace gases in the atmosphere:

H_2 molar mass 2 grams
Xe molar mass 132 grams

(i) Calculate the ratio: $\dfrac{\text{speed of hydrogen molecule with average kinetic energy}}{\text{speed of xenon atom with average kinetic energy}}$.

Make your reasoning clear.

ratio = ... **[3]**

This involved finding the ratio of $c_{\text{r.m.s}}$. of two trace gases in the Earth's atmosphere, hydrogen and xenon. Successful responses developed reasoning that the gases share the same average kinetic energy per molecule, and hence the speed ratio is the square root of the inverse mass ratio. Candidates expressed this algebraically and were credited two marks for doing so. The final mark was credited for the evaluation to √ 66 or 8.1. Common errors occurred where candidates lost their way with their own algebra and ended up with the inverse answer. The use of subscript labels for two different cases is to be encouraged i.e. c_H / c_{Xe} and could help candidates with their reasoning and algebra.

Question 39(b)(ii)

(ii) The escape velocity for planet Earth is $11.2\,\text{km}\,\text{s}^{-1}$.

Use the Boltzmann factor to estimate the number of H_2 molecules per mole with sufficient energy to escape the atmosphere and the Earth's gravitational field at a temperature of 288 K.

number = ... mole^{-1} **[4]**

Exemplar 10

Use the Boltzmann factor to estimate the number of H_2 molecules per mole with sufficient energy to escape the atmosphere and the Earth's gravitational field at a temperature of 288 K.

$$f_B = e^{-\frac{\epsilon}{kT}}$$

$$= e^{-\frac{\frac{1}{2}\times\frac{0.002}{6.02\times10^{23}}\times(11.2\times10^3)^2}{1.38\times10^{-23}\times288}}$$

$$= 1.70\times10^{-23}$$

$$6.02\times10^{23}\times1.7\times10^{-23} = 10.2$$

$$= 10$$

number = ~~1.70 × 10^-23^~~ 10 (3sf) mole^{-1} **[4]**

This part asked candidates to find the number of hydrogen molecules per mole of particles with sufficient energy to reach the Earth's escape velocity (11.2 km s^{-1}) at a temperature of 288 K. They were advised to use the Boltzmann factor but otherwise given no further structure, so this was a stretch and challenge question. The Boltzmann factor containing a negative inverse exponent is very sensitive to exponent value, the values of the physical constants used, and to rounding. As a result, answers in the range 8 to 52 molecules were accepted if the calculations were justified for the full four marks as in this exemplar. Part marks were credited for setting up the calculation as number of molecules = $N_{Avogadro} \times e^{-E/kT}$ and for recognising the E as the kinetic energy of one hydrogen molecule travelling at the escape velocity (2.1 x 10^{-19} J) or for getting as far as calculating the Boltzmann exponent (-52) or Boltzmann factor (3.2 x 10^{-23}). Common errors included writing down the Earth's gravitational potential (unnecessary because escape velocity given), finding the kinetic energy for one mole of hydrogen gas with escape velocity (rather than a single molecule) or forgetting to multiply the Boltzmann factor by the Avogadro number. Candidates who confused grams and kg in expressing molar mass had a resulting power of ten error (of 1000) in the exponent. This yields an error message on most calculators, which typically only handle numbers down to 10^{-99} in size, confusing some candidates.

Question 40(a)

40 **Fig. 40.1** shows a simplified diagram of a d.c. motor with permanent magnets.
Fig. 40.2 shows the graph of current in the coil against frequency of rotation for this motor.

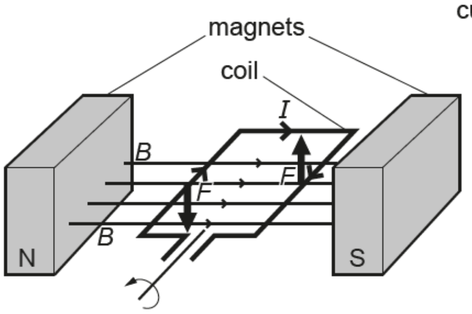


Fig. 40.1

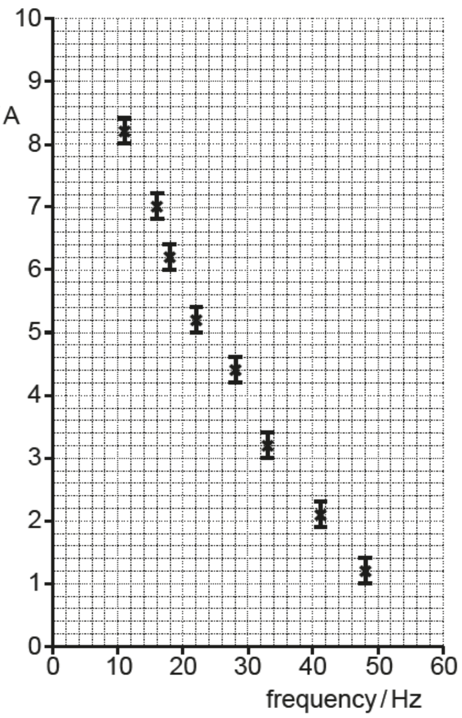


Fig. 40.2

The coil is connected to a 12.0 V supply of negligible internal resistance shown in **Fig. 40.1**. This produces the force to keep the motor turning against a mechanical load.

(a) Draw a **straight line** of best fit on **Fig. 40.2** and use it to predict the current in the coil when the motor is not rotating.
Use your prediction to calculate the resistance of the coil.

resistance = ... Ω **[3]**

Candidates were given data for a motor showing an inverse relationship between the current to the rotor coil and the frequency of rotation. They were asked to draw a straight line of best fit to the data and to extrapolate the current in the coil when the motor has stopped rotating (stalled) under mechanical load (9.7 ± 0.3 A). Successful candidates could then go on to use this current to predict the electrical resistance of the rotor coil by evaluating 12 V / 9.7 A to give 1.2 Ω.

Question 40(b)

(b)* This type of d.c. motor is described as a self-regulating device. As more mechanical load is put on the motor it slows down and draws more current from the supply to produce the extra force required.

Use the laws of electromagnetism to explain how this device can act as a self-regulating motor.

....

....

....

....

....

.... **[6]**

This question, worth six marks, asked candidates to explain, using the laws of electromagnetism, how a d.c. motor can act as a self-regulating device. For full credit candidates needed to include a clear explanation of two strands – self-regulating d.c. motor & induced emf and the laws of Faraday and Lenz – and to present the answer as a well-developed line of reasoning which is clear and logically structured. Candidates find electromagnetism a challenging part of the specification and a number gave no response to this part of the question. Of those that did, some were restricted to a Level 1 mark because they only considering one of the strands. The most able candidates wrote well about load slowing the motor, reducing the induced back emf in the coil and allowing more current to flow in from the supply to do the work / increase the torque on the rotor coil, or vice-versa when the load is decreased again. Few candidates scored full marks – to do so they really needed to explain the laws of Faraday ($\varepsilon = - N\,\Delta\Phi / \Delta t$) and Lenz (the opposition implied by the negative sign).

Exemplar 11

motor.

Emf $\propto \frac{\Delta\Phi}{\Delta t}$ the Emf supplied ~~will reduce~~ by electromagnetic induc

$F = BIL$ → As the turning force created by the current carrying wire is being counteracted by the mechanical load, the force will need to be increased, therefore the current will increase within the coil.

Slow down caused due to motor load ∴ $F = BIL$, ∴ more I needed to produce more force as B (mag. field) is constant so can't increase $\frac{\Delta\Phi}{\Delta t}$ → proportional to emf produced.

This response was credited four marks out of six. Whilst there is not the clear explanation required for a Level 3 response, the candidate has covered both strands using a range of Physics ideas. The motor concept, use of F=BIL and the concept of self-regulation are all drawn from Strand 1; consideration of emf and rate of change of flux gives some coverage of Strand 2. The response is credited the higher mark within the level since the line of reasoning is well-developed, clear and logically structured.

Question 41(a)(i)

41 This question is about the electric field around protons.

(a) Two protons are separated by 1.0×10^{-9} m as shown in **Fig. 41.1**. Point **X** is equidistant from each proton as shown.

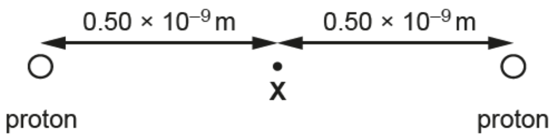


Fig. 41.1 not to scale

(i) Explain why the electric field strength at **X** is zero.

....

....

.... **[1]**

Successful candidates correctly identified that the field strengths at point X from each proton are equal in magnitude but opposite in direction. Weaker responses that were not awarded credit just stated that the forces are equal and opposite without mentioning a test charge or the force per unit charge.

Question 41(a)(ii)

(ii) Calculate the electric potential at **X**.

potential = ... V **[2]**

Candidates were asked to calculate the potential at the mid-way point between the two protons 1.0 nm apart using V = 2kQ / R to give an answer of 5.8 V. A common error was to forget to double the potential due to there being two contributing protons.

Question 41(b)(i)

(b) Imagine a third proton is positioned as shown in **Fig. 41.2**.

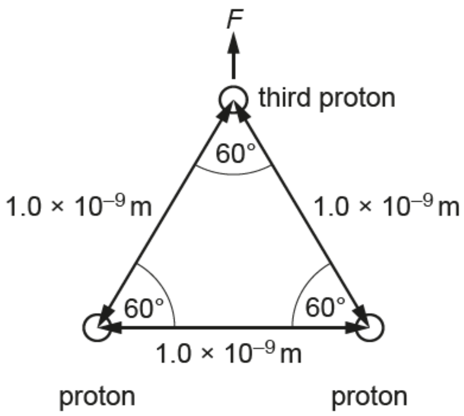


Fig. 41.2 not to scale

(i) Show that the resultant force F on the third proton is about 4×10^{-10} N in the direction shown. Explain your reasoning. You may include a diagram in your answer.

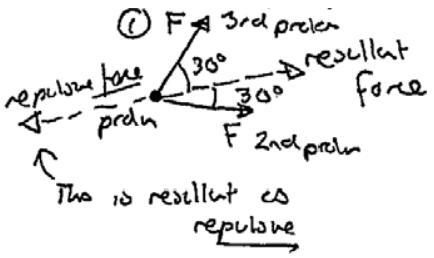
....

....

....

.... **[4]**

Exemplar 12



$F = \frac{kQq}{r^2} = \frac{8.98\times10^9(1.6\times10^{-19})^2}{(1.0\times10^{-9})^2}$ Force due to one proton

$= 2.299\times10^{-10}$

$F_{resultant} = 2F\cos30$

$= 2(2.299\times10^{-10})(\cos30)$

$= 3.981\times10^{-10}$

As all protons positively charged force is repulsive hence outwards.

Resultant force F is component of other two forces both acting at 30° to F.

(see ①). Hence resultant force is outwards and is $F_{from\ 1\ proton}\cos30 \times 2$ (as experiencing forces from 2 other protons) **[4]**

In this part of the question the resultant electrical force on a third symmetrically placed proton was considered. Many candidates were able to score full marks for showing the size of the force is about 4 x 10^{-10} N. Two marks were credited for candidates who were able to calculate the force on the third proton due to one other proton as 2.3 x 10^{-10} N . A third mark was gained, as in this exemplar, by those who, by showing the vector addition of the two forces on a diagram or by using "vertical" components cos 60° or sin 30° of this force, demonstrated that the horizontal components of the forces cancel.

Question 41(b)(ii)

(ii) The separation of protons in a lithium $^{6}_{3}$Li nucleus is of the order of 10^{-15} m. Estimate the magnitude of the resultant electric force on a proton in the nucleus if the protons are arranged symmetrically as in **Fig. 41.2**.

force = ... N **[2]**

Many lower ability candidates omitted this final stretch and challenge question. Candidates were asked to consider the three protons in a $^{6}Li_{3}$ nucleus and the electrical force of repulsion on them. Better candidates realised it was the same problem as in part b(i) only scaled down in distance by 10^{-6} so they could reason that, as the force goes up with 1/ R^{2} and it therefore scaled by 1 / $(10^{-6})^{2}$ = 10^{12} . Errors carried forward from part b(i) were allowed as was the use of the "show that" value given of 4 x 10^{-10} N to obtain an answer of 400 N.

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