IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

Physics
Higher level and standard level

Specimen paper 1s, 2s and 3s

For first examinations in 2009

CONTENTS

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

PHYSICS
HIGHER LEVEL
PAPER 1

SPECIMEN PAPER

1 hour

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Answer all the questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.

1. The volume V of a cylinder of height h and radius r is given by the expression

$$V = \pi r^2 h.$$

In a particular experiment, r is to be determined from measurements of V and h. The uncertainties in V and in h are as shown below.

V	$\pm 7\%$
h	$\pm 3\%$

The approximate uncertainty in r is

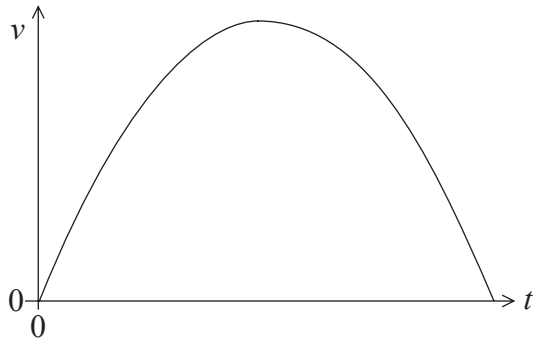
A. 10%.

B. 5%.

C. 4%.

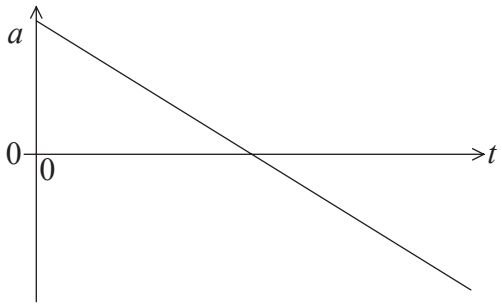
D. 2%.

2. The graph below shows the variation with time t of the velocity v of an object moving on a straight-line.

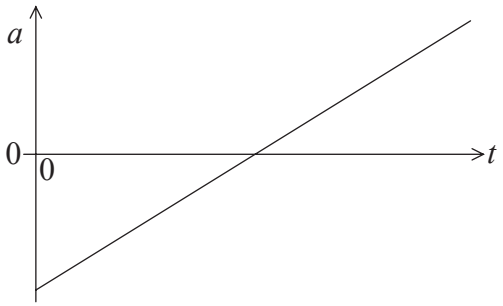


Which of the graphs below best represents the variation with time t of the acceleration a of the object?

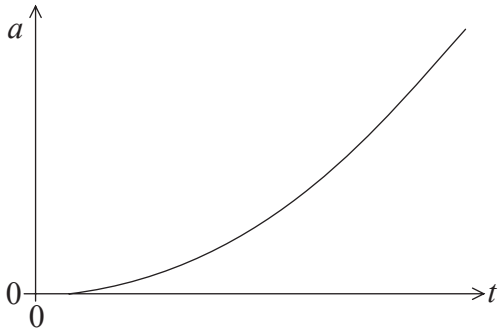
A.



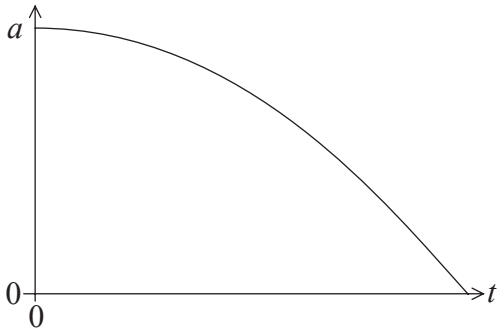
B.



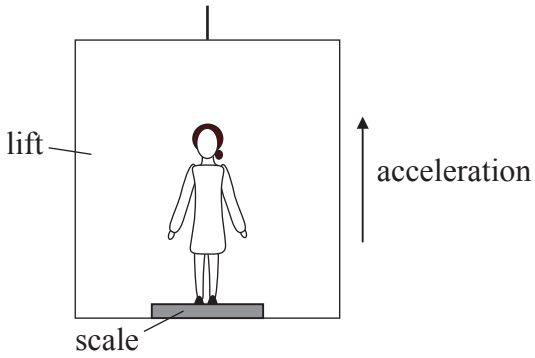
C.



D.



3. Mandy stands on a weighing scale inside a lift (elevator) that accelerates vertically upwards as shown in the diagram below. The forces on Mandy are her weight W and the reaction force from the scale R.



The reading of the scale is

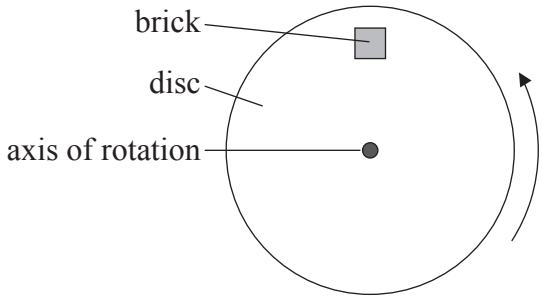
A. $R+W$.

B. W.

C. R.

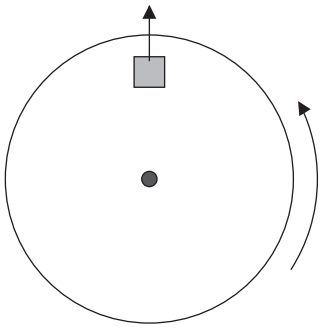
D. $R-W$.

4. A brick is placed on the surface of a flat horizontal disc as shown in the diagram below. The disc is rotating at constant speed about a vertical axis through its centre. The brick does not move relative to the disc.

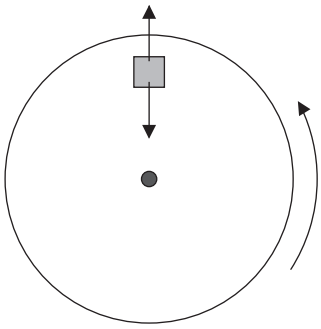


Which of the diagrams below correctly represents the **horizontal** force or forces acting on the brick?

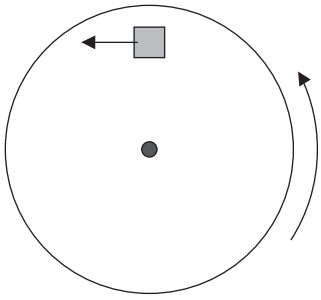
A.



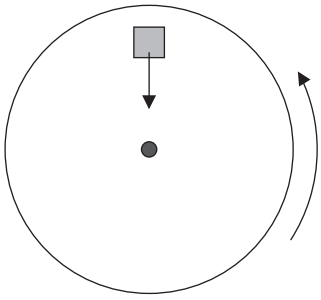
B.



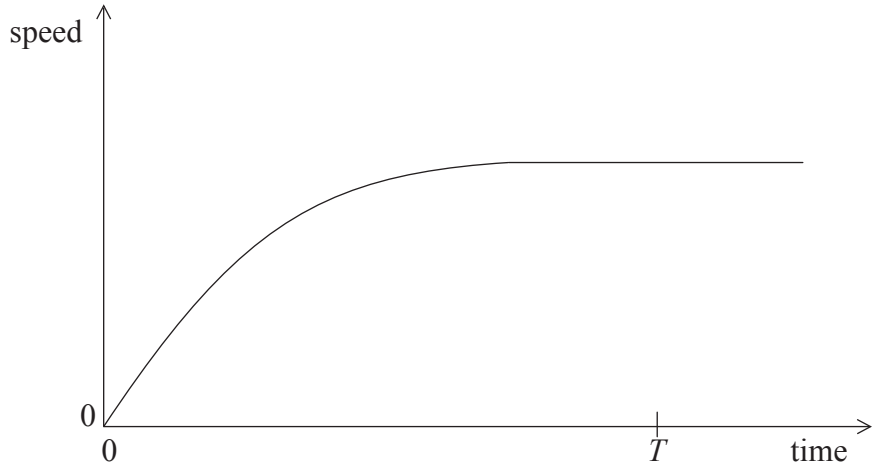
C.



D.



5. The variation with time of the vertical speed of a ball falling in air is shown below.



During the time from 0 to T, the ball gains kinetic energy and loses gravitational potential energy ΔE_p. Which of the following statements is true?

A. ΔE_p is equal to the gain in kinetic energy.

B. ΔE_p is greater than the gain in kinetic energy.

C. ΔE_p is equal to the work done against air resistance.

D. ΔE_p is less than the work done against air resistance.

6. A satellite is in orbit about Earth. The satellite moves to an orbit closer to Earth. Which of the following correctly gives the change in the potential energy and the kinetic energy of the satellite?

	change in potential energy	**change in kinetic energy**
A.	decreases	increases
B.	decreases	decreases
C.	increases	increases
D.	increases	decreases

7. A spacecraft orbits Earth. An astronaut inside the spacecraft feels "weightless" because

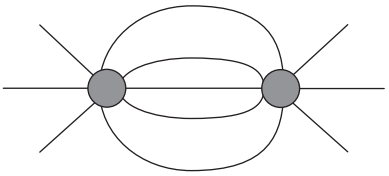
A. the gravitational field in the spacecraft is negligible.

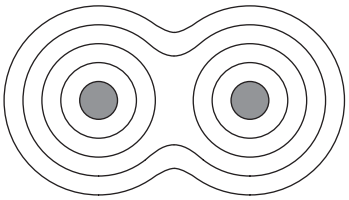
B. the Earth exerts equal forces on the spacecraft and the astronaut.

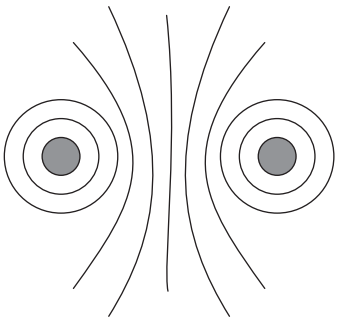
C. the spacecraft and the astronaut have the same acceleration towards the Earth.

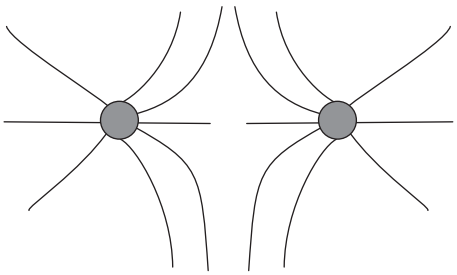
D. the spacecraft and the astronaut exert equal and opposite forces on each other.

8. Which of the following diagrams best represents the gravitational equipotential surfaces due to two equal spherical masses?

A. 

B. 

C. 

D. 

9. The internal energy of a solid substance is equal to the

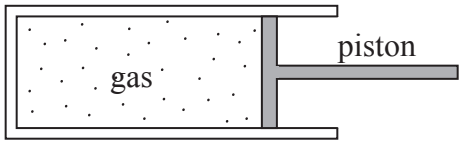
A. average kinetic energy of the molecules.

B. total kinetic energy of the molecules.

C. total potential energy of the molecules.

D. total potential and total kinetic energy of the molecules.

10. A gas is contained in a cylinder fitted with a piston as shown below.



When the gas is compressed rapidly by the piston its temperature rises **because** the molecules of the gas

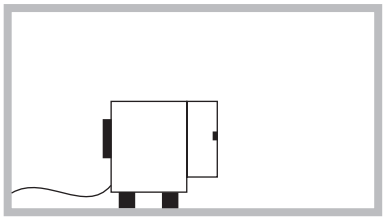
A. are squeezed closer together.

B. collide with each other more frequently.

C. collide with the walls of the container more frequently.

D. gain energy from the moving piston.

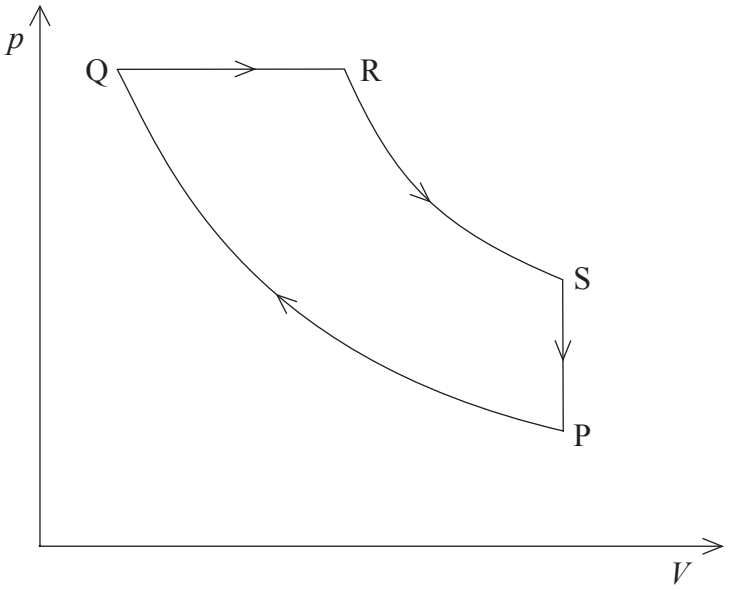
11. An operating refrigerator with its door open is placed in a thermally insulated room.



The refrigerator operates for a long period of time. Which of the following correctly gives the change in temperature and the entropy of the air in the room?

	Temperature	**Entropy**
A.	increases	increases
B.	increases	decreases
C.	decreases	decreases
D.	decreases	increases

12. The diagram shows the pressure / volume (p/V) diagram for one cycle PQRS of an engine.



In which sections of the cycle is work done **on** the engine?

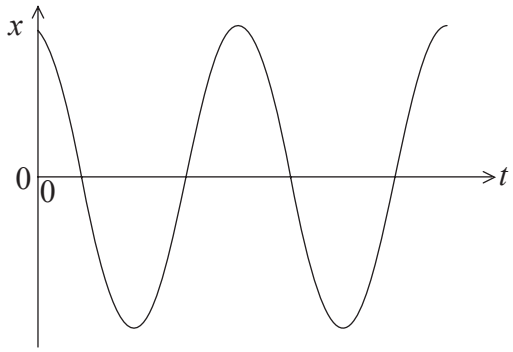
A. SP only

B. PQ only

C. SP and PQ only

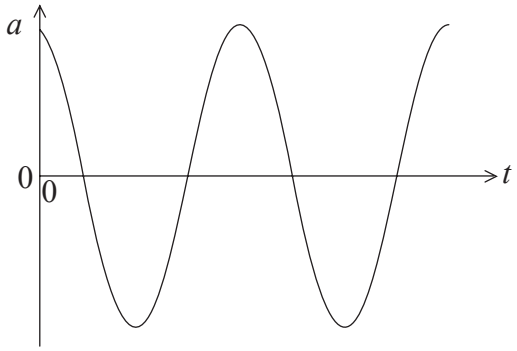
D. RS and SP only

13. The graph below shows the variation with time t of the displacement x of a particle undergoing simple harmonic motion.

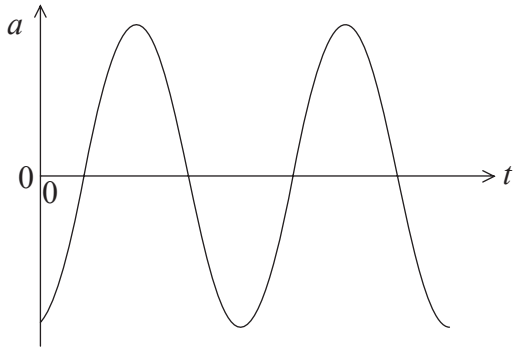


Which graph correctly shows the variation with time t of the acceleration a of the particle?

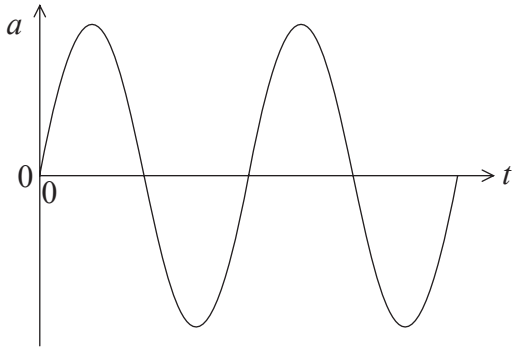
A.



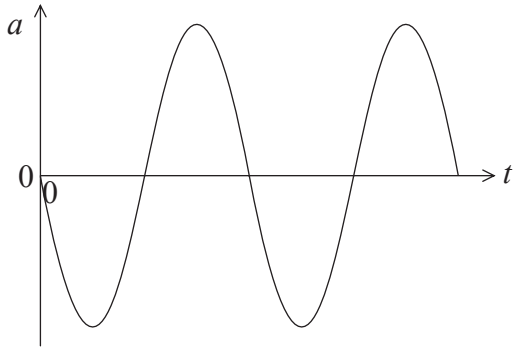
B.



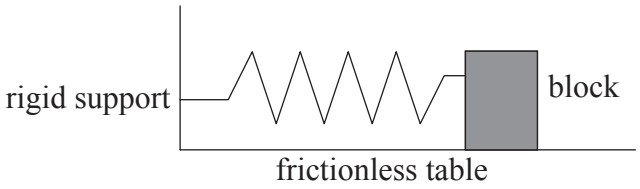
C.



D.



14. A wooden block is at rest on a horizontal frictionless surface. A horizontal spring is attached between the block and a rigid support.

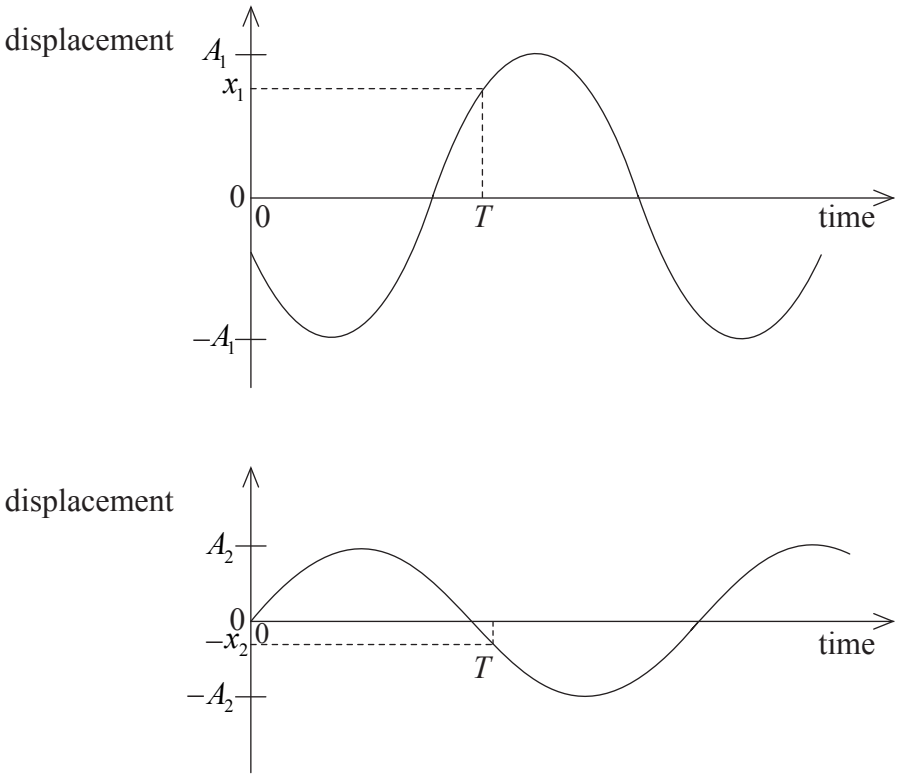


The block is displaced to the right by an amount X and is then released. The period of oscillations is T and the total energy of the system is E.

For an initial displacement of $\frac{X}{2}$ which of the following is the best estimate for the period of oscillations and the total energy of the system?

	Period	Total energy
A.	T	$\frac{E}{2}$
B.	T	$\frac{E}{4}$
C.	$\frac{T}{2}$	$\frac{E}{2}$
D.	$\frac{T}{2}$	$\frac{E}{4}$

15. The two graphs show the variation with time of the individual displacements of two waves as they pass through the same point.



The displacement of the resultant wave at the point at time T is equal to

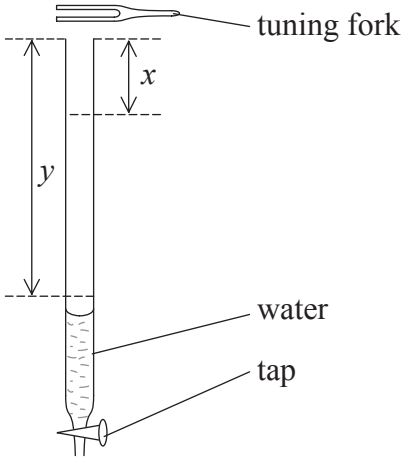
A. $x_1 + x_2$.

B. $x_1 - x_2$.

C. $A_1 + A_2$.

D. $A_1 - A_2$.

16. A tube is filled with water and a vibrating tuning fork is held above its open end.



The tap at the base of the tube is opened. As the water runs out, the sound is loudest when the water level is a distance x below the top of the tube. A second loud sound is heard when the water level is a distance y below the top. Which of the following is a correct expression for the wavelength λ of the sound produced by the tuning fork?

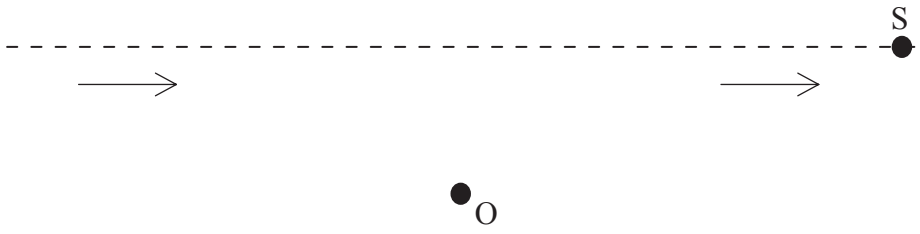
A. $\lambda = y$

B. $\lambda = 2x$

C. $\lambda = y - x$

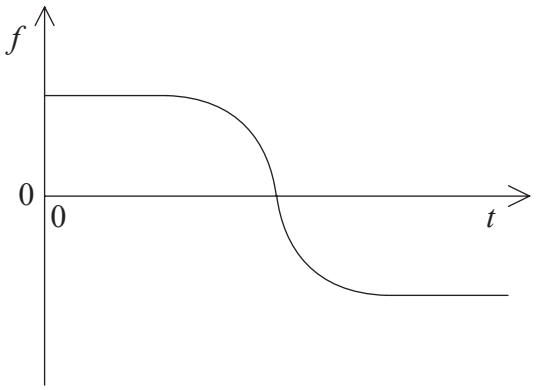
D. $\lambda = 2(y - x)$

17. A source S, moving at constant speed, emits a sound of constant frequency. The source passes by a stationary observer O, as shown below.

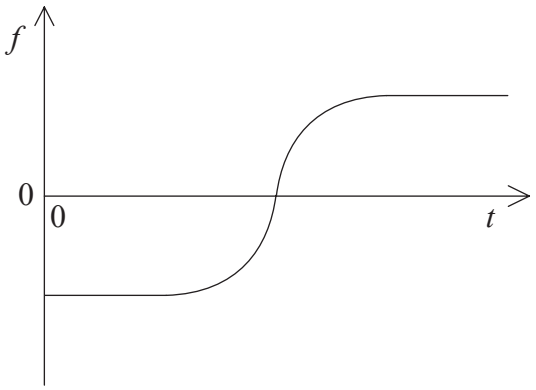


Which of the following shows the variation with time t of the frequency f observed at O as the source S approaches and passes by the observer?

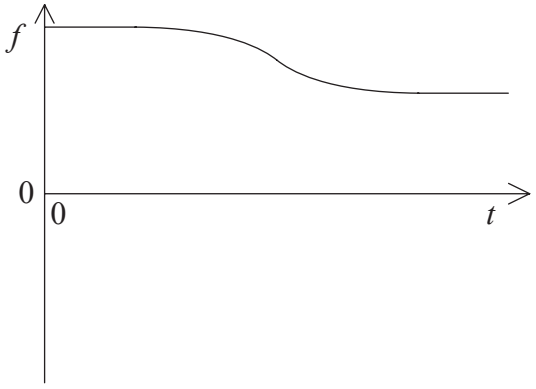
A.



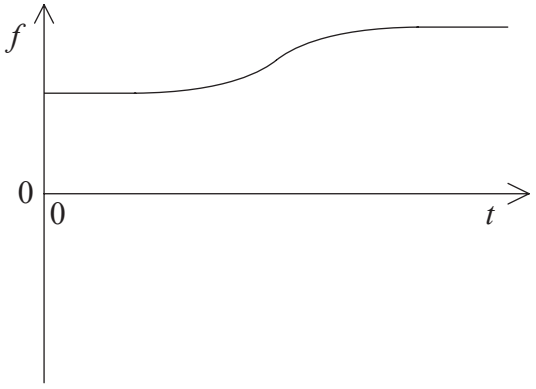
B.



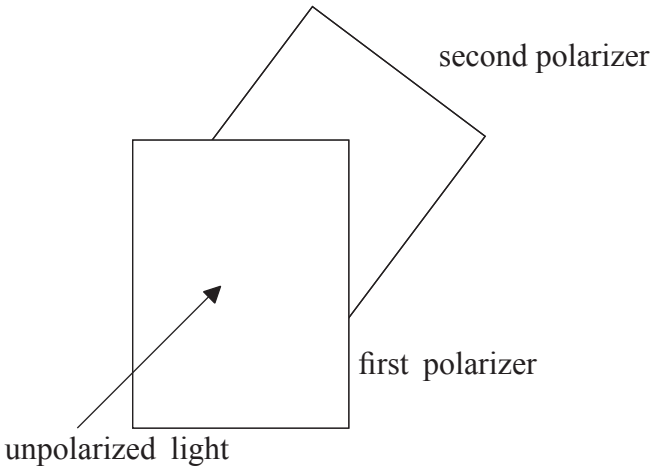
C.



D.



18. Unpolarized light of intensity I_0 is incident on a polarizer. The transmitted light is then incident on a second polarizer. The axis of the second polarizer makes an angle of 60° to the axis of the first polarizer.



The cosine of 60° is $\frac{1}{2}$. The intensity of the light transmitted through the second polarizer is

A. I_0.

B. $\frac{I_0}{2}$.

C. $\frac{I_0}{4}$.

D. $\frac{I_0}{8}$.

19. Two binary stars emit radio waves of wavelength $6.0\times10^{-2}\,\text{m}$. The waves are received by a radio telescope whose collecting dish has a diameter of 120 m. The two stars are just resolved if their **minimum** angular separation in radians is of the order of

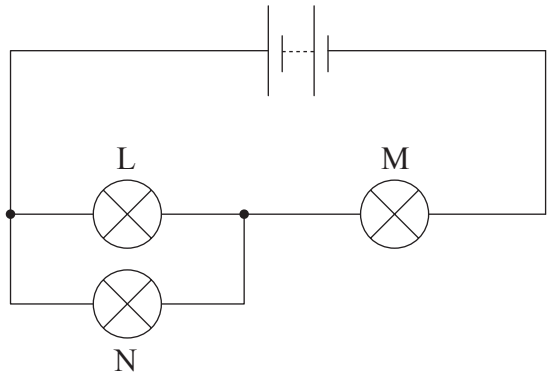
A. 2×10^{4}.

B. 2×10^{2}.

C. 5×10^{-2}.

D. 5×10^{-4}.

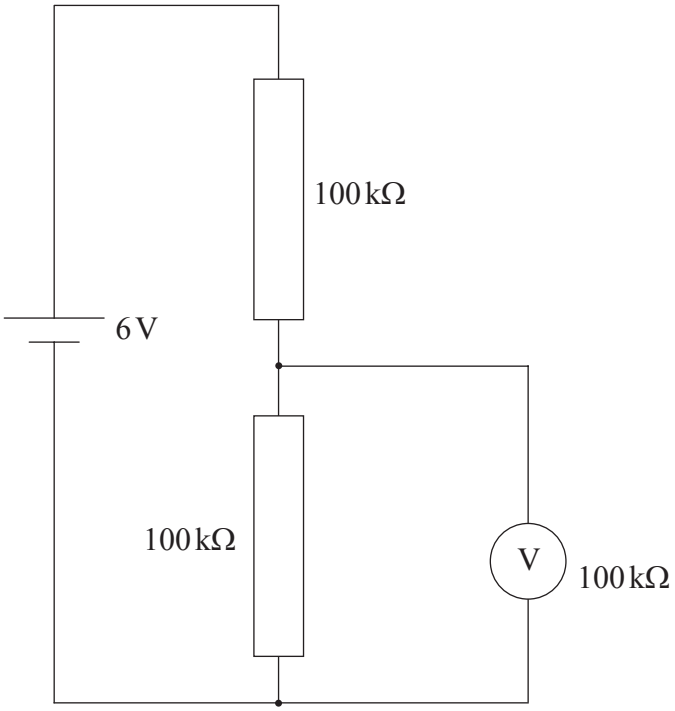
20. In the circuit below, the battery has negligible internal resistance. Three identical lamps L, M and N of constant resistance are connected as shown.



The filament of lamp N breaks. Which of the following shows the subsequent changes to the brightness of lamp L and lamp M?

	Lamp L	**Lamp M**
A.	stays the same	decreases
B.	increases	stays the same
C.	increases	decreases
D.	decreases	increases

21. In the circuit below, the voltmeter has a resistance 100 kΩ. The battery has negligible internal resistance and e.m.f. 6 V.



The reading on the voltmeter is

A. 0 V.

B. 2 V.

C. 3 V.

D. 4 V.

22. The electric field strength at a point may be defined as

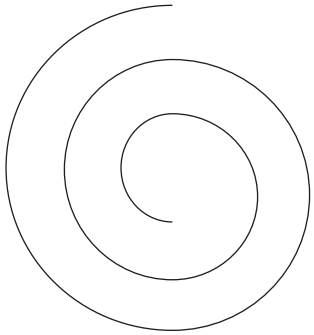
A. the force exerted on unit positive charge placed at that point.

B. the force per unit positive charge on a small test charge placed at that point.

C. the work done on unit positive charge to move the charge to that point from infinity.

D. the work done per unit positive charge to move a small test charge to that point from infinity.

23. An electron is moving in air at right angles to a uniform magnetic field. The diagram below shows the path of the electron. The electron is slowing down.



region of magnetic field

Which of the following correctly gives the direction of motion of the electron and the direction of the magnetic field?

	Direction of motion	Direction of magnetic field
A.	clockwise	into plane of paper
B.	clockwise	out of plane of paper
C.	anti-clockwise	into plane of paper
D.	anti-clockwise	out of plane of paper

24. An AC generator produces a voltage of **peak** value V. The frequency of rotation of the coil of the generator is doubled. The **r.m.s.** value of the voltage produced is

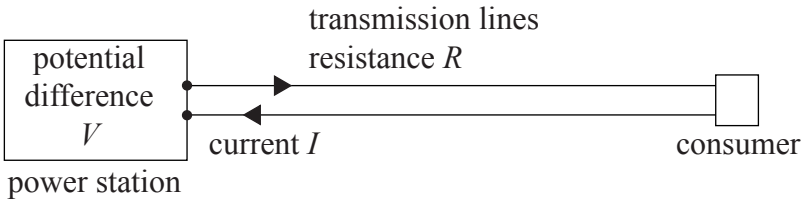
A. $\frac{V}{2\sqrt{2}}$.

B. $\frac{V}{\sqrt{2}}$.

C. $V\sqrt{2}$.

D. $2V\sqrt{2}$.

25. A power station generates electrical energy at a potential difference V and current I. The resistance of the transmission lines between the power station and the consumer is R.



The power lost in the transmission lines is

A. 0.

B. $\frac{V^2}{R}$.

C. RI^2.

D. VI.

26. Which of the following provides evidence for de Broglie's hypothesis concerning matter waves?

A. Electron diffraction

B. Atomic energy levels

C. Nuclear energy levels

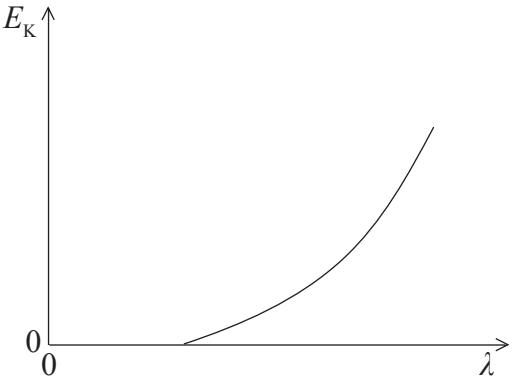
D. The photoelectric effect

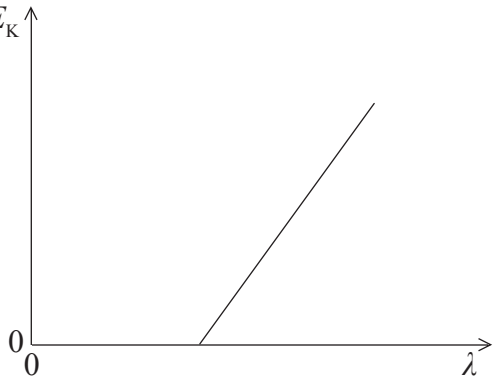
27. Which of the following correctly identifies the mass and momentum of a photon?

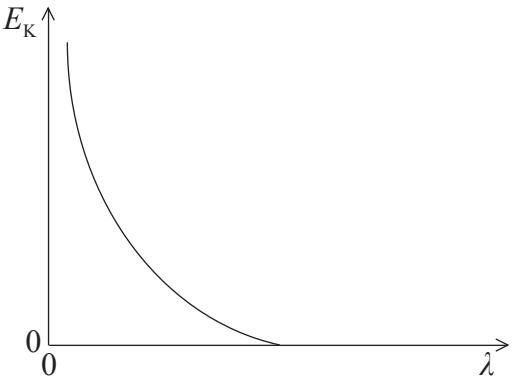
	Mass	**Momentum**
A.	zero	zero
B.	zero	non-zero
C.	non-zero	zero
D.	non-zero	non-zero

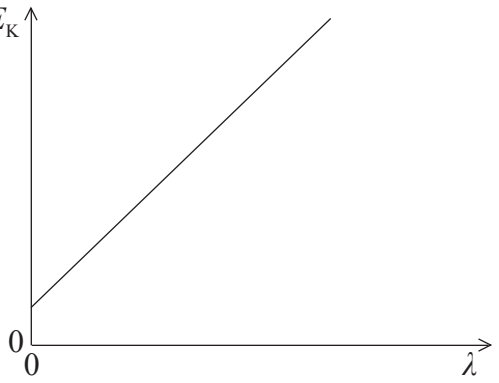
28. Light of wavelength λ is incident on a metal surface in a vacuum. Photoelectrons are emitted from the surface of the metal.

Which of the following best shows the variation with λ of the maximum kinetic energy E_K of the emitted electrons?

A.


B.


C.


D.


29. The binding energy per nucleon of the nucleus $^{7}_{3}\text{Li}$ is approximately 5 MeV. The total energy required to completely separate the nucleons of this nucleus is approximately

A. 15 MeV.

B. 20 MeV.

C. 35 MeV.

D. 50 MeV.

30. A radioactive isotope has a half-life of five minutes. A particular nucleus of this isotope has **not** decayed within a time interval of five minutes. A correct statement about the **next** five minute interval is that this nucleus

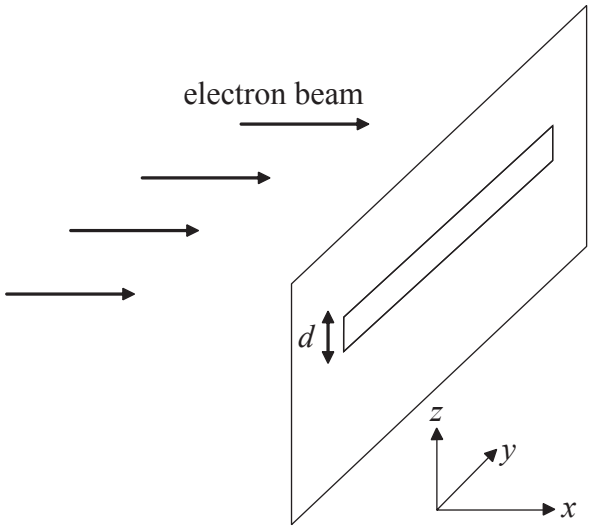
A. has a lower than 50 % chance of decaying.

B. will certainly decay.

C. has a 50 % chance of decaying.

D. has a better than 50 % chance of decaying.

31. A beam of electrons of uniquely defined wavelength λ is incident on an aperture of height d. The beam is traveling along the x direction. The height d is of the same order as λ.

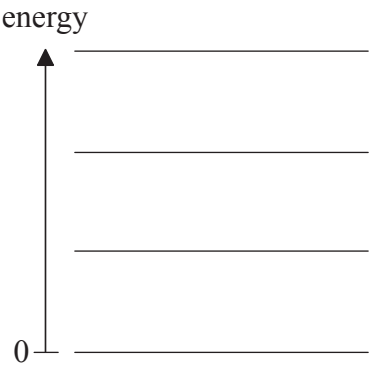


After passing through the aperture, the component of momentum in the x direction is p_x and the component in z the direction is p_z. Which of the following shows the uncertainty in p_x and the uncertainty in p_z?

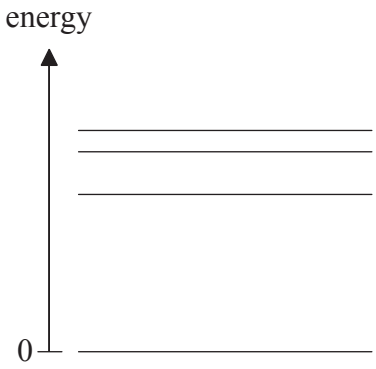
	Δp_x	Δp_z
A.	0	0
B.	0	$\frac{h}{4\pi d}$
C.	$\frac{h}{4\pi d}$	0
D.	$\frac{h}{4\pi d}$	$\frac{h}{4\pi d}$

32. A free electron is confined within a one dimensional region of fixed length. Which of the diagrams below shows the four lowest energy levels of the electron?

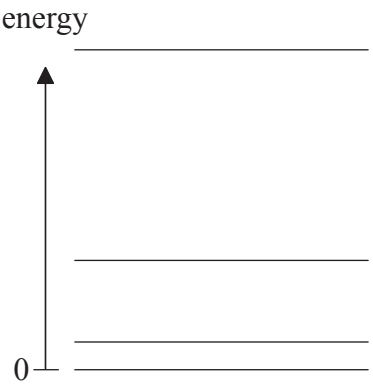
A.



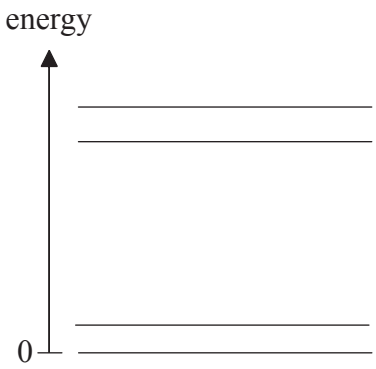
B.



C.



D.



33. Which of the following correctly describes the nature of the energy spectra of alpha (α), beta (β), and gamma (γ) radiation?

	α	**β**	**γ**
A.	discrete	continuous	discrete
B.	continuous	discrete	discrete
C.	discrete	discrete	continuous
D.	continuous	continuous	discrete

34. The volume of a given mass of water at a temperature of T_1 is V_1. The volume increases to V_2 at temperature T_2. The coefficient of volume expansion of water may be calculated from

A. $\frac{V_2}{T_2} - \frac{V_1}{T_1}$.

B. $\frac{V_2 - V_1}{T_2 - T_1}$.

C. $\frac{V_2 - V_1}{V_1(T_2 - T_1)}$.

D. $\frac{V_2 - V_1}{V_2(T_2 - T_1)}$.

35. A wind generator produces 5.0 kW of power for a wind speed of $6.0\,\text{m s}^{-1}$. The best estimate for the power produced for a wind speed of $12.0\,\text{m s}^{-1}$ is

A. 10 kW.

B. 25 kW.

C. 40 kW.

D. 125 kW.

36. It is hypothesized that global warming may lead to significant changes in the average sea-level. This hypothesis assumes that

A. average rainfall will increase.

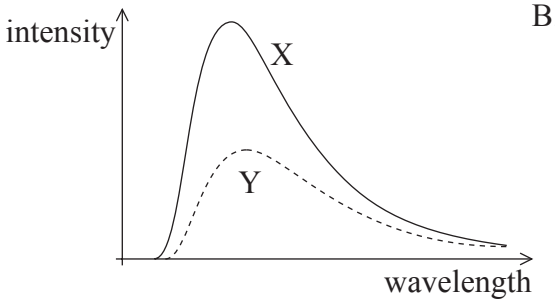
B. icebergs will melt.

C. glaciers will melt.

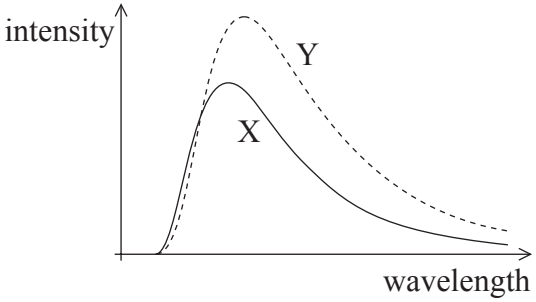
D. the rate of evaporation of seawater will increase.

37. Two black bodies X and Y are at different temperatures. The temperature of body Y is higher than that of body X. Which of the following shows the black body spectra for the two bodies?

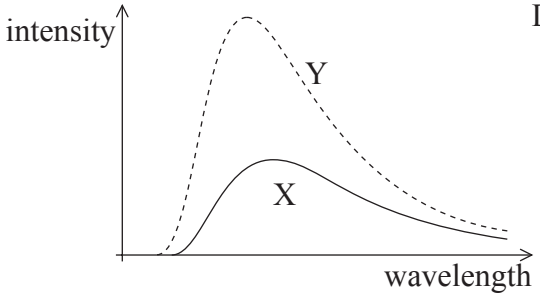
A.



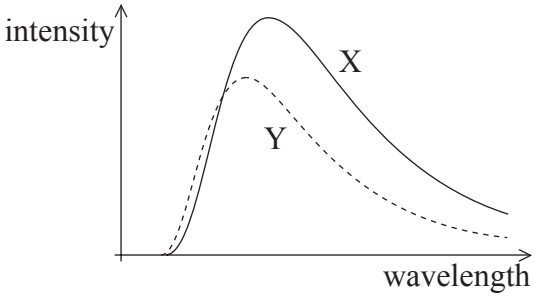
B.



C.



D.



38. The binary equivalent of the number 12 is

A. 1010.

B. 1100.

C. 0011.

D. 0101.

39. The depth of a "pit" on a CD is 150 nm. The wavelength of the laser used to read the information on the CD must be

A. 600 nm.

B. 450 nm.

C. 300 nm.

D. 150 nm.

40. The amount of charge that builds on a pixel in a charged coupled device (CCD) is proportional to which property of the incident light?

A Intensity

B. Wavelength

C. Frequency

D. Amplitude

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/HPM/ENG/TZ0/XX/M

MARKSCHEME

SPECIMEN PAPER

PHYSICS

Higher Level

Paper 1

2 pages

1.	B	16.	D	31.	B	46.	–
2.	A	17.	C	32.	C	47.	–
3.	C	18.	D	33.	A	48.	–
4.	D	19.	D	34.	C	49.	–
5.	B	20.	C	35.	C	50.	–
6.	A	21.	B	36.	C	51.	–
7.	C	22.	B	37.	C	52.	–
8.	B	23.	D	38.	B	53.	–
9.	D	24.	C	39.	A	54.	–
10.	D	25.	C	40.	A	55.	–
11.	A	26.	A	41.	–	56.	–
12.	B	27.	B	42.	–	57.	–
13.	B	28.	C	43.	–	58.	–
14.	B	29.	C	44.	–	59.	–
15.	B	30.	C	45.	–	60.	–

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

PHYSICS
HIGHER LEVEL
PAPER 2

SPECIMEN PAPER

2 hours 15 minutes

Candidate session number

0	0							

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer two questions from Section B in the spaces provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet.

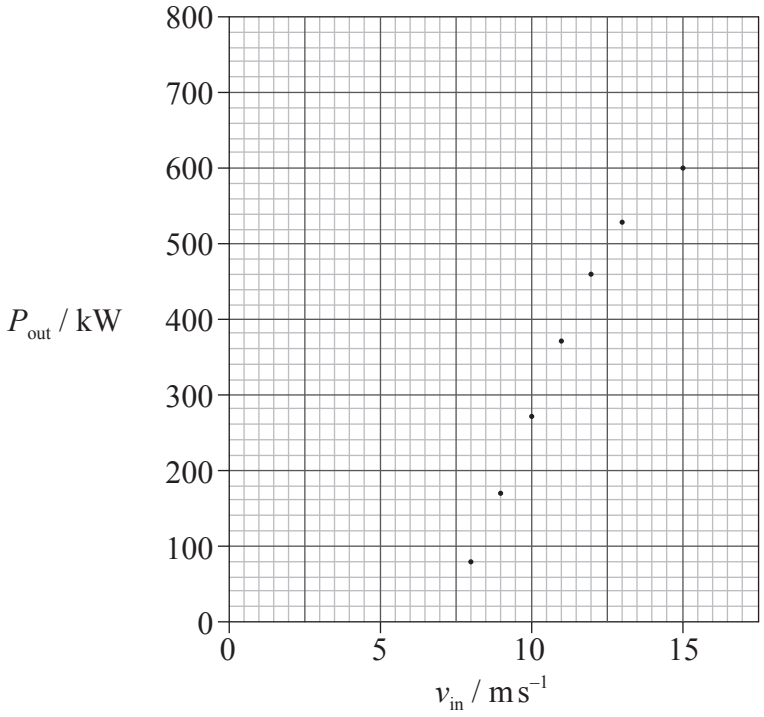
SECTION A

*Answer **all** the questions in the spaces provided.*

A1. This question is about the electrical power available from a wind turbine.

The maximum electrical power generated by a wind turbine, P_{out}, was measured over a range of incident wind speeds, v_{in}.

The graph below shows the variation with v_{in} of P_{out}. Uncertainties for the data are not shown.



(a) It is suggested that P_{out} is proportional to $\sqrt{v_{in}}$.

(i) Draw the line of best-fit for the data points. *[1]*

(ii) State **one** reason why the line you have drawn does not support this hypothesis. *[1]*

. . . . . .

. . . . . .

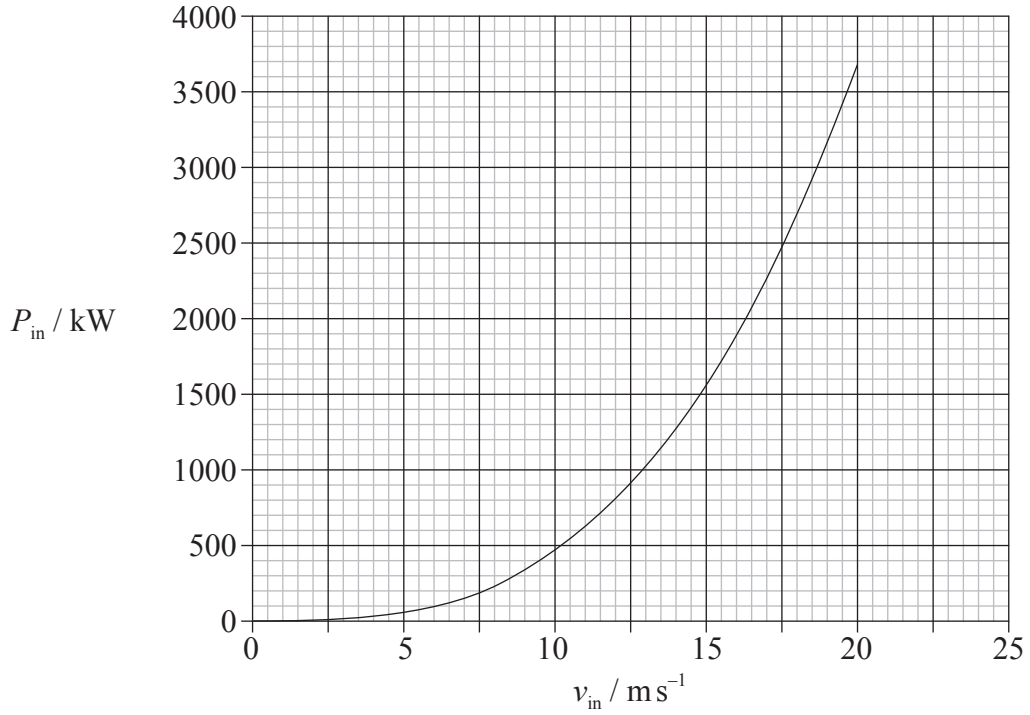
. . . . . .

(iii) The uncertainty in the power at 15 m s^{-1} is 5 %. Draw an error bar on the graph to represent this uncertainty. *[2]*

(This question continues on the following page)

(Question A1 continued)

(b) The theoretical relationship between the available power in the wind, P_{in}, and incident wind speed is shown in the graph below.



Using both graphs,

(i) determine the efficiency of the turbine for an incident wind speed of 14 m s^{-1}. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) suggest, without calculation, how the efficiency of the turbine changes with increasing wind speed. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question A1 continued)

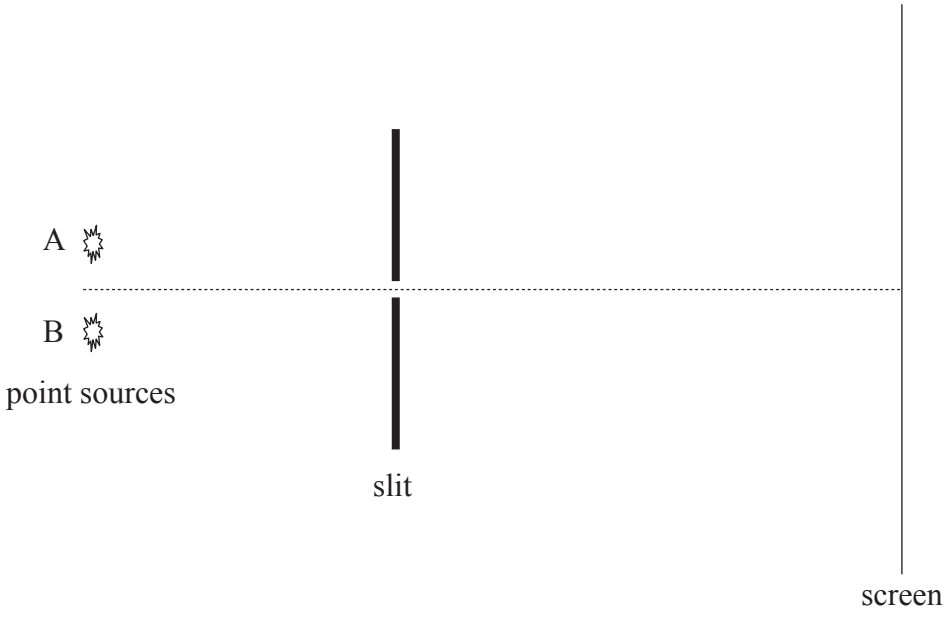
(c) Outline **one** advantage and **one** disadvantage of using wind turbines to generate electrical energy. *[2]*

Advantage: . . . . . .
. . . . . .
. . . . . .
. . . . . .

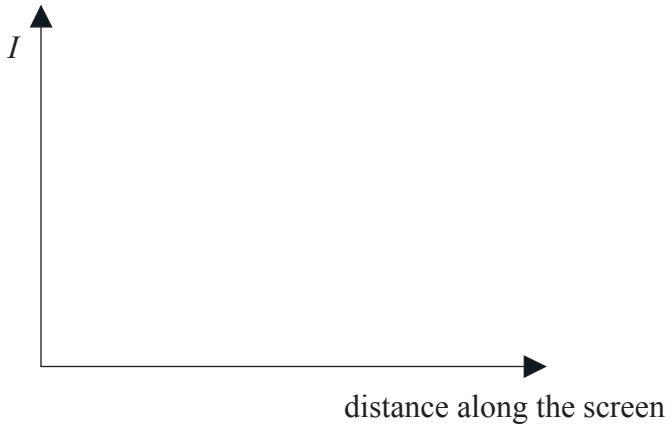
Disadvantage: . . . . . .
. . . . . .
. . . . . .
. . . . . .

A2. This question is about optical resolution.

The two point sources shown in the diagram below (not to scale) emit light of the same frequency. The light is incident on a rectangular narrow slit and, after passing through the slit, is brought to a focus on the screen.



(a) Point source B is covered. Using the axes below, sketch a graph to show how the intensity I of the light from point source A varies with distance along the screen. Label the curve you have drawn A. *[2]*



(b) Point source B is now uncovered. The images of A and B on the screen are just resolved. Using the axes above, sketch a graph to show how the intensity I of the light from point source B varies with distance along the screen. Label this curve B. *[1]*

(This question continues on the following page)

(Question A2 continued)

(c) The bright star Sirius A is accompanied by a much fainter star, Sirius B. The mean distance of the stars from Earth is 8.1×10^{16} m. Under ideal atmospheric conditions, a telescope with an objective lens of diameter 25 cm can just resolve the stars as two separate images.

Assuming that the average wavelength emitted by the stars is 500 nm, estimate the apparent, linear separation of the two stars. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

A3. This question is about polarization and liquid crystals.

(a) A liquid crystal has the property of being able to rotate the plane of polarization of light. Explain what is meant by the expression "able to rotate the plane of polarization of light". *[2]*

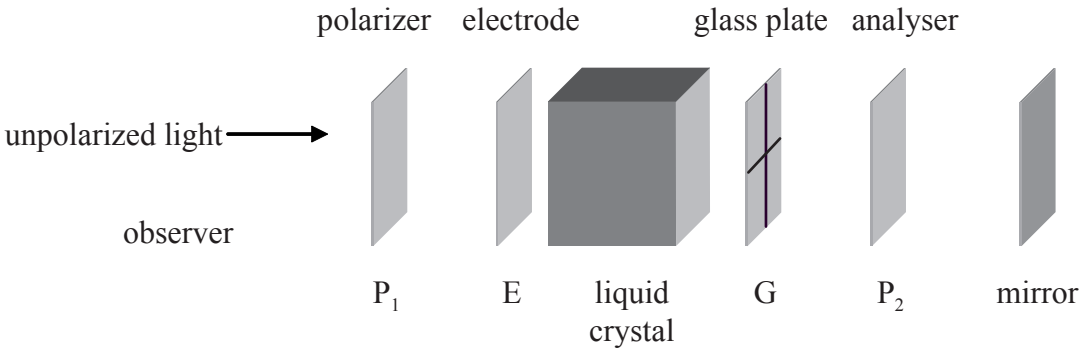
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The diagram below is a representation of a liquid crystal display.



P_1 is a polarizer and P_2 is an analyser. The transmission axis of P_2 is at right angles to that of P_1. E is an electrode. G is a glass plate upon which a shaped electrode is etched. Unpolarized light is incident on P_1.

(i) State, and explain, what the observer would see if the liquid crystal were not present. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Outline how the application of a potential difference between E and the electrode etched on G enables the observer to see the shape of the electrode. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

A4. This question is about an ideal gas.

(a) The pressure P of a fixed mass of an ideal gas is directly proportional to the kelvin temperature T of the gas. That is,

$$P \propto T .$$

State the relation between the

(i) pressure P and the volume V for a change at constant temperature. *[1]*

. . . . . .

. . . . . .

(ii) volume V and kelvin temperature T for a change at a constant pressure. *[1]*

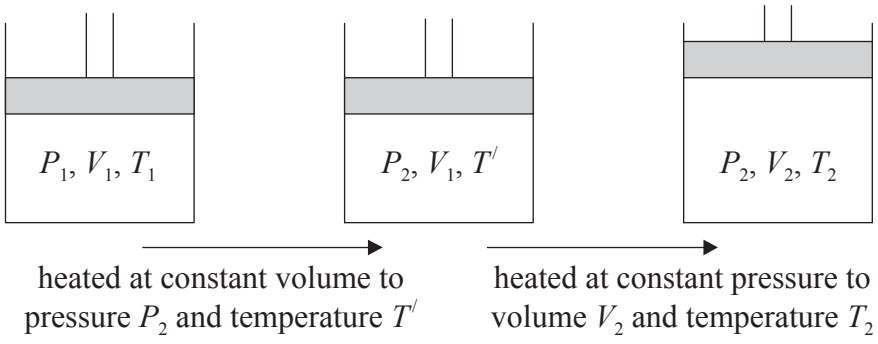
. . . . . .

. . . . . .

(This question continues on the following page)

(Question A4 continued)

(b) The ideal gas is held in a cylinder by a moveable piston. The pressure of the gas is P_1, its volume is V_1 and its kelvin temperature is T_1. The pressure, volume and temperature are changed to P_2, V_2 and T_2 respectively. The change is brought about as illustrated below.



State the relation between

(i) P_1, P_2, T_1 and T'. *[1]*

. . . . . .

. . . . . .

(ii) V_1, V_2, T' and T_2. *[1]*

. . . . . .

. . . . . .

(c) Use your answers to (b) to deduce, that for an ideal gas

$$PV=KT,$$

where K is a constant. *[4]*

. . . . . .

. . . . . .

. . . . . .

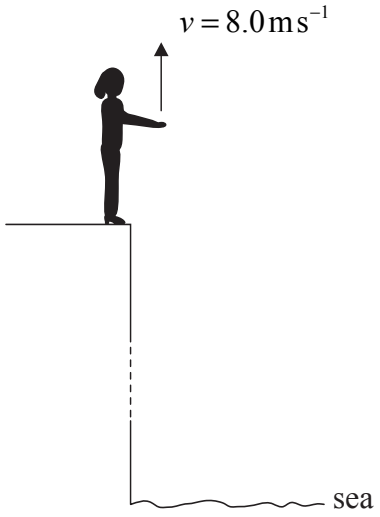
. . . . . .

. . . . . .

. . . . . .

A5. This question is about throwing a stone from a cliff.

Antonia stands at the edge of a vertical cliff and throws a stone vertically upwards.



The stone leaves Antonia's hand with a speed $v = 8.0\,\text{m s}^{-1}$. Ignore air resistance, the acceleration of free fall g is $10\,\text{m s}^{-2}$ and all distance measurements are taken from the point where the stone leaves Antonia's hand.

(a) Determine,

(i) the maximum height reached by the stone. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) the time taken by the stone to reach its maximum height. *[1]*

. . . . . .

. . . . . .

(b) The time between the stone leaving Antonia's hand and hitting the sea is 3.0 s. Determine the height of the cliff. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

A6. This question is about gravitational fields.

(a) Define *gravitational field strength*. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) The gravitational field strength at the surface of Jupiter is $25\,\text{N}\,\text{kg}^{-1}$ and the radius of Jupiter is $7.1\times10^{7}\,\text{m}$.

(i) Derive an expression for the gravitational field strength at the surface of a planet in terms of its mass M, its radius R and the gravitational constant G. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Use your expression in (b)(i) above to estimate the mass of Jupiter. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

SECTION B

*This section consists of four questions: B1, B2, B3 and B4. Answer **two** questions.*

B1. This question is in **two** parts. **Part 1** is about simple harmonic motion and its connection with the greenhouse effect. **Part 2** is about a charge coupled device (CCD).

Part 1 Simple harmonic motion and the greenhouse effect

(a) A body is displaced from equilibrium. State the **two** conditions necessary for the body to execute simple harmonic motion. *[2]*

1. . . . . .

. . . . . .

2. . . . . .

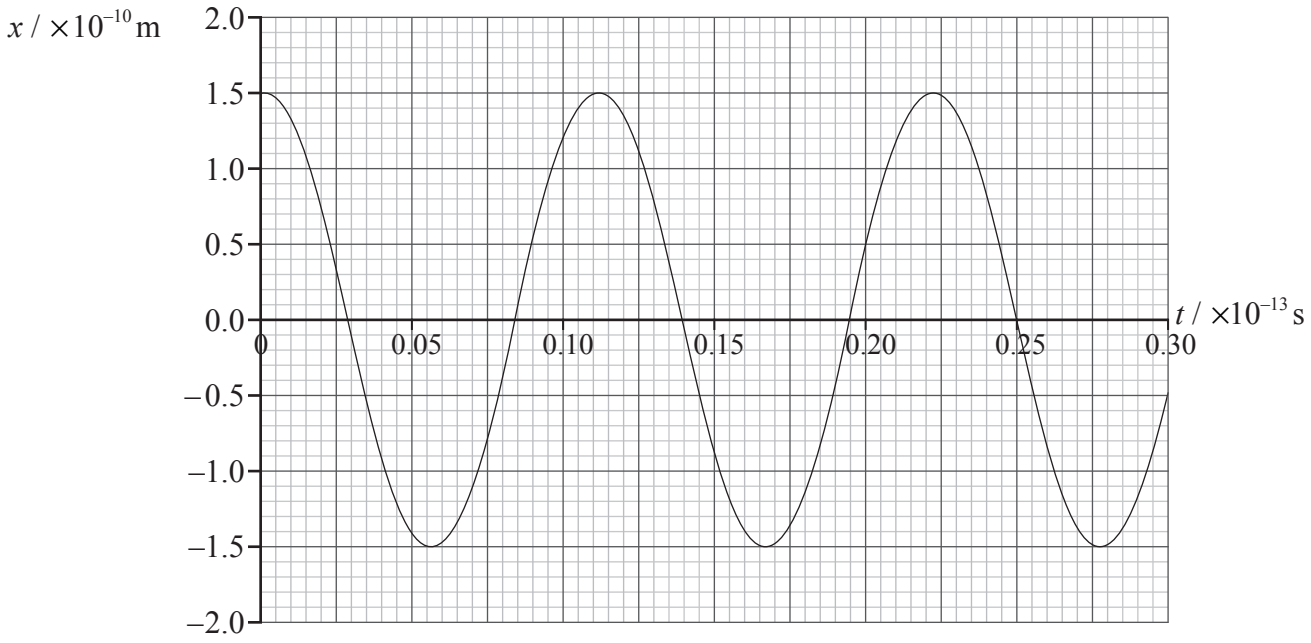
. . . . . .

(This question continues on the following page)

(Question B1, part 1 continued)

(b) In a simple model of a methane molecule, a hydrogen atom and the carbon atom can be regarded as two masses attached by a spring. A hydrogen atom is much less massive than the carbon atom such that any displacement of the carbon atom may be ignored.

The graph below shows the variation with time t of the displacement x from its equilibrium position of a hydrogen atom in a molecule of methane.



The mass of hydrogen atom is 1.7×10^{-27} kg. Use data from the graph above

(i) to determine its amplitude of oscillation. *[1]*

. . . . . .

(ii) to show that the frequency of its oscillation is 9.1×10^{13} Hz. *[2]*

. . . . . .

. . . . . .

(iii) to show that the maximum kinetic energy of the hydrogen atom is 6.2×10^{-18} J. *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 1 continued)

(c) Assuming that the motion of the hydrogen atom is simple harmonic, its frequency of oscillation f is given by the expression

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_p}},$$

where k is the force per unit displacement between a hydrogen atom and the carbon atom and m_p is the mass of a proton.

(i) Show that the value of k is approximately $560\,\text{N m}^{-1}$. *[1]*

. . . . . .

. . . . . .

(ii) Estimate, using your answer to (c)(i), the maximum acceleration of the hydrogen atom. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(d) Methane is classified as a greenhouse gas.

(i) Describe what is meant by a greenhouse gas. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Electromagnetic radiation of frequency $9.1\times10^{13}\,\text{Hz}$ is in the infrared region of the electromagnetic spectrum. Suggest, based on the information given in (b)(ii), why methane is classified as a greenhouse gas. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1 continued)

Part 2 Charge coupled device (CCD)

(a) A digital camera is used to take a photograph of a plant. The CCD in the camera has 1.6×10^{7} square pixels. Each pixel has an area of $2.3\times10^{-10}\,m^2$. A particular leaf of the plant has an area of $2.5\times10^{-2}\,m^2$. The image of the leaf formed on the CCD is $1.0\times10^{-3}\,m^2$. Two indentations on the leaf are separated by 0.50 mm. Deduce whether the images of the two indentations will be resolved. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Light is incident on the image collection area for a time of 100 ms. The number of photons incident on one pixel is 5.5×10^{4}. Each pixel has a quantum efficiency of 80 % and a capacitance 40 pF.

(i) State what is meant by quantum efficiency. *[1]*

. . . . . .

. . . . . .

(ii) Estimate the change in potential difference across each pixel. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 2 continued)

(c) Outline how the variation in potential difference across individual pixels enables a black and white image to be produced by a digital camera. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

B2. This question is in **two** parts. **Part 1** is about nuclear power production. **Part 2** is about electromagnetic induction.

Part 1 Nuclear power production

(a) With reference to the concept of fuel enrichment in a nuclear reactor explain,

(i) the advantage of enriching the uranium used in a nuclear reactor. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) from an international point of view, a possible risk to which fuel enrichment could lead. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2, part 1 continued)

(b) A particular nuclear reactor uses uranium-235 as its fuel source. When a nucleus of uranium-235 absorbs a neutron, the following reaction can take place.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{144}_{54}\mathrm{Xe} + {}^{90}_{38}\mathrm{Sr} + 2\,{}^{1}_{0}\mathrm{n}$$

The following data are available.

$$\text{rest mass of } {}^{235}_{92}\mathrm{U} = 2.1895 \times 10^{5}\,\mathrm{MeV\,c^{-2}}$$
$$\text{rest mass of } {}^{144}_{54}\mathrm{Xe} = 1.3408 \times 10^{5}\,\mathrm{MeV\,c^{-2}}$$
$$\text{rest mass of } {}^{90}_{38}\mathrm{Sr} = 8.3749 \times 10^{4}\,\mathrm{MeV\,c^{-2}}$$
$$\text{rest mass of } {}^{1}_{0}\mathrm{n} = 939.56\,\mathrm{MeV\,c^{-2}}$$

(i) Show that the energy released in the reaction is approximately 180 MeV. *[1]*

. . . . . .

. . . . . .

(ii) State the form in which the energy appears. *[1]*

. . . . . .

(c) The energy released by one atom of carbon-12 during combustion is approximately 4 eV.

(i) Using the answer to (b)(i), estimate the ratio

$$\frac{\text{energy density of uranium-235}}{\text{energy density of carbon-12}}.$$ *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Suggest, with reference to your answer in (c)(i), **one** advantage of uranium-235 compared with fossil fuels. *[1]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2, part 1 continued)

(d) A sample of waste produced by the reactor contains 1.0 kg of strontium 90 (Sr-90). Sr-90 has a half-life of 9.1×10^{8} s.

For the strontium in the sample,

(i) show that its initial activity of is 5.1×10^{15} Bq. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) calculate its activity after a period of 70 years. ($1\text{ yr}=3.2\times10^{7}$ s) *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) Based on your answers to (d), comment on a problem associated with using uranium-235 as an energy source. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

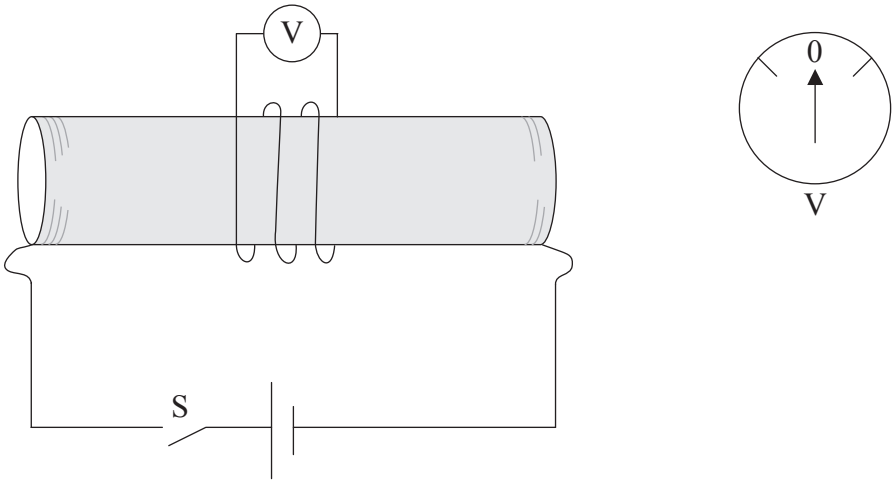
Part 2 Electromagnetic induction

(a) State Lenz's law. *[1]*

. . . . . .

. . . . . .

(b) A long solenoid is connected in series with a battery and a switch S. Several loops of wire are wrapped around the solenoid close to its midpoint as shown below.



The ends of the wire are connected to a high resistance voltmeter V that has a centre zero scale (as shown in the inset diagram). The switch S is closed and it is observed that the needle on V moves to the right and then drops back to zero.

Describe and explain, the deflection on the voltmeter when the switch S is re-opened. *[4]*

Description: . . . . . .

. . . . . .

. . . . . .

. . . . . .

Explanation: . . . . . .

. . . . . .

. . . . . .

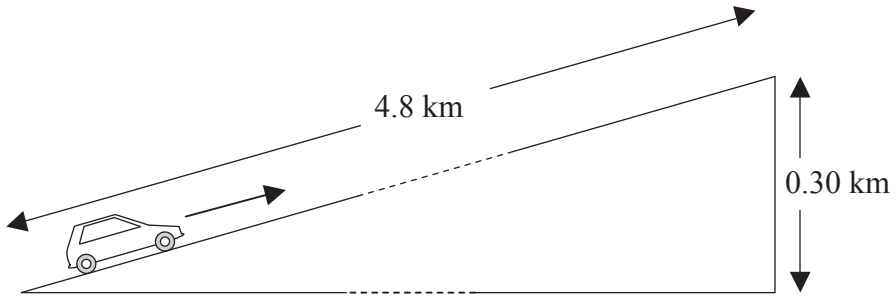
. . . . . .

. . . . . .

B3. This question is in **two** parts. **Part 1** is about mechanical power. **Part 2** is about gravitational potential.

Part 1 Mechanical power

(a) A car drives up a straight incline that is 4.8 km long. The total height of the incline is 0.30 km.



The car moves up the incline at a steady speed of $16\,m\,s^{-1}$. During the climb, the average friction force acting on the car is $5.0\times10^{2}\,N$. The total weight of the car and the driver is $1.2\times10^{4}\,N$.

(i) Determine the time it takes the car to travel from the bottom to the top of the incline. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) Determine the work done against the gravitational force in travelling from the bottom to the top of the incline. *[1]*

. . . . . .

(iii) Using your answers to (a)(i) and (a)(ii), calculate a value for the minimum power output of the car engine needed to move the car from the bottom to the top of the incline. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

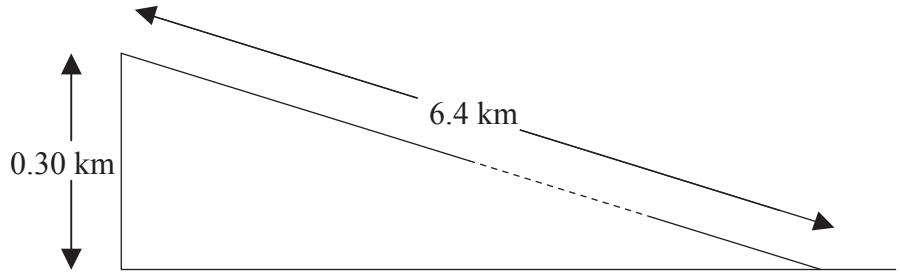
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 1 continued)

(b) From the top of the incline, the road continues downwards in a straight line. At the point where the road starts to go downwards, the driver of the car in (a), stops the car to look at the view. In continuing his journey, the driver decides to save fuel. He switches off the engine and allows the car to move freely down the hill. The car descends a height of 0.30 km in a distance of 6.4 km before levelling out.



The average resistive force acting on the car is 5.0×10^2 N.

Estimate

(i) the acceleration of the car down the incline. *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) the speed of the car at the bottom of the incline. *[2]*

. . . . . .

. . . . . .

(c) In fact, for the last few hundred metres of its journey down the hill, the car travels at constant speed. State the value of the frictional force acting on the car whilst it is moving at constant speed. *[1]*

. . . . . .

(This question continues on the following page)

(Question B3 continued)

Part 2 Gravitational potential

(a) Define *gravitational potential* at a point in a gravitational field. *[3]*

. . . . . .

. . . . . .

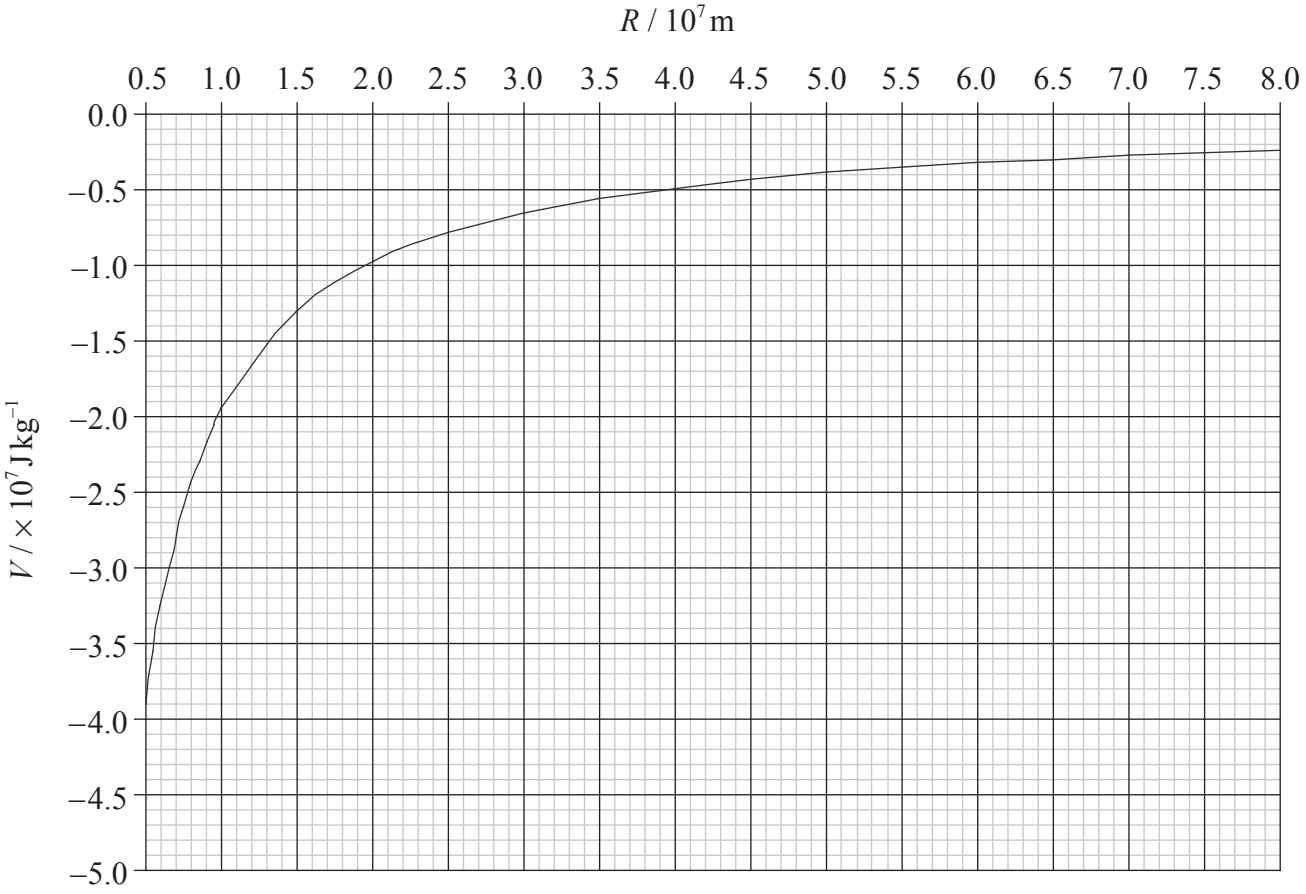
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 2 continued)

(b) The graph below shows the variation with distance R from the centre of a planet of the gravitational potential V. The radius R_0 of the planet $= 5.0 \times 10^6$ m. Values of V are not shown for $R < R_0$.



Use the graph to determine the magnitude of the gravitational field strength at the surface of the planet. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 2 continued)

(c) A satellite of mass 3.2×10^{3} kg is launched from the surface of the planet. Use the graph to determine the minimum launch speed that the satellite must have in order to reach a height of 2.0×10^{7} m above the surface of the planet. (You may assume that it reaches its maximum speed immediately after launch.) *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

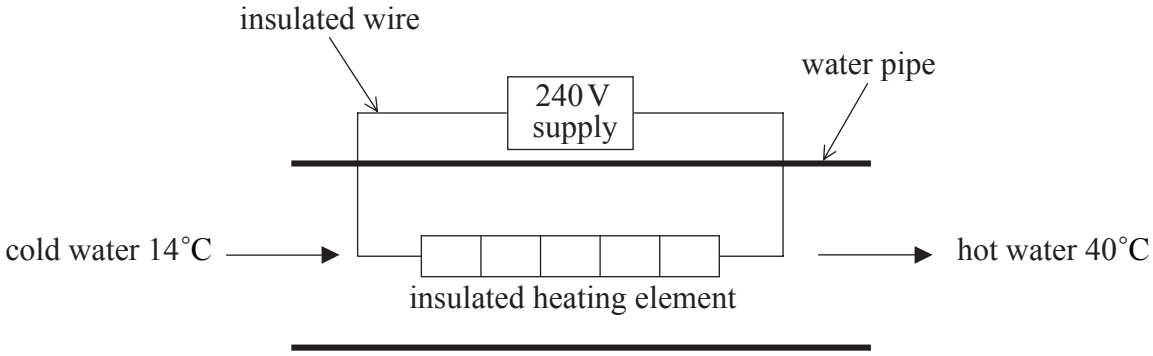
. . . . . .

. . . . . .

B4. This question is in **two** parts. **Part 1** is about heating water for a domestic shower. **Part 2** is about the photoelectric effect.

Part 1 Domestic shower

(a) The diagram below shows part of the heating circuit of a domestic shower.



Cold water enters the shower unit and flows over an insulated heating element. The heating element is rated at 7.2 kW, 240 V. The water enters at a temperature of 14 °C and leaves at a temperature of 40 °C. The specific heat capacity of water is $4.2\times10^{3}\,\text{J kg}^{-1}\,\text{K}^{-1}$.

(i) Define *specific heat capacity*. *[1]*

. . . . . .

. . . . . .

. . . . . .

(ii) Estimate the flow rate of the water. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B4, part 1 continued)

(iii) Suggest **two** reasons why your answer to (a)(ii) is only an estimate. *[2]*

1. . . . . .

. . . . . .

2. . . . . .

. . . . . .

(iv) Calculate the current in the heating element when the element is operating at 7.2 kW. *[2]*

. . . . . .

. . . . . .

. . . . . .

(v) Explain why, when the shower unit is switched on, the initial current in the heating element is greater than the current calculated in (a)(iv). *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on page 29)

Blank page

(Question B4, part 1 continued)

(b) In some countries, shower units are operated from a 110 V supply. A heating element operating with a 240 V supply has resistance R_{240} and an element operating from a 110 V supply has resistance R_{110}.

Show that for heating elements to have identical power outputs

$$\frac{R_{110}}{R_{240}} = 0.21. \qquad \textit{[3]}$$

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

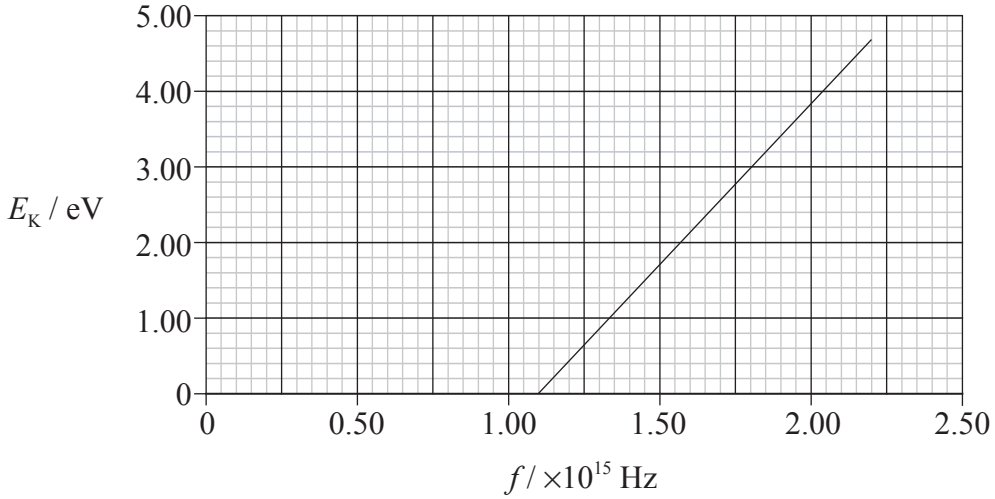
. . . . . .

(This question continues on the following page)

(Question B4 continued)

Part 2 Photoelectric effect

A metal is placed in a vacuum and light of frequency f is incident on its surface. As a result, electrons are emitted from the surface. The graph below shows the variation with frequency f of the maximum kinetic energy E_K of the emitted electrons.



(a) The graph above shows that there is a threshold frequency of the incident light below which no electrons are emitted from the surface. With reference to the Planck constant and the photoelectric work function, explain how Einstein's photoelectric theory accounts for this threshold frequency. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B4, part 2 continued)

(b) Use the graph in (a) to calculate the

(i) threshold frequency. *[1]*

. . . . . .

(ii) Planck constant. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) work function of the metal. *[2]*

. . . . . .

. . . . . .

. . . . . .

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/HP2/ENG/TZ0/XX/M

MARKSCHEME

SPECIMEN PAPER

PHYSICS

Higher Level

Paper 2

13 pages

SECTION A

A1. (a) (i) reasonable curve drawn up to $15\,\text{ms}^{-1}$ that does not go through zero; ***[1]***
Expect smooth single-line within one square of each correctly plotted point.

(ii) shape of curve wrong / curve does not go through zero; ***[1]***

(iii) $5\% = \pm 30$;
correct drawing of error bar; ***[2]***

(b) (i) when $v_{\text{in}} = 14\,\text{ms}^{-1}$, $P_{\text{out}} = 570\,(\pm 20)\,\text{kW}$;
$P_{\text{in}} = 1250\,(\pm 50)\,\text{kW}$;
Allow $\pm\frac{1}{2}$ *a square.*
efficiency $= \dfrac{570}{1250} = 0.46$ *or* 46%; ***[3]***

(ii) the efficiency decreases;
for a given increase in velocity the increase in P_{out} gets smaller;
whereas the increase in theoretical P_{in} gets larger;

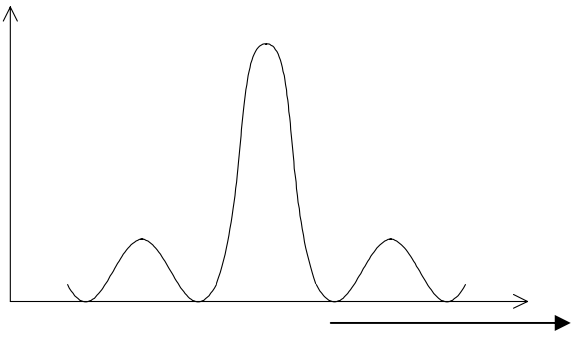
or

as the P_{out} graph starts to flatten / *OWTTE*;
the P_{in} graph steepens; ***[3]***

(c) *advantage*:
wind is renewable so no resources used up / wind is free / no chemical pollution / carbon dioxide emission / does not add to the enhanced greenhouse effect;

disadvantage:
expensive initial/capital costs / large land area needed / visual / noise pollution / winds unpredictable/not constant / affect on birds; ***[2]***
Award any other suitable advantage or disadvantage.

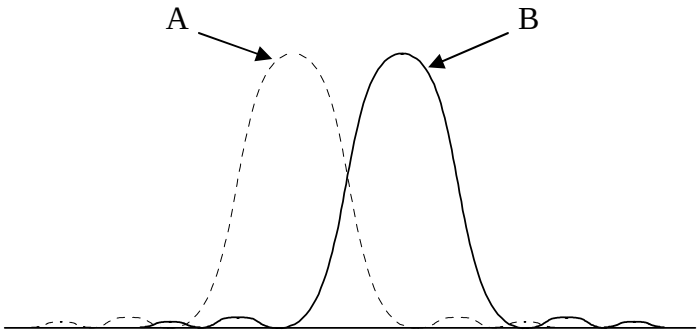
A2. (a) Intensity



Distance along screen

general shape;
relative position of secondary maxima / relative heights of secondary maxima; ***[2]***
*Award **[1 max]** if not touching x-axis.*

(b)



maximum of B coincides with first minimum of A; ***[1]***

(c) $\theta = \frac{1.22\lambda}{b} = \frac{1.22\times5\times10^{-7}}{25\times10^{-2}} = 2.4\times10^{-6}\ \text{rad}$;

$= \frac{x}{8.1\times10^{16}}$;

to give $x = 2.0\times10^{11}\ \text{m}$; ***[3]***

A3. (a) polarized light is light in which the (electric) field vector vibrates in one plane only / *OWTTE*;
the liquid crystal changes the plane in which (electric) field vector rotates; ***[2]***

(b) (i) nothing / whole area black;
since the optical axes of P_1 and P_2 are at right angles / *OWTTE*; ***[2]***

(ii) since the liquid crystal rotates the plane of polarisation light is now transmitted by P_2 / *OWTTE*;
the electric field across the parts of the liquid crystal in the shape of the electrode on G no longer rotates the plane of polarization;
the field of view of the observer will now contain a black area corresponding to the shape of the electrode on G / *OWTTE*; ***[3]***

A4. (a) (i) $P \propto \frac{1}{V}$ *or* $V \propto \frac{1}{P}$ *or* pressure inversely proportional to volume *etc*.; ***[1]***

(ii) $V \propto T$ *etc*.; ***[1]***

(b) (i) $\frac{P_1}{T_1} = \frac{P_2}{T'}$; ***[1]***

(ii) $\frac{V_1}{T'} = \frac{V_2}{T_2}$; ***[1]***

(c) from (i) $T' = \frac{P_2 T_1}{P_1}$;

from (ii) $T' = \frac{V_1 T_2}{V_2}$;

equate to get $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$;

so that $\frac{PV}{T} = \text{constant}$ *or* $PV = KT$; ***[4]***

A5. (a) (i) $h = \frac{v^2}{2g}$;

to give $h = 3.2\,\text{m}$; ***[2]***

(ii) $0.80\,\text{s}$; ***[1]***

(b) time to go from top of cliff to the sea $= 3.0 - 1.6 = 1.4\,\text{s}$;

recognise to use $s = ut + \frac{1}{2}at^2$ with correct substitution, $s = 8.0 \times 1.4 + 5.0 \times (1.4)^2$;

to give $s = 21\,\text{m}$; ***[3]***

Candidates might find the speed with which the stone hits the sea from $v = u + at$, *(*$42\,\text{m s}^{-1}$*) and then use* $v^2 = u^2 + 2as$.

A6. (a) the force exerted per unit mass;
on a point (small) mass; ***[2]***

(b) (i) use of $g = \frac{F}{m}$ and $F = G\frac{Mm}{R^2}$;
combine to get $g = G\frac{M}{R^2}$; ***[2]***

(ii) $M = \frac{gR^2}{G}$;
substitute to get $M = 1.9 \times 10^{27}$ kg; ***[2]***

SECTION B

B1. Part 1 Simple harmonic motion and the greenhouse effect

(a) the force acting/accelerating (on the body) is directed towards equilibrium (position);
and is proportional to its/the bodies displacement from equilibrium; ***[2]***

(b) (i) $1.5\times10^{-10}\ \text{m}$; ***[1]***

(ii) $T = 1.1\times10^{-12}\ \text{s}$;

$$f = \left(\frac{1}{1.1\times10^{-12}}\right);$$

$$= 9.1\times10^{13}\ \text{Hz}$$ ***[2]***

(iii) $\omega = (2\pi f) = 5.7\times10^{14}\ (\text{rad s}^{-1})$;

$$E_{\max} = \left(\tfrac{1}{2}m\omega^2 x_0{}^2\right) = \tfrac{1}{2}\times1.7\times10^{-27}\times(1.5)^2\times10^{-20}\times(5.7)^2\times10^{28};$$

$$= 6.2\times10^{-18}\ \text{J}$$ ***[2]***

(c) (i) $k = (4\pi^2 f^2 m_{\text{p}}) = 40\times83\times10^{26}\times1.7\times10^{-27}$;

$$\approx 560\ \text{N m}^{-1}$$ ***[1]***

(ii) use of $F = kx$ and $F = ma$;

to give $a = \dfrac{560\times1.5\times10^{-10}}{1.7\times10^{-27}} = 5.0\times10^{19}\ \text{m s}^{-2}$; ***[2]***

(d) (i) infra red radiation radiated <u>from Earth</u> will be absorbed by greenhouse gases;
and so increase the temperature of the atmosphere/Earth; ***[2]***

(ii) the natural frequency of oscillation (of a methane molecule) is equal to $9.1\times10^{13}\ \text{Hz}$;
because of resonance the molecule will readily absorb radiation of this frequency; ***[2]***

Part 2 Charge coupled device (CCD)

(a) $\dfrac{\text{image length}}{\text{object length}} = \left(\sqrt{\dfrac{1.0\times10^{-3}}{2.5\times10^{-2}}}\right) = 0.20$;

length of pixel $= 1.5\times10^{-5}$ m;

separation of 5.0×10^{-4} m on CCD $= 5.0\times10^{-4}\times0.20 = 1.0\times10^{-4}$ m;

$= 6.7$ pixels so resolved; ***[4]***

(b) (i) the ratio of the number electrons emitted to the number of photons incident on the pixel / *OWTTE*; ***[1]***

(ii) number of electrons emitted $= 0.8\times5.5\times10^{4}$;

amount of charge generated on pixel $= 0.8\times5.5\times10^{4}\times1.6\times10^{-19} = 7.0\times10^{-15}$ C;

$V = \dfrac{Q}{C}$;

$\dfrac{7.0\times10^{-15}}{4.0\times10^{-11}} = 0.18\,\text{mV}$; ***[4]***

(c) the variation of pd across the collection area is a "map" of the image of the object on the collection area;
each pd can be converted to a digital signal;
these digital signals can be converted to an image on an LCD/screen; ***[2 max]***

B2. Part 1 Nuclear power production

(a) (i) fuel enrichment means that the amount of uranium-235 present in the fuel is increased / *OWTTE*;
this means that more U-235 available for fission;
therefore the reaction can be sustained; ***[3]***

(ii) enriched fuel can be used in the manufacture of nuclear weapons;
so possibly threatening World peace; ***[2]***

(b) (i) $(\text{energy released}) = 2.1895\times10^{5} - (1.3408 + 0.83749 + 0.0093956)\times10^{5}$;
$= 181.44 \approx 180\,\text{MeV}$ ***[1]***

(ii) kinetic; ***[1]***

(c) (i) number of atoms in 1 kg of carbon $= \dfrac{N_{\text{A}}\times1000}{12}$ and number in 1 kg of U-235 $= \dfrac{N_{\text{A}}\times1000}{235}$;

energy per kg carbon $= \dfrac{4N_{\text{A}}}{12}\,\text{keV}$ and per kg U-235 $= \dfrac{N_{\text{A}}\times1.8\times10^{8}}{235}\,\text{keV}$;

therefore, ratio $= 2.3\times10^{6}$; ***[3]***

(ii) a much higher energy density implies that uranium will produce more energy per kg / smaller quantity of uranium needed to produce same amount of energy / *OWTTE*; ***[1]***

(d) (i) $\text{no of atoms} = \left(\dfrac{6.0\times10^{26}}{90}\right) = 6.7\times10^{24}$;

$\lambda = \dfrac{0.69}{9.1\times10^{8}} = 7.6\times10^{-10}\,(\text{s}^{-1})$;

$\text{activity} = 7.6\times10^{-10}\times6.7\times10^{24}$;

$= 5.1\times10^{15}\,\text{Bq}$ ***[3]***

(ii) $\lambda = 0.024\,\text{yr}^{-1}$;

$\text{activity} = 5.1\times10^{15}\times\text{e}^{-0.024\times70}$;

$= 9.6\times10^{14}\,\text{Bq}$; ***[3]***

(e) initial activity is very high;
it is still highly radioactive after 70 years;
thereby posing a severe health risk/causing problems of disposal / *OWTTE*; ***[3]***

Part 2 Electromagnetic induction

(a) the induced emf is induced in such a direction that its effect is to oppose the change to which it is due / *OWTTE*; ***[1]***

(b) *description*:
on opening the switch, the reading on the voltmeter will deflect to the left and then drop to zero;

explanation:
when the switch is opened the field drops to zero – so again a time changing flux;
which will induce an emf in the opposite direction as the emf will now be such as to oppose the field falling to zero/Lenz's law;
when the current reaches zero, there will no longer be a flux change; ***[4]***

B3. Part 1 Mechanical power

(a) (i) $t = \frac{d}{v}$;

$= \frac{4800}{16} = 300\,\text{s}$; ***[2]***

(ii) $W = mgh = 1.2\times10^4 \times 300 = 3.6\times10^6\,\text{J}$; ***[1]***

(iii) work done against friction $= 4.8\times10^3 \times 5.0\times10^2$;
total work done $= 2.4\times10^6 + 3.6\times10^6$;
total work done $= P\times t = 6.0\times10^6$;
to give $P = \frac{6.0\times10^6}{300} = 20\,\text{kW}$; ***[4]***

(b) (i) $\sin\theta = \frac{0.30}{6.4} = 0.047$;
weight down the plane $= W\sin\theta = 1.2\times10^4 \times 0.047 = 5.6\times10^2\,\text{N}$;
net force on car $F = 5.6\times10^2 - 5.0\times10^2 = 60\,\text{N}$;
$a = \frac{F}{m}$;
$\frac{60}{1.2\times10^3} = 5.0\times10^{-2}\,\text{m s}^{-2}$; ***[5]***

(ii) $v^2 = 2as = 2\times5.0\times10^{-2}\times6.4\times10^3$;
to give $v = 25\,\text{m s}^{-1}$; ***[2]***

(c) $5.6\times10^2\,\text{N}$; ***[1]***

Part 2 Gravitational potential

(a) the work done per unit mass;
in bringing a small/point mass;
from infinity to the point (in the gravitational field); ***[3]***

(b) from the graph $V_0 = 3.9(\pm 0.2)\times 10^7\ \text{J kg}^{-1}$;

$g_0 = \dfrac{V_0}{R_0} = \dfrac{39}{5}$;

$= 7.8(\pm 2)\ \text{N kg}^{-1}$; ***[3]***

(c) 2.0×10^7 m above surface is 2.5×10^7 m from centre;

ΔV between surface and $2.5\times 10^7\ \text{m} = (3.9 - 0.80)\times 10^7 = 3.1(\pm 0.2)\times 10^7\ \text{J kg}^{-1}$;

$v = \sqrt{\dfrac{2m\Delta V}{m}} = \sqrt{2\Delta V}$;

$= \sqrt{6.2\times 10^7} = 7.9(\pm 0.2)\times 10^3\ \text{m s}^{-1}$; ***[4]***

*Award **[3 max]** if the candidate forgets that the distances are from the centre (answer $3.2\times 10^3\ \text{m s}^{-1}$), i.e. the candidate must show ΔV.*

B4. Part 1 Domestic shower

(a) (i) the amount of energy/heat required to raise the temperature of 1kg of a substance through 1K / 1°C; ***[1]***

(ii) energy supplied by heater in 1s = 7.2×10^3 J;
energy per second = mass per second × sp ht × rise in temperature;
7.2×10^3 = mass per second × $4.2\times10^3\times26$;
to give mass per second = 0.066 kg; ***[4]***

(iii) energy is lost to the surroundings;
flow rate is not uniform; ***[2]***
Do not allow "the heating element is not in contact with all the water flowing in the unit".

(iv) $P = VI \quad I = \frac{P}{V}$;
$= \frac{7.2\times10^3}{240} = 30\,\text{A}$; ***[2]***

(v) when operating at 7.2 kW the element is at a higher temperature/hotter than when first switched on;
therefore, resistance is greater (and so current is smaller) / *OWTTE*;

or

element is cold /*OWTTE* when first switched on;
therefore, smaller resistance than when hot (and so current is larger); ***[2]***

(b) $P = \frac{V^2}{R}$;
$\frac{240^2}{R_{240}} = \frac{110^2}{R_{110}}$;
$\frac{R_{110}}{R_{240}} = \left(\frac{110}{240}\right)^2$;
$= 0.21$

or

from $P = VI$
$240I_2 = 110I_1$ to give $I_2 = \frac{11}{24}I_1$;
$I_2^{\,2}R_2 = I_1^{\,2}R_1$;
$\frac{R_1}{R_2} = \frac{I_2^{\,2}}{I_1^{\,2}} = \left(\frac{11}{24}\right)^2$;
$= 0.21$ ***[3 max]***

Part 2 Photoelectric effect

(a) light consists of photons;
the energy of each photon $= hf$ where h is the Planck constant;
a certain amount of energy, the work function ϕ is required to remove an electron from the metal surface;
if $f < \frac{\phi}{h}$ then no electrons will be emitted; ***[4]***

*Award **[4]** for these precise points as they are needed in view of the question. Award **[2 max]** for a purely qualitative answer.*

(b) (i) 1.1×10^{15} Hz; ***[1]***

(ii) $E_K = hf - \phi = Ve$;
slope of graph $= \frac{h}{e}$;
slope $= 4.2(\pm0.4)\times10^{-15}$;
$h = 4.2(\pm0.4)\times10^{-15}\times1.6\times10^{-19} = 6.7(\pm0.4)\times10^{-34}$ J s;
Note**: the answer must show that the graph has been used – if not, award **[0]** for a bald answer as this could have been taken from the data book.* ***[4]

(iii) $\phi = hf_0$;
$= 1.1\times10^{15}\times6.7\times10^{-34} = 7.4\times10^{-19}$ J;
The value of h from (b)(ii) must be used.

or

from the intercept on E_K axis;
$= 4.5(\pm0.2)$ eV; ***[2]***

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

PHYSICS
HIGHER LEVEL
PAPER 3

SPECIMEN PAPER

1 hour 15 minutes

Candidate session number

0	0							

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet.

Option E — Astrophysics

E1. This question is about stars.

Betelgeuse and Rigel are two super giants in the constellation of Orion.

(a) Distinguish between a *constellation* and a *stellar cluster*. *[2]*

Constellation: . . . . . .

. . . . . .

Stellar cluster: . . . . . .

. . . . . .

(b) The star Betelgeuse has a parallax of 0.0077 arc second. Deduce that its distance from Earth is approximately 130 pc. *[1]*

. . . . . .

. . . . . .

(c) State why the Hipparcos satellite which orbits Earth is able to measure stellar parallaxes for stars at considerably greater distances than 130 pc. *[1]*

. . . . . .

(This question continues on the following page)

(Question E1 continued)

(d) The table below gives some information about the types and magnitudes of Betelgeuse and Rigel.

Star	Type	Apparent magnitude	Colour	Apparent brightness
Betelgeuse	M	–0.04		$2.0\times10^{-7}\,\mathrm{W\,m^{-2}}$
Rigel	B	0.12		$3.4\times10^{-8}\,\mathrm{W\,m^{-2}}$

(i) Complete the above table for the colours of the stars. *[2]*

(ii) State why Betelgeuse has a lower apparent magnitude than Rigel. *[1]*

. . . . . .

. . . . . .

(iii) Given that the distance of Betelgeuse from Earth is 130 pc, calculate the luminosity of Betelgeuse. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) The luminosity of Rigel is 2.3×10^{31} W. Without any further calculation, explain whether Rigel is closer or further than Betelgeuse from Earth. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

E2. This question is about Olbers' paradox.

(a) Newton assumed that the universe is static and that the stars are uniformly distributed. State **one** further assumption of the Newtonian universe. *[1]*

. . . . . .

(b) Explain how Newton's assumptions led to Olbers' paradox. *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

E3. This question is about stars.

Describe the final nuclear reaction in the core, and the final evolutionary state, of

(a) a low-mass star (of the order of 1 solar mass). *[2]*

nuclear reaction: . . . . . .

. . . . . .

evolutionary state: . . . . . .

. . . . . .

(b) a high-mass star (of approximately 15 solar masses). *[2]*

nuclear reaction: . . . . . .

. . . . . .

evolutionary state: . . . . . .

. . . . . .

E4. This question is about extragalactic astrophysics.

(a) In an observation of a distant galaxy, spectral lines are recorded. Spectral lines at these wavelengths cannot be produced in the laboratory. Explain this phenomenon. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) Describe how Hubble's law is used to determine the distance from the Earth to distant galaxies. *[2]*

. . . . . .

. . . . . .

. . . . . .

(c) Explain why Hubble's law is not used to measure distances to nearby stars or nearby galaxies (such as Andromeda). *[2]*

. . . . . .

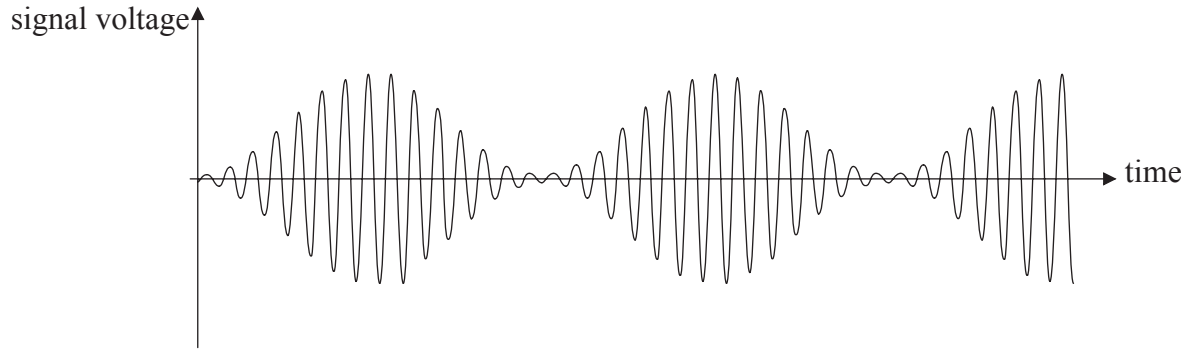
. . . . . .

. . . . . .

Option F — Communications

F1. This question is about amplitude-modulated radio waves.

The diagram below shows a sketch graph of signal voltage against time for an amplitude-modulated radio wave.



(a) The information signal consists of a continuous single frequency sine wave. The frequency of the carrier wave is 18 kHz.

(i) Determine the frequency of the information signal. *[3]*

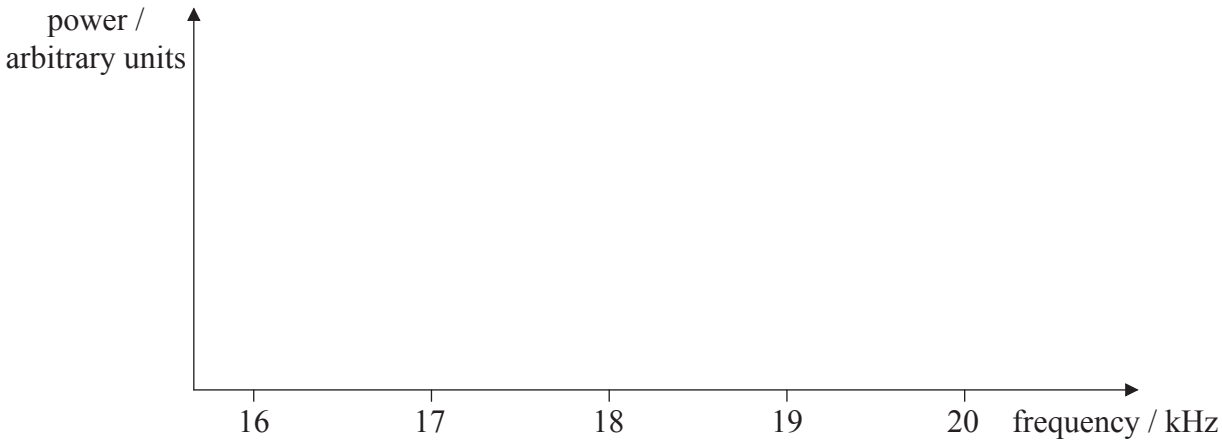
. . . . . .

. . . . . .

. . . . . .

. . . . . .

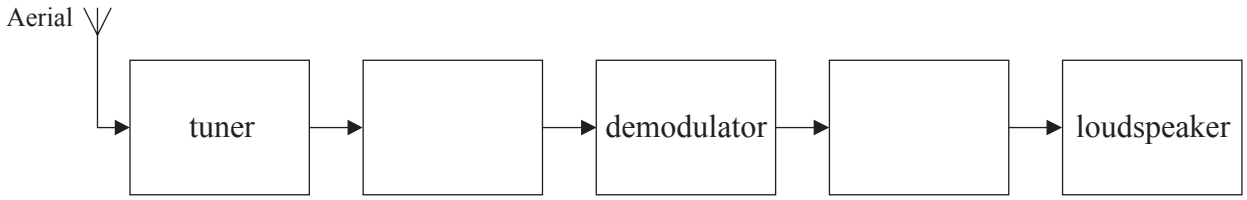
(ii) On the axes below, draw the power spectrum for the amplitude-modulated wave. *(Numerical values are not required on the power axis.)* *[3]*



(This question continues on the following page)

(Question F1 continued)

(b) The block diagram below shows the principal systems in a radio that receives an amplitude-modulated signal. The unlabelled boxes represent amplifiers.



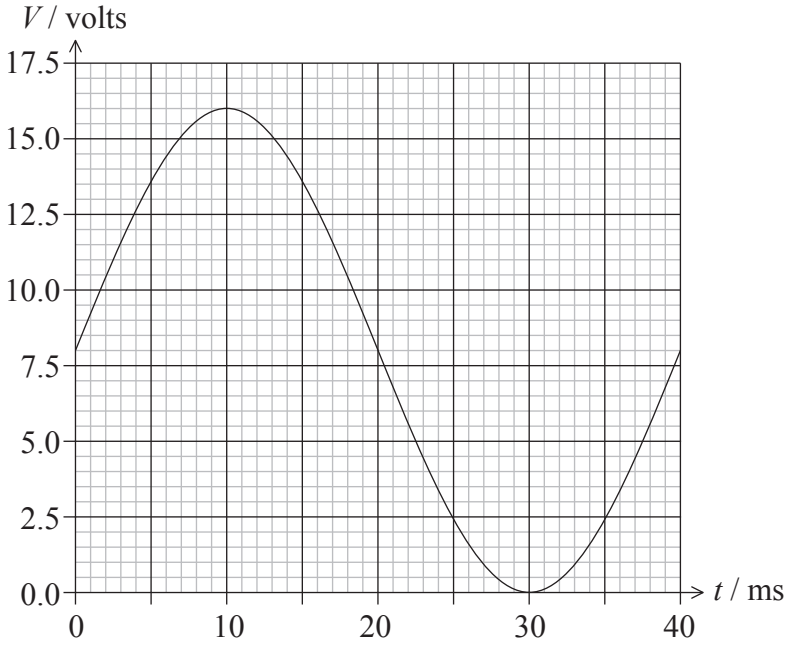
(i) Label the blank boxes with the type of amplifier used. *[1]*

(ii) State the function of the demodulator. *[1]*

. . . . . .

. . . . . .

F2. The graph below shows the variation with time t of the voltage V of an analogue signal.



The signal is sampled at a frequency of 200 Hz and digitized using a three-bit analogue to digital converter (ADC). The first sample is taken at $t = 0$.

The possible outputs of the ADC are given below.

Analogue signal / volts	ADC binary output
	111
14	110
12	101
10	100
8	011
6	010
4	001
2	000
0	

(a) Calculate the time at which the fourth sample is taken. *[2]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question F2 continued)

(b) Determine the binary output of the fourth sample. *[2]*

. . . . . .

. . . . . .

(c) The ADC output is fed into a three-bit digital to analogue converter (DAC). State, and explain, whether the output of the DAC will be a faithful reproduction of the original analogue signal. *[2]*

. . . . . .

. . . . . .

F3. This question is about communication channels.

(a) State the order of magnitude of the frequencies used for communication with geostationary satellites. *[1]*

. . . . . .

(b) A voice communication channel is to be established between a scientific base in the northern hemisphere and its headquarters in the southern hemisphere.

For this communication channel, state and explain **one** advantage of using

(i) a geostationary satellite. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) a polar orbiting satellite. *[2]*

. . . . . .

. . . . . .

. . . . . .

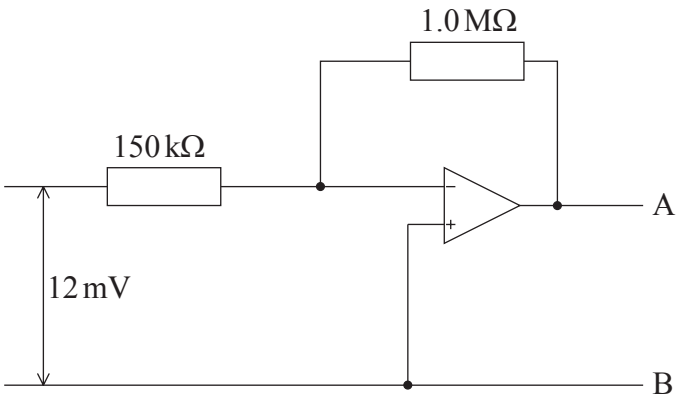
. . . . . .

(c) State **one** reason why the up-link frequency and the down-link frequency for communication satellites are different. *[1]*

. . . . . .

. . . . . .

F4. The diagram below shows an inverting amplifier circuit.



(a) State what is meant by an inverting amplifier circuit. *[1]*

. . . . . .

(b) The input voltage is 12 mV. Calculate

(i) the current in the 150 kΩ resistor. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) the potential difference between A and B. *[1]*

. . . . . .

. . . . . .

(c) Outline any assumptions that you have made in (b). *[2]*

. . . . . .

. . . . . .

. . . . . .

F5. In a mobile phone system an area is divided into a large number of cells.

(a) State what is meant by a cell. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) Suggest **two** advantages of organizing the mobile phone system in this way. *[2]*

. . . . . .

. . . . . .

. . . . . .

Option G — Electromagnetic waves

G1. This question is about laser light.

(a) State **two** differences between the light emitted by a laser and that emitted by a filament lamp. *[2]*

1. . . . . .

2. . . . . .

(b) The production of laser light relies on population inversion. Outline the meaning of the term population inversion. *[2]*

. . . . . .

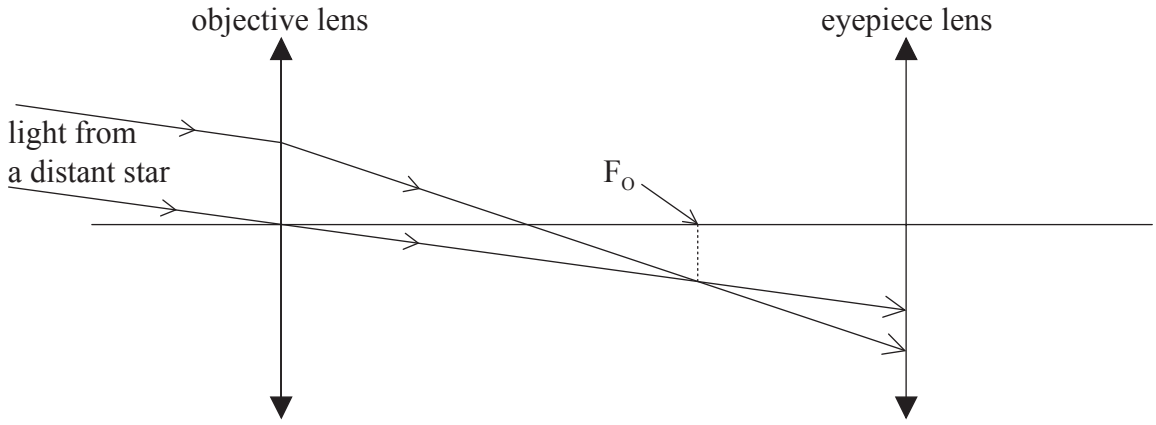
. . . . . .

. . . . . .

. . . . . .

G2. This question is about an astronomical telescope.

(a) The diagram below shows two rays of light from a distant star incident on the objective of an astronomical telescope. The paths of the rays are also shown after they pass through the objective lens and are incident on the eyepiece lens of the telescope.



The principal focus of the objective lens is F_O.

On the diagram above, mark the position of the

(i) principal focus of the eyepiece lens (label this F_E). *[1]*

(ii) image of the star formed by the objective lens (label this I). *[1]*

(b) State where the final image is formed when the telescope is in normal adjustment. *[1]*

. . . . . .

(c) Complete the diagram in (a) to show the direction in which the final image of the star is formed for the telescope in normal adjustment. *[2]*

(This question continues on the following page)

(Question G2 continued)

The eye ring of an astronomical telescope is a device that is placed outside the eyepiece lens of the telescope at the position where the image of the objective lens is formed by the eyepiece lens. The diameter of the eye ring is the same as the diameter of the image of the objective lens. This ensures that all the light passing through the telescope passes through the eye ring.

(d) A particular astronomical telescope has an objective lens of focal length 98.0 cm and an eyepiece lens of focal length 2.00 cm (*i.e.* f_O = 98.0 cm, f_E = 2.00 cm). Determine the position of the eye ring. *[4]*

. . . . . .

. . . . . .

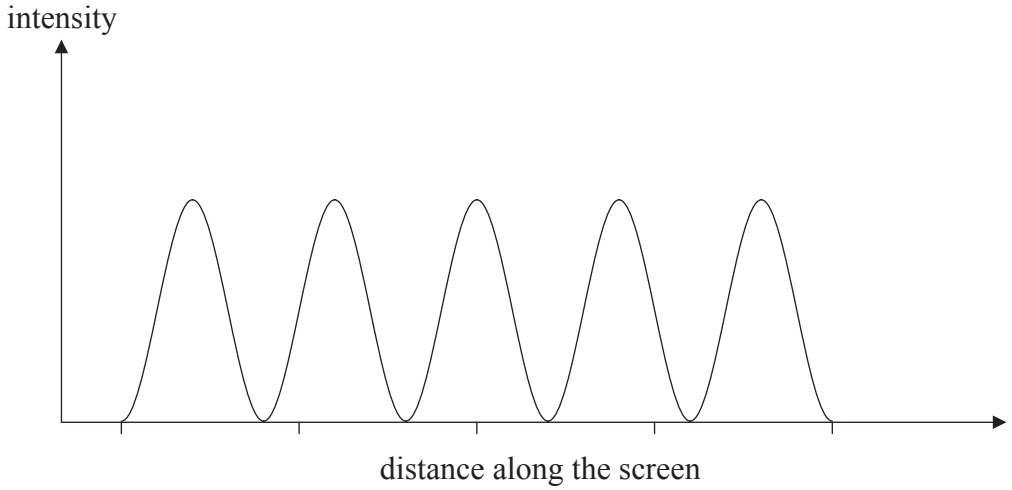
. . . . . .

. . . . . .

. . . . . .

G3. This question is about interference and diffraction.

Light from a laser is incident on two slits of equal width. After passing through the slits, the light is incident on a screen. The diagram below shows the intensity distribution of the light on the screen.



(a) The wavelength of the light from the laser is 633 nm and the angular separation of the bright fringes on the screen is 4.00×10^{-4} rad. Calculate the separation of the slits. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Light from the laser is incident on many slits of the same width as the widths of the slits above. Draw, on the above diagram, a possible new intensity distribution of the light on the screen. *[2]*

(c) The laser is replaced by a source of white light. Describe, if any, the changes to the fringes on the screen. *[2]*

. . . . . .

. . . . . .

. . . . . .

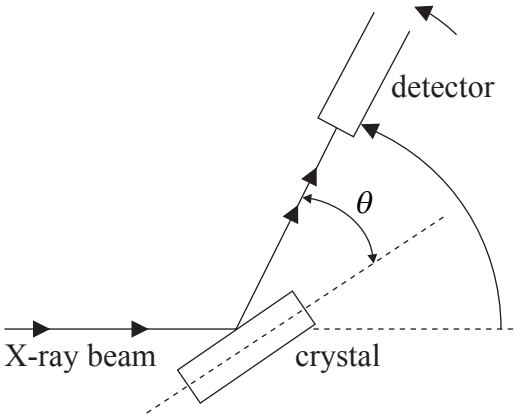
. . . . . .

(Option G continues on page 18)

Blank page

G4. This question is about X-ray diffraction.

The diagram below represents an arrangement for measuring the intensity of X-rays scattered from the surface of a cubic crystal. The angle between the surface of the crystal and the reflected ray is θ.



(This question continues on the following page)

(Question G4 continued)

The diagram below represents two lattice planes of the crystal. The lattice ions are represented by the black dots.

(a) Add lines to the diagram above to represent the incident and scattered X-rays, explain why, as the detector of the scattered X-rays is rotated, it registers a maximum of intensity at various values of the angle θ. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The wavelength of the incident X-rays is 1.2×10^{-10} m. The first maximum value of intensity is recorded at $\theta = 12^{\circ}$. Show that the lattice spacing d in the diagram above is 2.9×10^{-10} m. *[1]*

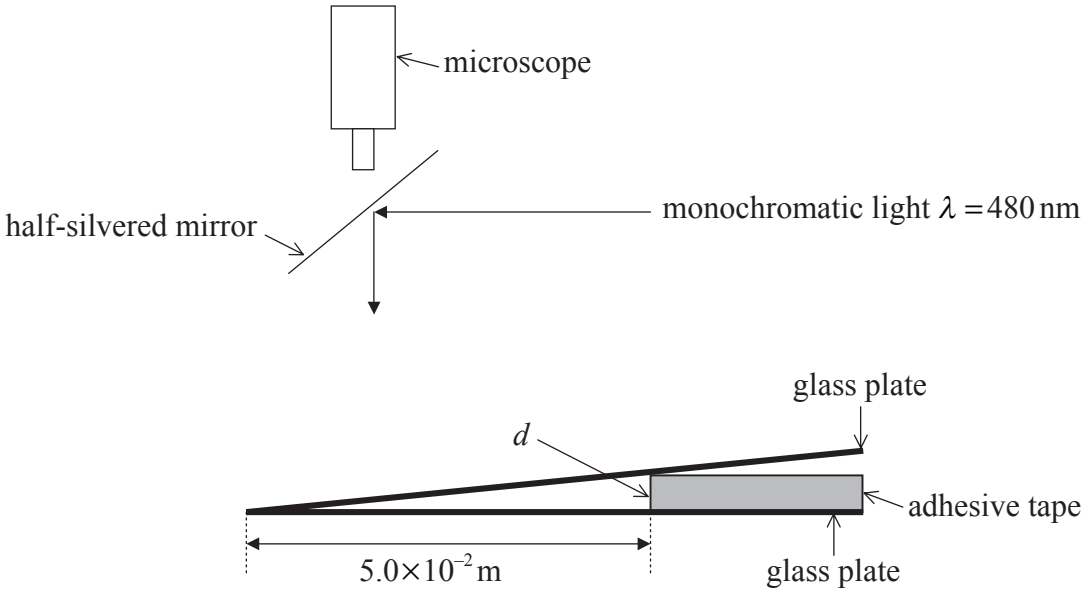
. . . . . .

. . . . . .

. . . . . .

G5. This question is about a wedge film.

In an experiment to measure the thickness d of a piece of adhesive tape, the tape is used to separate two flat plates of glass as shown below. This forms a wedge shaped air film.



A beam of monochromatic light is incident on the wedge film. The light that is reflected at right angles to the wedge, is viewed using the microscope. A system of parallel fringes of equal spacing is observed in the field of view of the microscope.

(a) Outline how the fringe system is formed. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The spacing between the fringes is $1.2\times10^{-4}\,\text{m}$. The distance from where the two plates of glass touch and the edge of the adhesive tape is $5.0\times10^{-2}\,\text{m}$. The wavelength of the light is 480 nm. Estimate the thickness d of the adhesive tape. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option H — Relativity

H1. This question is about relativistic kinematics.

(a) State what is meant by an inertial frame of reference. *[2]*

. . . . . .

. . . . . .

(b) A spacecraft is moving with a speed of 0.80c with respect to observers on Earth. After 6.0 years of travel, according to the spacecraft clocks, the spacecraft arrives at a distant solar system.

(i) Calculate the time the journey has taken according to an observer on Earth. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Calculate the distance between the Earth and the solar system according to an observer on Earth. *[2]*

. . . . . .

. . . . . .

. . . . . .

(iii) The spacecraft observers send a signal to Earth to announce that they have arrived at the solar system. The spacecraft continues to move. Determine how long it will take the signal to arrive on Earth according to the **spacecraft** observers. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

H2. Two electrons are travelling directly towards one another. Each has a speed of 0.80c relative to a stationary observer. Calculate the relative velocity of approach, as measured in the frame of reference of one of the electrons. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

H3. This question is about mass-energy.

(a) Distinguish between the rest mass-energy of a particle and its total energy. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) The rest mass of a proton is 938 MeV c^{-2}. State the value of its rest mass-energy. *[1]*

. . . . . .

(c) A proton is accelerated from rest through a potential difference V until it reaches a speed of 0.980c. Determine the potential difference V as measured by an observer at rest in the laboratory frame of reference. *[4]*

. . . . . .

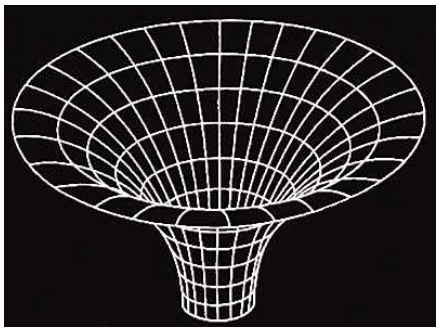
. . . . . .

. . . . . .

. . . . . .

. . . . . .

H4. The diagram below illustrates the distortion of space by the gravitational field of a black hole.



(a) (i) Describe what is meant by the *centre* and the *surface* of a black hole. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) With reference to your answer in (a)(i), define the *Schwarzschild radius*. *[1]*

. . . . . .

. . . . . .

(iii) Calculate the Schwarzschild radius for an object having a mass of 2.0×10^{31} kg (ten solar masses). *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) Science fiction frequently portrays black holes as objects that "swallow" everything in the universe.

A spacecraft is travelling towards the object in (a)(iii) such that, if it continues in a straight-line, its distance of closest approach would be about 10^7 m. By reference to the diagram and your answer in (a)(iii), suggest whether the fate of the spacecraft is consistent with the fate as portrayed in science fiction. *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question H4 continued)

(b) In 1979, Wahl, Carswell and Weymann discovered "two" very distant quasars separated by a small angle. Spectroscopic examination of the images showed that they were identical.

Outline how these observations give support to the theory of General Relativity. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option I — Medical physics

I1. This question is about sound intensity levels.

(a) Distinguish between sound intensity and loudness. *[2]*

. . . . . .

. . . . . .

(b) An engine generates 2.4 W of sound power that is emitted uniformly in all directions. The intensity level at the ear must not exceed 82 dB. Calculate the minimum distance that any person must be from the engine unless wearing ear protection. (The surface area of a sphere of radius r is $4\pi r^2$) *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

I2. Nuclear magnetic resonance (NMR) imaging is a technique in which protons inside the patient are made to emit an electromagnetic signal.

(a) Outline the mechanism by which the signal is emitted by the protons. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) State **one** advantage to the patient of using NMR imaging compared to X-ray radiography. *[1]*

. . . . . .

. . . . . .

I3. This question is about X-rays.

A parallel beam of X-rays is used to investigate a broken bone. The attenuation coefficient for soft tissue (muscle) is $0.035\,\text{cm}^{-1}$. The X-ray half-value thickness for bone is about 150 times less than that for soft tissue.

(a) Define the term *half-value thickness*. *[1]*

. . . . . .

. . . . . .

(b) Deduce that the attenuation coefficient for bone is $5.3\,\text{cm}^{-1}$. *[2]*

. . . . . .

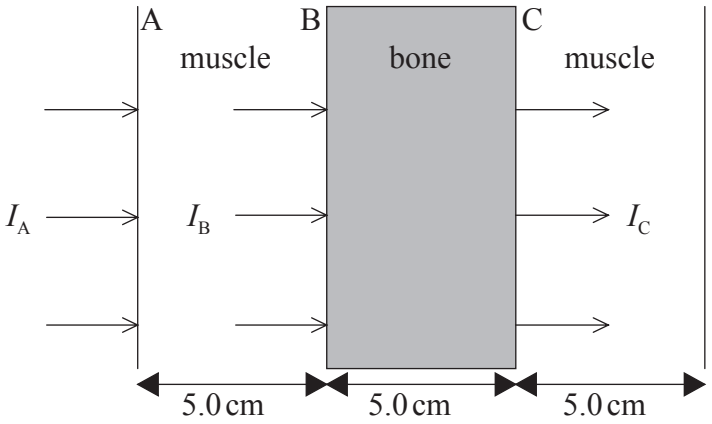
. . . . . .

. . . . . .

(This question continues on the following page)

(Question I3 continued)

(c) The parallel beam of X-rays is incident on a human leg. The leg has a bone of diameter 5.0 cm, surrounded by muscle on each side of thickness 5.0 cm. A section through the leg is shown in the diagram below.



The intensity of the X-ray beam at the surface A of the leg is I_A. At the surface B of the bone, the intensity is I_B and the intensity of the beam emerging at surface C of the bone is I_C.

Determine the ratio

(i) $\frac{I_B}{I_A}$. *[2]*

. . . . . .

. . . . . .

(ii) $\frac{I_C}{I_B}$. *[1]*

. . . . . .

. . . . . .

(d) Use your answers in (c) to explain how it is possible to obtain a shadow image of the leg and bone. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

I4. This question is about dosimetry.

(a) Explain what is meant by *quality factor* (relative biological effectiveness). *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The radioactive isotope potassium-40 occurs naturally in the body. Use the data below to calculate the annual dose equivalent that the body receives from the decay of potassium-40 within the body. *[2]*

number of atoms of potassium-40 per kilogram of the body $= 8.0 \times 10^{18}$

decay constant of potassium-40 $= 5.3 \times 10^{-10}$ year^{-1}

energy absorbed by the body from the decay of one atom of potassium-40 $= 4.0 \times 10^{-14}$ J

quality factor of the radiation from decay of potassium-40 $= 1$

. . . . . .

. . . . . .

. . . . . .

. . . . . .

I5. This question is about radioactive isotopes of iodine.

The isotope iodine-131 is used to treat malignant growths in the thyroid gland. The isotope has a physical half-life of 8 days and a biological half-life of 21 days.

(a) Explain the term biological half-life. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Calculate the effective half-life of the isotope. *[2]*

. . . . . .

. . . . . .

. . . . . .

(c) The isotope iodine-123 has a physical half-life of 13 hours.

Suggest why it is preferable to use this isotope for **imaging** the thyroid rather than iodine-131. *[1]*

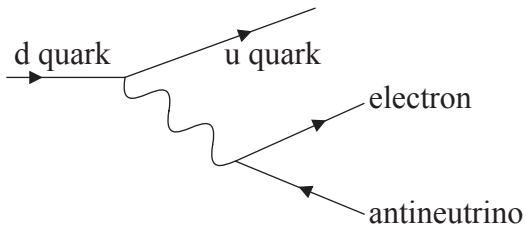
. . . . . .

. . . . . .

Option J — Particle physics

J1. This question is about fundamental interactions.

(a) The Feynman diagram below represents a β^- decay via the weak interaction process.



The exchange particle in this weak interaction is a virtual particle.

(i) State what is meant by a virtual particle. *[1]*

. . . . . .

. . . . . .

(ii) Determine whether the virtual particle in the process represented by the Feynman diagram is a W^+, a W^- **or** a Z^0 boson. *[2]*

. . . . . .

(b) The order of magnitude of the mass of the $W^\pm$ and Z^0 bosons is $100\,GeV\,c^{-2}$. Estimate the range of the weak interaction. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

J2. This question is about a proton.

The proton particle is made out of three quarks.

(a) Explain why the three quarks in the proton do not violate the Pauli exclusion principle. *[2]*

. . . . . .

(b) Quarks have spin $\frac{1}{2}$. Explain how it is possible for the proton to also have spin $\frac{1}{2}$. *[2]*

. . . . . .

. . . . . .

J3. This question is about the synchrotron and particle production.

(a) In a synchrotron ring, a beam of protons and another beam of antiprotons move in opposite directions through regions of electric and magnetic fields as they circle the ring.

Describe the purpose of the

(i) electric fields. *[1]*

. . . . . .

(ii) magnetic fields. *[1]*

. . . . . .

(b) Explain why the magnitudes of the magnetic fields in a synchrotron must be increased as the energy of the accelerated particles increases. *[3]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question J3 continued)

(c) The neutral lambda baryon Λ and its antiparticle may be produced in proton-antiproton collisions according to the following reaction.

$$p + \overline{p} \rightarrow \Lambda + \overline{\Lambda}$$

The minimum energy required to produce the Λ and the $\overline{\Lambda}$ is 2240 MeV. The rest mass of the proton is 938 MeV c^{-2}.

Calculate the **minimum** kinetic energy, E_K, of the antiproton, in order to produce the Λ and $\overline{\Lambda}$ particles when

(i) the proton and the antiproton are each accelerated to a kinetic energy E_K. *[1]*

. . . . . .

. . . . . .

. . . . . .

(ii) the antiproton is accelerated to a kinetic energy E_K and collides with a stationary proton. *[3]*

. . . . . .

. . . . . .

. . . . . .

(d) By reference to your answers to (c), state an advantage of collisions between protons and antiprotons in a synchrotron compared with collisions between stationary protons and moving antiprotons. *[1]*

. . . . . .

. . . . . .

J4. (a) Outline

(i) what is meant by a deep inelastic scattering experiment. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) how deep inelastic scattering experiments give evidence in support of the existence of quarks and gluons. *[4]*

quarks: . . . . . .

. . . . . .

gluons: . . . . . .

. . . . . .

(b) Deep inelastic scattering experiments indicate that the quarks inside hadrons behave as free particles. Suggest a reason for this. *[2]*

. . . . . .

. . . . . .

(c) State **two** fundamental differences between the standard model for quarks and leptons and the theory of strings. *[2]*

. . . . . .

. . . . . .

. . . . . .

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/HP3/ENG/TZ0/XX/M

MARKSCHEME

SPECIMEN PAPER

PHYSICS

Higher Level

Paper 3

14 pages

Option E — Astrophysics

E1. (a) *constellation*: pattern of stars;
Candidates must indicate that stars are not close together.

stellar cluster: group of stars bound by gravitation / in same region of space; ***[2]***

(b) $d = \frac{1}{0.0077}$;
$= 130\,\text{pc}$ ***[1]***

(c) no atmospheric turbulence / irregular refraction; ***[1]***

(d) (i) red/red-orange; *(not orange)*
blue / blue-white / white; ***[2]***

(ii) Betelgeuse looks brighter; ***[1]***

(iii) $L = 4\pi bd^2$;
Rearrangement of formula on data sheet required.
$d = 4.0 \times 10^{18}\,\text{m}$;
$L = 4\pi \times 2.0 \times 10^{-7} \times (4.0 \times 10^{18})^2$;
$L = 4.0 \times 10^{31}\,\text{W}$; ***[4]***

(iv) $L = 4\pi bd^2$
luminosity of Rigel is about half that of Betelgeuse; *(or ECF from (iii))*
brightness of Rigel is about 0.1 times that of Betelgeuse;
so Rigel is more distant; { *(must be a consistent conclusion from statements about luminosity and brightness)* } ***[3]***
Do not allow mark for fallacious or no argument.
*Award **[1 max]** for a mere statement that luminosity and brightness are less so Rigel is more distant.*

E2. (a) universe is infinite; ***[1]***

(b) number of stars in shell increases as R^2;
intensity decreases as $\frac{1}{R^2}$;
brightness of shell is constant;
adding all shells to infinity;
sky would be as bright as Sun / uniformly bright; ***[5]***
*Award **[2 max]** for argument based on any line of sight lands on a star.*

E3. (a) low mass stars will finish burning helium (into carbon and oxygen);
and collapse to a white dwarf; ***[2]***

(b) high mass stars will finish burning (silicon) to iron;
and collapse into a neutron star / black hole; ***[2]***

E4. (a) wavelengths are shifted;
universe is expanding / galaxies receding / Doppler Shift; ***[2]***

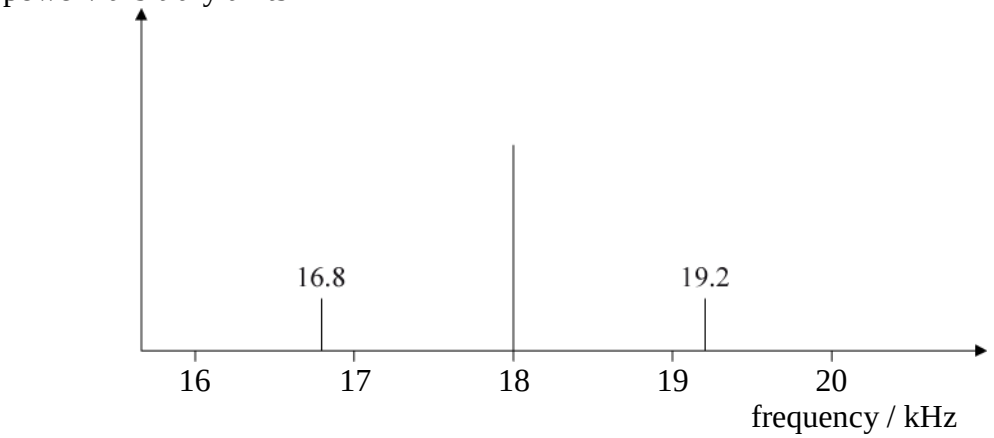
(b) statement of Hubble's law (*e.g.* $v = Hd$) with symbols explained;
v obtained from spectral lines / Doppler Shift; ***[2]***

(c) the expansion of the universe is very small on local scales;
it would be impossible to distinguish between random velocities and expansion; ***[2]***

Option F — Communications

F1. (a) (i) $15\,(\pm 1)$ carrier cycles $= 1$ information cycle;
so information frequency $= 18000 \div 15\ (\pm 1)$; *(condone $18000 \div 30$)*
$1200\,(\pm 100)$ Hz ; (condone $600\ (\pm 20)$ Hz) ; ***[3]***

(ii) centre frequency;
sidebands placed about 1200 Hz by eye each side of centre;
correct relative power (centre larger than sidebands); ***[3]***



(b) (i) radio frequency/RF amplifier between tuner and demodulator and audio frequency/AF amplifier between demodulator and loudspeaker; ***[1]***

(ii) separates information signal from carrier signal; ***[1]***

F2. (a) $T = \frac{1}{f} = 5\,\text{ms}$;
fourth sample is at 15 ms; ***[2]***

(b) $V = 13.6$;
(output is) 110; ***[2]***

(c) it will not be a faithful reproduction;
the sampling frequency is (far) too low compared to the frequency of the signal / quantization error large compared to amplitude of the signal; ***[2]***

F3. (a) $0.1 - 10\,\text{GHz}$; ***[1]***
Accept 0.1/1/10 GHz.

(b) (i) needs no tracking system / always available;
always above same point on Earth's surface; ***[2]***

(ii) polar closer;
so signal stronger / required transmission power lower;
communication possible with all points in both hemispheres (at some time); ***[2 max]***

(c) to avoid feedback / resonance / outgoing signal swamping incoming / *OWTTE*; ***[1]***

F4. (a) a circuit whose output (signal) is proportional and opposite to the input; ***[1]***

(b) (i) $I = \frac{12 \times 10^{-3}}{1.5 \times 10^{5}}$;
8.0×10^{-8}; ***[2]***

(ii) 80 mV; ***[1]***

(iii) junction between resistors is at (about) 0 V / virtual earth;
no current flows into op-amp / very high input resistance;
very high gain; ***[2 max]***

F5. (a) a <u>geographical</u> area;
allocated a specific frequency; ***[2]***

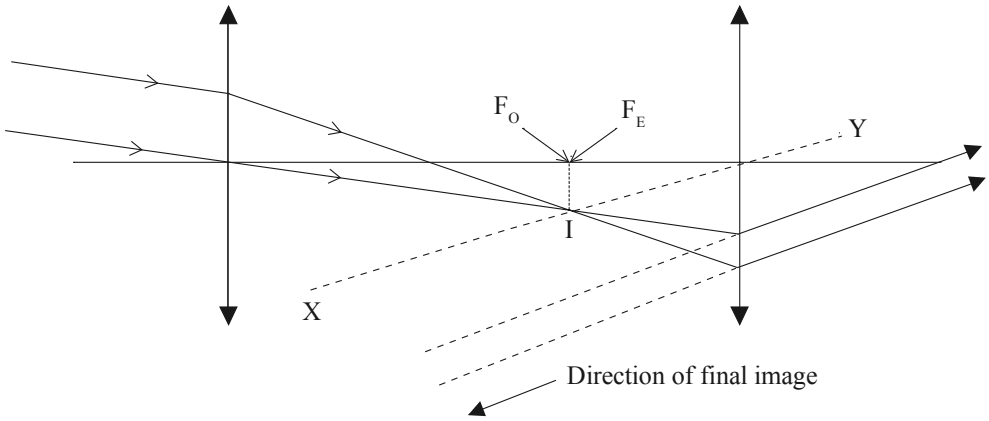
(b) different frequencies avoid interference;
large number means small cells so small power needed / small size; ***[2]***

Option G — Electromagnetic waves

G1. (a) coherent;
monochromatic / single frequency; ***[2]***

(b) <u>normally electrons occupy lowest available energy levels</u>;
to produce laser light a large number of electrons are promoted to a higher energy level / *OWTTE*;
any other valid point; ***[2 max]***

G2. (a)



(i) at F_O; ***[1]***

(ii) as shown on diagram; ***[1]***

(b) at infinity; ***[1]***

(c) two rays parallel to XY; *(judge by eye)*
extrapolated to show direction of final image; ***[2]***

(d) object distance $u = f_O + f_E = 100\,\text{cm}$;
$\frac{1}{v} + \frac{1}{100} = \frac{1}{f_E} = \frac{1}{2}$;
$\frac{1}{v} = \frac{1}{2} - \frac{1}{100}$ to give $v = 2.04\,\text{cm}$;
beyond eyepiece lens / between eyepiece lens and eye;

or

scale drawing: *(not a good idea!)*
suitable scale;
object distance;
rays to locate image;
image distance 2 cm beyond eyepiece lens; ***[4]***

G3. (a) $d = \frac{\lambda D}{s}$;

$= \frac{\lambda}{\theta}$;

$= \frac{6.33\times10^{-7}}{4.00\times10^{-4}} = 1.58\,\text{mm}$;

or

accept use of $d\sin\theta = n\lambda$ with $n = 1$;

$\sin\theta = \theta$;

$d = \frac{6.33\times10^{-7}}{4.00\times10^{-4}} = 1.58\,\text{mm}$; ***[3]***

(b) same number of maxima at the same place but much sharper;
greater intensity than double slit; ***[2]***

(c) fringes are coloured;
blue on the inside / red on the outside;

also accept:
no fringes will be seen;
light is not coherent; ***[2 max]***

G4. (a)

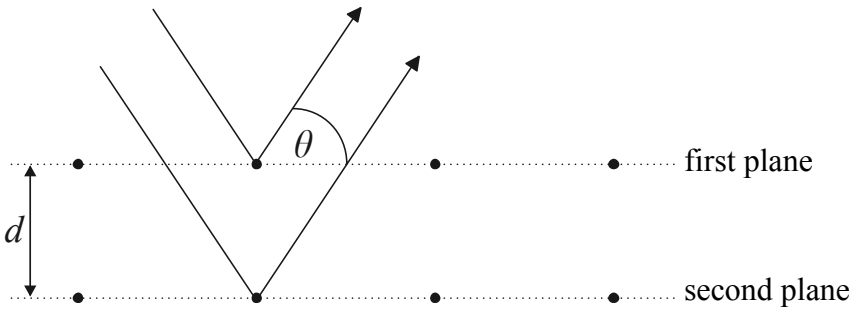


diagram showing X-rays scattered at first and second plane;
there is interference between the two reflected/scattered rays;
if path difference between the rays is integral number of wavelengths the rays will interfere constructively;
some comment to the effect that all rays scattered at this angle from all the adjacent lattice ions will reinforce; ***[4]***

(b) use of $2d\sin\theta = n\lambda$

$d = \frac{1.2\times10^{-10}}{2.0\times0.21}$;

$= 2.9\times10^{-10}\,\text{m}$ ***[1]***

G5. (a) light reflected from the top surface of the wedge interferes with light reflected from the bottom surface;
some statement about the condition for maximum/minimum in relation to the thickness of the film
e.g. path difference depends on wedge thickness so goes through maximum and minimum / *OWTTE*; *(no need to mention phase change on reflection)* ***[2]***

(b) number of fringes in 5.0×10^{-2} m $= 4.2\times10^{2}$;
path difference at edge of tape $= m\lambda = 4.2\times10^{2}\times4.8\times10^{-7}$;
$= 2d$ to give $d = 1.0\times10^{-4}$ m; ***[3]***

Option H — Relativity

H1. (a) observers using rulers and clocks to measure positions and times of events;
these observers are not accelerating; ***[2]***

(b) (i) realization that 6.0 years is the proper time interval;
calculation of gamma factor $\gamma = \frac{1}{\sqrt{1-0.80^2}} = \frac{5}{3} (= 1.67)$;
time on Earth $\gamma \times 6.0 = 10 \text{ yrs}$; ***[3]***

(ii) realization that spacecraft has been travelling for 10 years at 0.80c;
so distance is $0.80\text{c} \times 10 = 8.0 \text{ ly}$; ***[2]***

(iii) let t be the time according to the spacecraft observers, then in this time Earth will move a distance of $0.80\text{c} \times t$ according to spacecraft;
Earth and spacecraft are already separated by $0.80\text{c} \times 6 = 4.8 \text{ ly}$ according to spacecraft;
and so $\text{c}t = (0.80\text{c} \times t) + 4.8 \Rightarrow t = \frac{4.8}{0.20} = 24 \text{ years}$; ***[3]***

H2. $u_x' = \frac{(u_x - v)}{\left(1 - \frac{u_x v}{c^2}\right)}$

identifies u_x as 0.8c;
identifies v *as* -0.8c;
to give answer of 0.98c; ***[3]***

H3. (a) *RME*: rest mass times c^2;
TE: sum of RME + kinetic energy (assuming no potential energy); ***[2]***

(b) 938 MeV; ***[1]***

(c) $\gamma m_0 c^2 = m_0 c^2 + Ve$;
$Ve = \gamma m_0 c^2 - m_0 c^2$
$Ve = m_0 c^2 (\gamma - 1)$;
$Ve = 938(4.0)$;
$V = 3750 \text{ MV}$; ***[4]***

H4. (a) (i) centre is single point to which all mass would collapse;
surface is where the escape speed is equal to c;
within this surface, mass has "disappeared" from the universe; ***[3]***

(ii) distance from point of singularity to the event horizon / *OWTTE*; ***[1]***

(iii) $R_{SCH} = \frac{2GM}{c^2} = \frac{(2 \times 6.67 \times 10^{-11} \times 2 \times 10^{31})}{(3 \times 10^8)^2}$;
$= 3.0 \times 10^4$ m; ***[2]***

(iv) at 10^7 km, space is not warped;
so Newtonian physics applies;
any other good comment; ***[2 max]***
*Award **[0]** for a statement of "no" without justification.*

(b) theory suggests that light is affected by gravitational fields;
diagrams or "words" to explain formation of two images; ***[2]***

Option I — Medical physics

I1. (a) intensity is power incident per unit area;
loudness is the response of the ear to intensity; ***[2]***

(b) substitution into $1\text{L} = 10\lg\left(\frac{I}{1\times10^{-12}}\right)$

$82 = 10\lg\left(I\times10^{12}\right)$;

$I = 1.58\times10^{-4}\ \text{Wm}^{-2}$;

$I = \frac{2.4}{4\pi r^2}$;

rearrange to give $r^2 = \frac{2.4}{4\pi\times1.58\times10^{-4}}$;

$r = 35\,\text{m}$; ***[5]***

I2. (a) patient subject to large uniform magnetic field;
this field aligns protons in body;
proton spins are perturbed/*OWTTE* by small non-uniform field;
RF/electromagnetic signal is emitted as the protons return to their original alignment/relax when non-uniform field is switched off; ***[4]***

(b) NMR can yield 3D image whereas X-ray is 2D / contrast can be a problem in X-ray, NMR can discriminate between tissues / sensible alternative; ***[1]***

I3. (a) the thickness needed to cause a beam to attenuate/be reduced in intensity by 50 % / *OWTTE*; ***[1]***

(b) indication that the ratio between the linear attenuation coefficients must be the same as the ratio between half-value thicknesses / $\mu_\text{T} x_{\frac{1}{2}\text{T}} = \mu_\text{B} x_{\frac{1}{2}\text{B}}$;

(therefore) linear attenuation coefficient for bone $= 150\times0.035$;

$= 5.3\,\text{cm}^{-1}$ ***[2]***

(c) (i) substitution into $I = I_0\text{e}^{-\mu\text{x}}$, $I_\text{B} = I_\text{A}\text{e}^{-0.035\times5.0}$;

$\frac{I_\text{B}}{I_\text{A}} = 0.84$; ***[2]***

(ii) substitution to give $\frac{I_\text{C}}{I_\text{B}} = 3.1\times10^{-12}$; ***[1]***

(d) all X-rays stopped by bone so total shadow;
few X-rays stopped by soft tissue/muscle;
so (good) contrast between (air), muscle and bone; ***[3]***

I4. (a) for the same absorbed dose;
this measures the relative effectiveness of different radiations in destroying cells / *OWTTE*; ***[2]***

(b) $\frac{dN}{dt} = -N\lambda = 8.0\times10^{18}\times5.3\times10^{-10} = 4.2\times10^{9}$;
dose equivalent $= 4.2\times10^{-9}\times4\times10^{-14} = 0.17\,\text{mSv}/\text{J}\,\text{kg}^{-1}$; ***[2]***

I5. (a) biological half-life is the time it takes the body to eject by natural bodily processes;
half of an ingested sample of a radioactive isotope; ***[2]***
*To award **[2]** some mention must be made of the general or specific method by which the amount of the isotope in the body is reduced.*

(b) $\frac{1}{T_E} = \frac{1}{21} + \frac{1}{8}$;
to give $T_E = 5.8$ days; ***[2]***

(c) because of its short physical half life it is much less likely to cause damage to the thyroid gland / because person is radioactive for a shorter time / because total dose received would be smaller / *OWTTE*; ***[1]***

Option J — Particle physics

J1. (a) (i) a particle that appears as an intermediate particle in a Feynman diagram / a particle that is not observed and may violate energy and momentum conservation at a vertex; ***[1]***

(ii) W^-;
applying charge conservation at either vertex;
e.g. $-\frac{1}{3} = \frac{2}{3} + x \Rightarrow x = -1$ *or* $x = -1 + 0 = -1$ ***[2]***

(b) conversion of mass into kg
$100\,\text{GeVc}^{-2} = \frac{100 \times 10^9 \times 1.6 \times 10^{-19}}{9 \times 10^{16}} = 1.78 \times 10^{-25}\,\text{kg}$;
correct substitution in $R = \frac{6.63 \times 10^{-34}}{4\pi(1.78 \times 10^{-25})(3 \times 10^8)}$;
to get $9.9 \times 10^{-19}\,\text{m} \approx 10^{-18}\,\text{m}$; ***[3]***

J2. (a) (The Pauli exclusion principle states:) it is impossible for two identical fermions/half integral spin particles to occupy the same quantum state / it is impossible for two fermions with the same quantum numbers to be in the same quantum state;
the three quarks are distinguished by an additional quantum number, colour; ***[2]***

(b) there are two states of spin;
and so one can make a spin $\frac{1}{2}$ particle out of three spin $\frac{1}{2}$ objects by having two parallel and one opposite / up + up + down / $+\frac{1}{2} + \frac{1}{2} - \frac{1}{2}$; ***[2]***

J3. (a) (i) the electric fields are used to accelerate the protons; ***[1]***

(ii) the magnetic fields are used to bend the protons into circular paths; ***[1]***

(b) the radius of the circular path increases as the speed increases;
since $R = \frac{mv}{qB}$;
to keep the protons in the same circular path B has to increase; ***[3]***

(c) (i) so each beam must have a kinetic energy of $1120 - 938 = 182\,\text{MeV}$; ***[1]***

(ii) hence total energy E of accelerated particle is given by
$2240^2 = 2(938)E + 2(938)^2$
$\Rightarrow E = 1740\,\text{MeV}$
to give $E_\text{K} = 1740 - 938 = 802\,\text{MeV}$; ***[3]***

(d) the energy needed is much less in collisions between moving particles; ***[1]***

J4. (a) (i) an experiment in which leptons scatter off hadrons;
imparting/transferring large amounts of energy/momentum (compared to rest masses) to the hadrons; ***[2]***

(ii) *quarks*: ***[2 max]***
scattering pattern is different from that expected from a single individual particle;
and consistent with three constituents inside baryons;

also accept:
deep inelastic scattering experiments measure the momentum carried by charged constituents inside hadrons;
the momentum carried by a constituent is about $\frac{1}{3}\left(\frac{1}{2}\right)$ of the total momentum indicating that there are 3 (2) constituents in baryons (mesons);

gluons: ***[2 max]***
the total momentum carried by the charged constituents does not add up to that of the hadron;
indicating that there must exist other neutral constituents inside the hadron; ***[4]***

(b) in deep inelastic scattering experiments the energy transferred is very large;
the strength of the interaction between quarks decreases as the energy of the interaction increases (due to a property called asymptotic freedom) hence quarks behave as almost free particles; ***[2]***

(c) in the standard model the fundamental building blocks of matter are point particles but in strings they are extended objects;
the standard model is formulated in four dimensions (accept three) – strings require many extra dimensions / *OWTTE*; ***[2]***

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

PHYSICS
STANDARD LEVEL
PAPER 1

SPECIMEN PAPER

45 minutes

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Answer all the questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.

1. The order of magnitude of the weight of an apple is

A. 10^{-4} N.

B. 10^{-2} N.

C. 1 N.

D. 10^{2} N.

2. The density of a metal cube is given by the expression $\rho = \frac{M}{V}$ where M is the mass and V is the volume of the cube. The percentage uncertainties in M and V are as shown below.

M	12 %
V	4.0 %

The percentage uncertainty in the calculated value of the density is

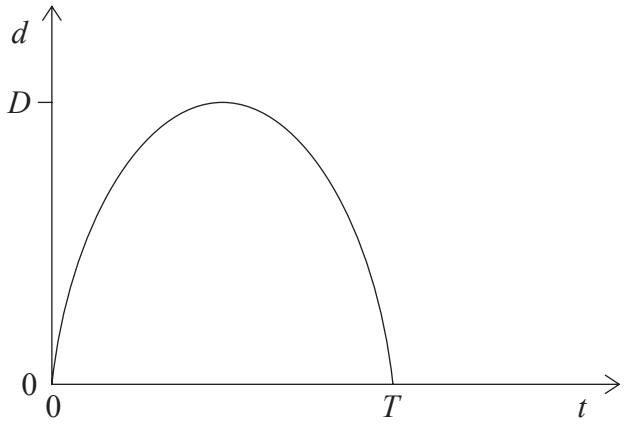
A. 3.0 %.

B. 8.0 %.

C. 16 %.

D. 48 %.

3. A ball is thrown vertically upwards from the ground. The graph shows the variation with time t of the vertical displacement d of the ball.



Which of the following gives the final displacement after time T and the average speed between time $t = 0$ and time $t = T$?

	Displacement	Average speed
A.	0	0
B.	0	$\frac{2D}{T}$
C.	$2D$	$\frac{2D}{T}$
D.	$2D$	0

4. A general expression for Newton's second law of motion is

$$F = \frac{\Delta p}{\Delta t}.$$

What condition is applied so that the law may be expressed in the form $F = ma$?

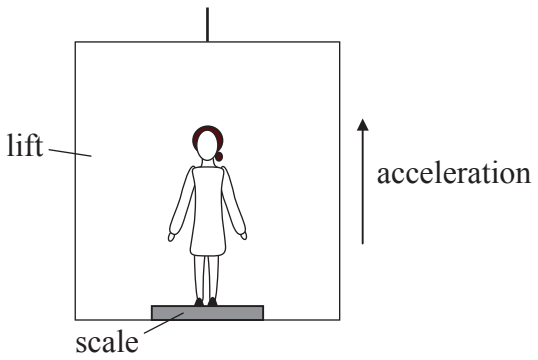
A. The mass m is constant.

B. The acceleration a is constant.

C. The force F is constant.

D. The direction of the force F is constant.

5. Mandy stands on a weighing scale inside a lift (elevator) that accelerates vertically upwards as shown in the diagram below. The forces on Mandy are her weight W and the reaction force from the scale R.



The reading of the scale is

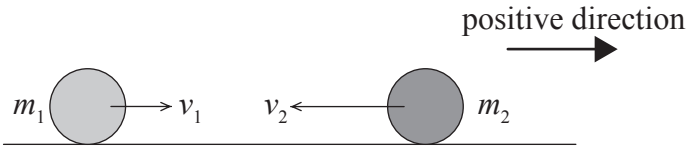
A. $R + W$.

B. W.

C. R.

D. $R - W$.

6. Two spheres of masses m_1 and m_2 are moving towards each other along the same straight-line with speeds v_1 and v_2 as shown.



The spheres collide. Which of the following gives the total change in linear momentum of the spheres as a result of the collision?

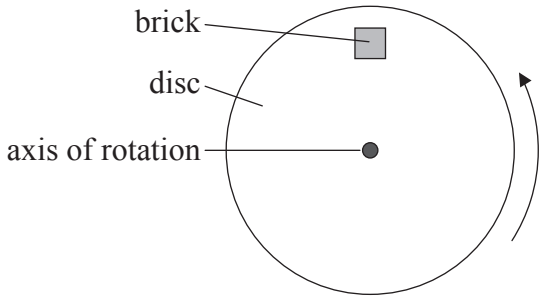
A. 0

B. $m_1v_1 + m_2v_2$

C. $m_1v_1 - m_2v_2$

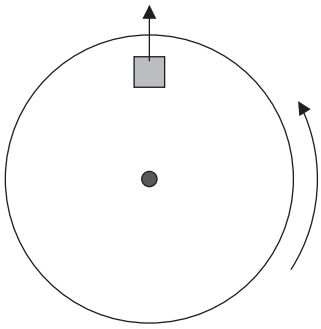
D. $m_2v_2 - m_1v_1$

7. A brick is placed on the surface of a flat horizontal disc as shown in the diagram below. The disc is rotating at constant speed about a vertical axis through its centre. The brick does not move relative to the disc.

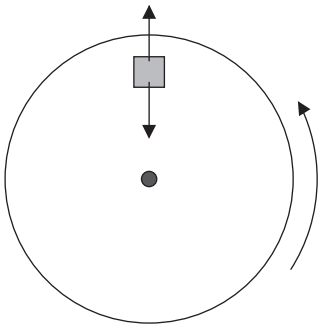


Which of the diagrams below correctly represents the **horizontal** force or forces acting on the brick?

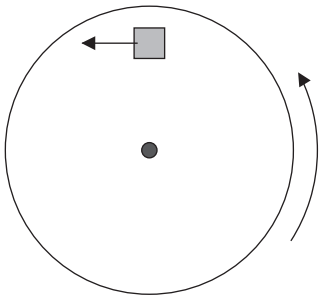
A.



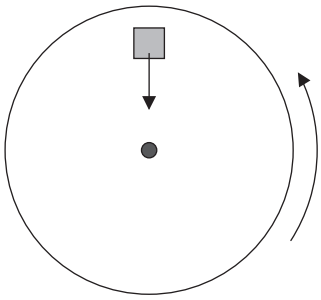
B.



C.



D.



8. A frictionless trolley of mass m moves down a slope with a constant acceleration a. A second similar frictionless trolley has mass $2m$. The acceleration of the second trolley as it moves down the slope is

A. $\frac{1}{2}a$.

B. a.

C. $2a$.

D. $4a$.

9. The internal energy of a solid substance is equal to the

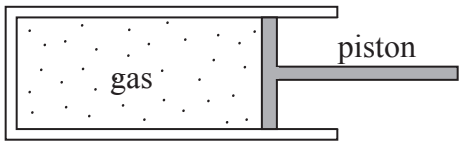
A. average kinetic energy of the molecules.

B. total kinetic energy of the molecules.

C. total potential energy of the molecules.

D. total potential and total kinetic energy of the molecules.

10. A gas is contained in a cylinder fitted with a piston as shown below.



When the gas is compressed rapidly by the piston its temperature rises **because** the molecules of the gas

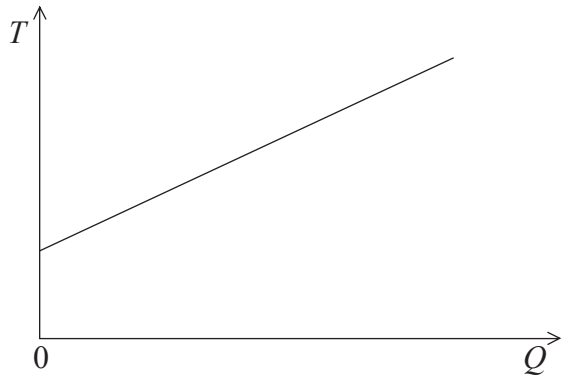
A. are squeezed closer together.

B. collide with each other more frequently.

C. collide with the walls of the container more frequently.

D. gain energy from the moving piston.

11. The specific heat capacity c of a solid block of mass m is determined by heating the block and measuring its temperature. The graph below shows the variation of the temperature T of the block with the thermal energy Q transferred to the block.



The gradient of the line is equal to

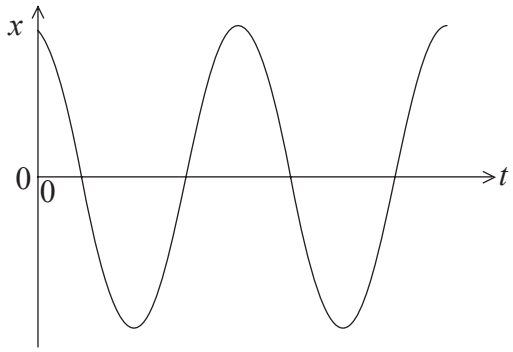
A. $\frac{c}{m}$.

B. $\frac{m}{c}$.

C. mc.

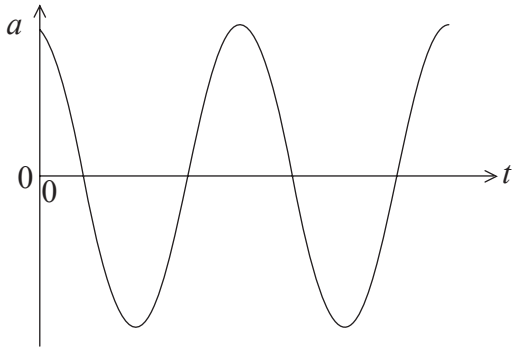
D. $\frac{1}{mc}$.

12. The graph below shows the variation with time t of the displacement x of a particle undergoing simple harmonic motion.

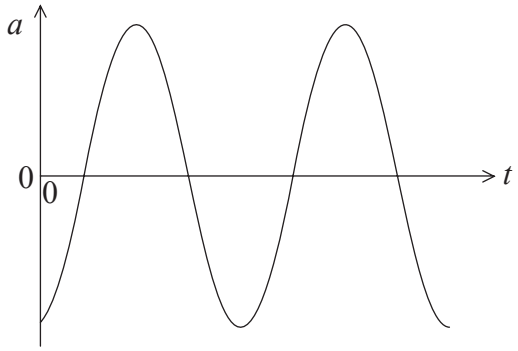


Which graph correctly shows the variation with time t of the acceleration a of the particle?

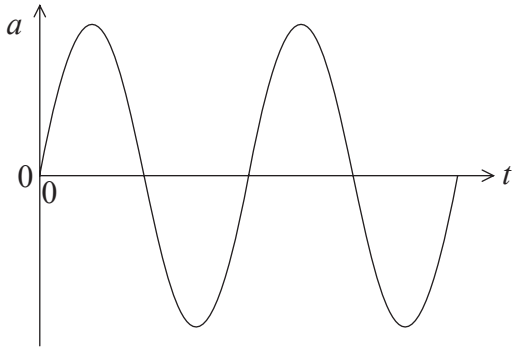
A.



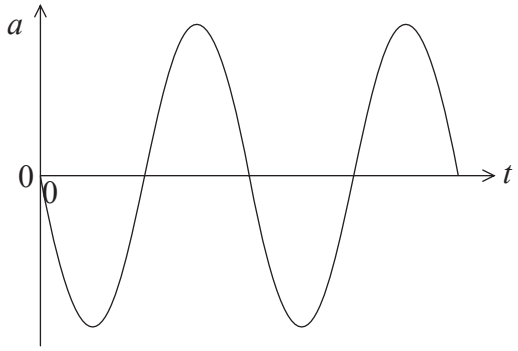
B.



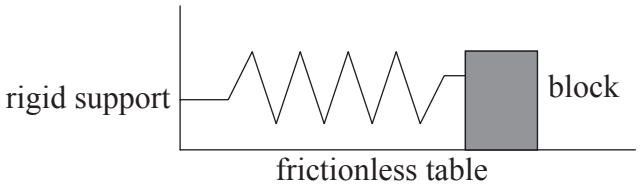
C.



D.



13. A wooden block is at rest on a horizontal frictionless surface. A horizontal spring is attached between the block and a rigid support.



The block is displaced to the right by an amount X and is then released. The period of oscillations is T and the total energy of the system is E.

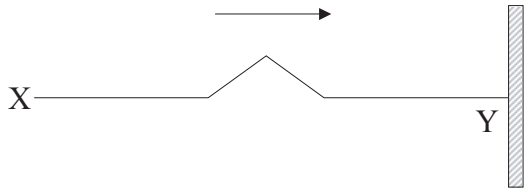
For an initial displacement of $\frac{X}{2}$ which of the following shows the best estimate for the period of oscillations and the total energy of the system?

	Period	Total energy
A.	T	$\frac{E}{2}$
B.	T	$\frac{E}{4}$
C.	$\frac{T}{2}$	$\frac{E}{2}$
D.	$\frac{T}{2}$	$\frac{E}{4}$

14. Which of the following correctly describes the change, if any, in the speed, wavelength and frequency of a light wave as it passes from air into glass?

	Speed	Wavelength	Frequency
A.	decreases	decreases	unchanged
B.	decreases	unchanged	decreases
C.	unchanged	increases	decreases
D.	increases	increases	unchanged

15. The diagram below shows a pulse travelling along a rope from X to Y. The end Y of the rope is tied to a fixed support.



When the pulse reaches end Y it will

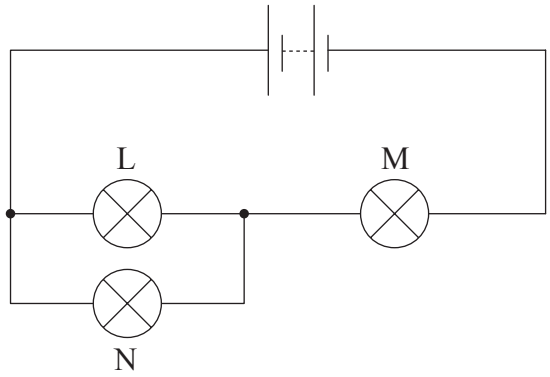
A. disappear.

B. cause the end of the rope at Y to oscillate up and down.

C. be reflected and be inverted.

D. be reflected and not be inverted.

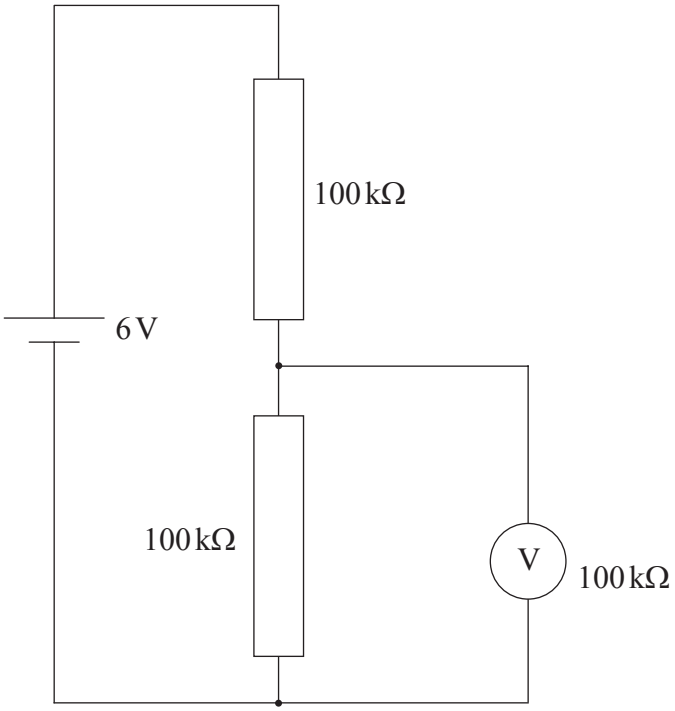
16. In the circuit below, the battery has negligible internal resistance. Three identical lamps L, M and N of constant resistance are connected as shown.



The filament of lamp N breaks. Which of the following shows the subsequent changes to the brightness of lamp L and lamp M?

	Lamp L	Lamp M
A.	stays the same	decreases
B.	increases	stays the same
C.	increases	decreases
D.	decreases	increases

17. In the circuit below, the voltmeter has a resistance 100 kΩ. The battery has negligible internal resistance and e.m.f. 6 V.



The reading on the voltmeter is

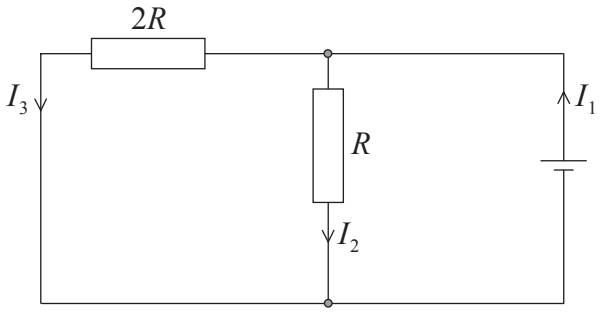
A. 0 V.

B. 2 V.

C. 3 V.

D. 4 V.

18. In the circuit shown below, the cell has negligible internal resistance.



Which of the following equations is correct?

A. $I_1 = 2I_2$

B. $I_1 = 2I_3$

C. $I_2 = 2I_3$

D. $I_3 = 2I_1$

19. In Newton's universal law of gravitation the masses are assumed to be

A. extended masses.

B. masses of planets.

C. point masses.

D. spherical masses.

20. The electric field strength at a point may be defined as

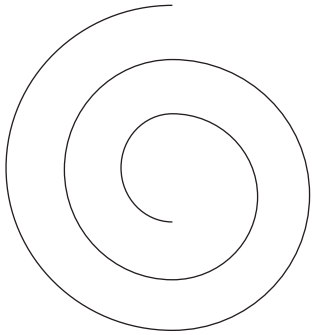
A. the force exerted on unit positive charge placed at that point.

B. the force per unit positive charge on a small test charge placed at that point.

C. the work done on unit positive charge to move the charge to that point from infinity.

D. the work done per unit positive charge to move a small test charge to that point from infinity.

21. An electron is moving in air at right angles to a uniform magnetic field. The diagram below shows the path of the electron. The electron is slowing down.



region of magnetic field

Which of the following correctly gives the direction of motion of the electron and the direction of the magnetic field?

	Direction of motion	Direction of magnetic field
A.	clockwise	into plane of paper
B.	clockwise	out of plane of paper
C.	anti-clockwise	into plane of paper
D.	anti-clockwise	out of plane of paper

22. The binding energy per nucleon of the nucleus $^{7}_{3}\text{Li}$ is approximately 5 MeV. The total energy required to completely separate the nucleons of this nucleus is approximately

A. 15 MeV.

B. 20 MeV.

C. 35 MeV.

D. 50 MeV.

23. The initial activity of a sample of a radioactive isotope of half-life 10 hours is A. What is the age of the sample when its activity is $\frac{A}{32}$?

A. 30 hours

B. 40 hours

C. 50 hours

D. 320 hours

24. When the isotope aluminium-27 is bombarded with alpha particles, the following nuclear reaction can take place.

$$^{4}_{2}\text{He} + ^{27}_{13}\text{Al} \rightarrow \text{X} + \text{neutron}$$

Which of the following correctly gives the atomic (proton) number and mass (nucleon) number of the nucleus X?

	Proton number	Nucleon number
A.	15	30
B.	16	31
C.	30	15
D.	31	16

25. The volume of a given mass of water at a temperature of T_1 is V_1. The volume increases to V_2 at temperature T_2. The coefficient of volume expansion of water may be calculated from

A. $\frac{V_2}{T_2} - \frac{V_1}{T_1}$.

B. $\frac{V_2 - V_1}{T_2 - T_1}$.

C. $\frac{V_2 - V_1}{V_1(T_2 - T_1)}$.

D. $\frac{V_2 - V_1}{V_2(T_2 - T_1)}$.

26. The commercial production of energy by nuclear fusion is not yet possible mainly due to difficulties with

A. obtaining plentiful supplies of a suitable fuel.

B. reaching the high temperatures required.

C. confining the hot plasma.

D. disposing of the radioactive waste products.

27. A wind generator produces 5.0 kW of power for a wind speed of $6.0\,m\,s^{-1}$. The best estimate for the power produced for a wind speed of $12.0\,m\,s^{-1}$ is

A. 10 kW.

B. 25 kW.

C. 40 kW.

D. 125 kW.

28. It is hypothesized that global warming may lead to significant changes in the average sea-level. This hypothesis assumes that

A. average rainfall will increase.

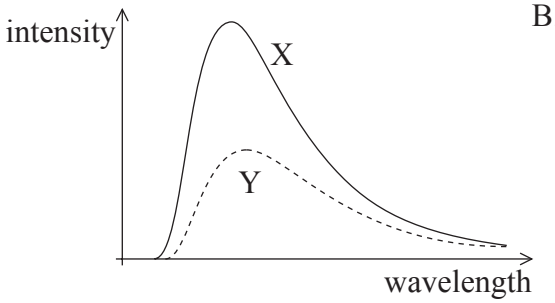
B. icebergs will melt.

C. glaciers will melt.

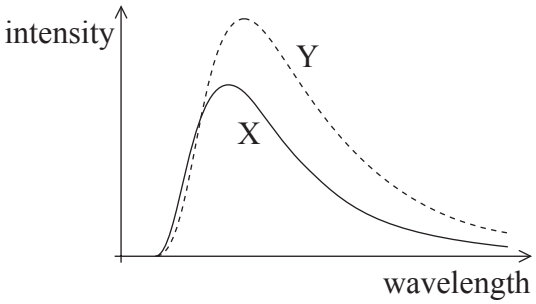
D. the rate of evaporation of seawater will increase.

29. Two black bodies X and Y are at different temperatures. The temperature of body Y is higher than that of body X. Which of the following shows the black body spectra for the two bodies?

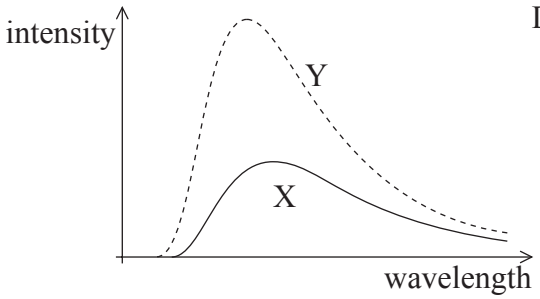
A.



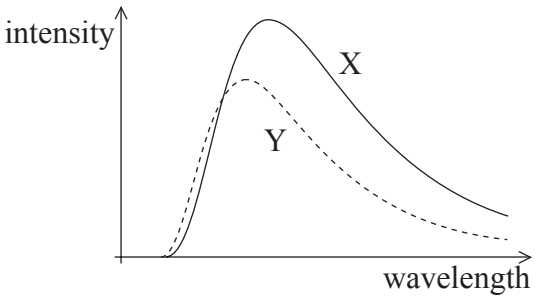
B.



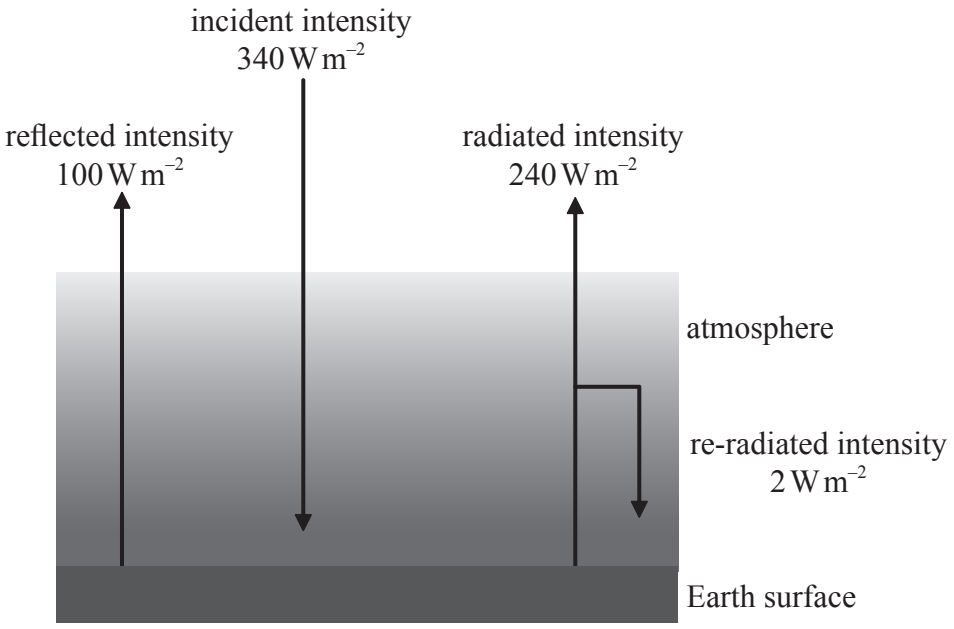
C.



D.



30. The diagram below shows a simplified model of the energy balance for Earth.



The albedo of the Earth according to this model is equal to

A. $\frac{2}{340}$.

B. $\frac{100}{340}$.

C. $\frac{238}{340}$.

D. $\frac{240}{340}$.

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/SPM/ENG/TZ0/XX/M

MARKSCHEME

SPECIMEN PAPER

PHYSICS

Standard Level

Paper 1

2 pages

1.	C	16.	C	31.	–	46.	–
2.	C	17.	B	32.	–	47.	–
3.	B	18.	C	33.	–	48.	–
4.	A	19.	C	34.	–	49.	–
5.	C	20.	B	35.	–	50.	–
6.	A	21.	D	36.	–	51.	–
7.	D	22.	C	37.	–	52.	–
8.	B	23.	C	38.	–	53.	–
9.	D	24.	A	39.	–	54.	–
10.	D	25.	C	40.	–	55.	–
11.	D	26.	C	41.	–	56.	–
12.	B	27.	C	42.	–	57.	–
13.	B	28.	C	43.	–	58.	–
14.	A	29.	C	44.	–	59.	–
15.	C	30.	B	45.	–	60.	–

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/SP2/ENG/TZ0/XX

PHYSICS
STANDARD LEVEL
PAPER 2

SPECIMEN PAPER

1 hour 15 minutes

Candidate session number

0	0							

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer one question from Section B in the spaces provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet.

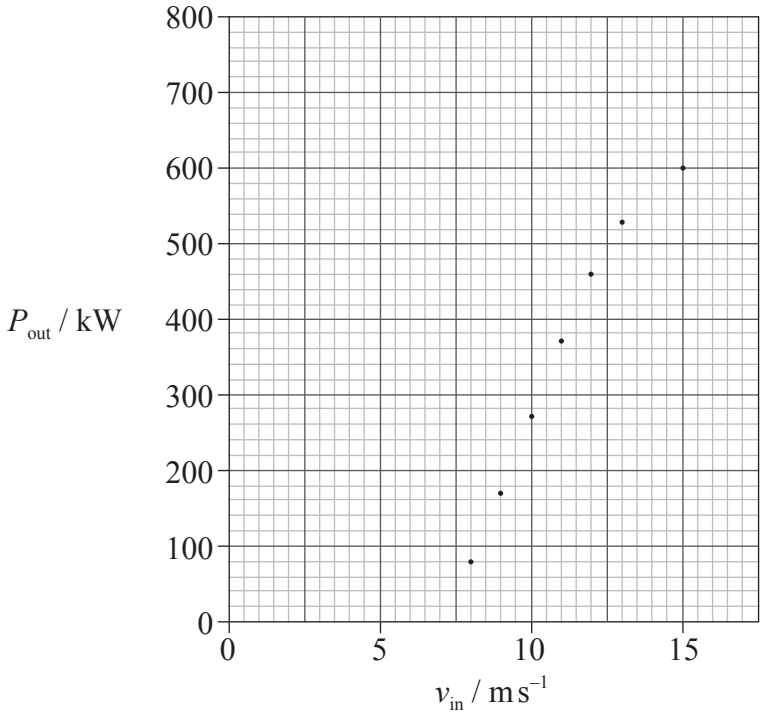
SECTION A

*Answer **all** the questions in the spaces provided.*

A1. This question is about the electrical power available from a wind turbine.

The maximum electrical power generated by a wind turbine, P_{out}, was measured over a range of incident wind speeds, v_{in}.

The graph below shows the variation with v_{in} of P_{out}. Uncertainties for the data are not shown.



(a) It is suggested that P_{out} is proportional to $\sqrt{v_{in}}$.

(i) Draw the line of best-fit for the data points. *[1]*

(ii) State **one** reason why the line you have drawn does not support this hypothesis. *[1]*

. . . . . .

. . . . . .

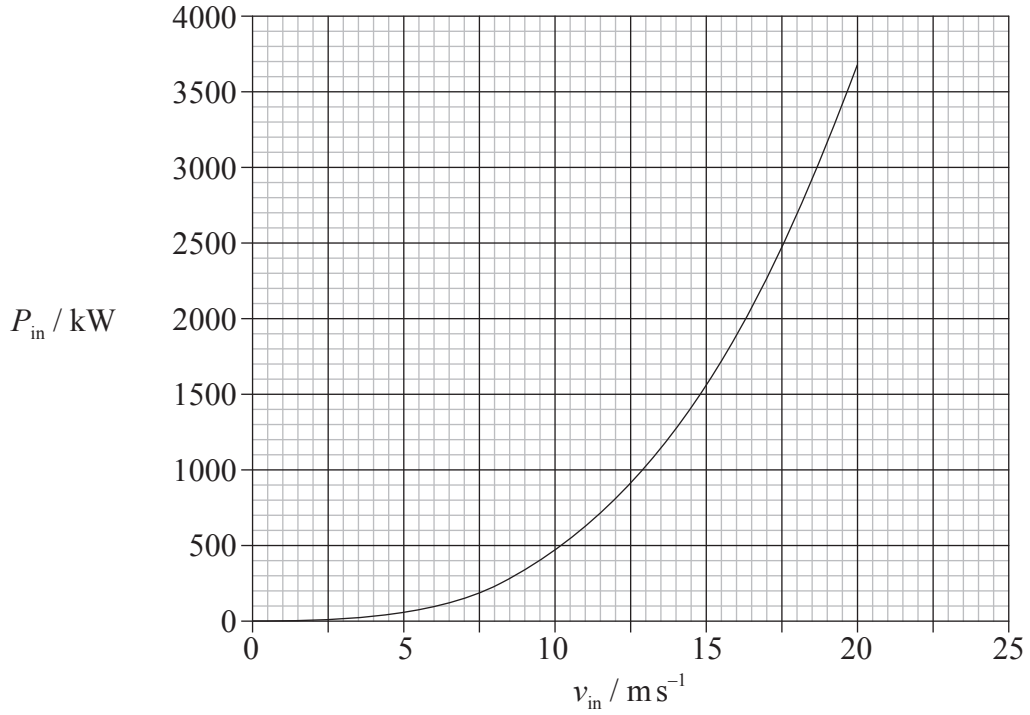
. . . . . .

(iii) The uncertainty in the power at 15 m s^{-1} is 5 %. Draw an error bar on the graph to represent this uncertainty. *[2]*

(This question continues on the following page)

(Question A1 continued)

(b) The theoretical relationship between the available power in the wind, P_{in}, and incident wind speed is shown in the graph below.



Using both graphs,

(i) determine the efficiency of the turbine for an incident wind speed of 14 m s^{-1}. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) suggest, without calculation, how the efficiency of the turbine changes with increasing wind speed. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question A1 continued)

(c) Outline **one** advantage and **one** disadvantage of using wind turbines to generate electrical energy. *[2]*

Advantage: . . . . . .
. . . . . .
. . . . . .
. . . . . .

Disadvantage: . . . . . .
. . . . . .
. . . . . .
. . . . . .

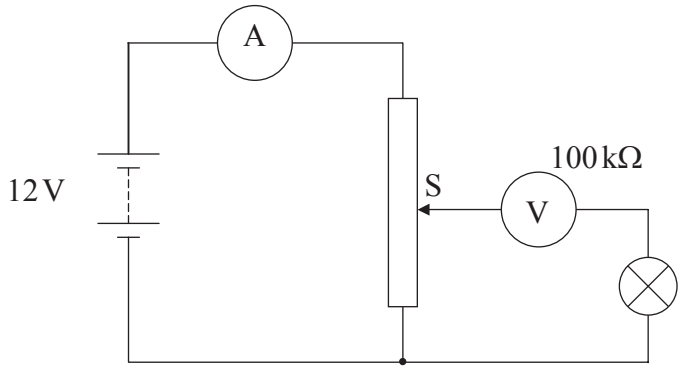
Blank page

A2. This question is about an electric circuit.

A particular filament lamp is rated at 12 V, 6.0 mA. It just lights when the potential difference across the filament is 6.0 V.

A student sets up an electric circuit to measure the *I-V* characteristic of the filament lamp.

In the circuit, shown below, the student has connected the voltmeter and the ammeter into the circuit **incorrectly**.



The battery has e.m.f. 12 V and negligible internal resistance. The ammeter has negligible resistance and the resistance of the voltmeter is 100 kΩ. The maximum resistance of the variable resistor is 15 Ω.

(a) Explain, without doing any calculations, whether there is a position of the slide S at which the lamp will be lit. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Estimate the maximum reading of the ammeter. *[2]*

. . . . . .

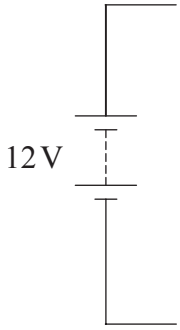
. . . . . .

. . . . . .

(This question continues on the following page)

(Question A2 continued)

(c) Complete the circuit diagram below showing the correct position of the voltmeter and of the ammeter in order to determine the *I-V* characteristic of the filament lamp. *[2]*



A3. This question is about gravitational fields.

(a) Define *gravitational field strength*. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) The gravitational field strength at the surface of Jupiter is $25\,\text{N}\,\text{kg}^{-1}$ and the radius of Jupiter is $7.1\times10^{7}\,\text{m}$.

(i) Derive an expression for the gravitational field strength at the surface of a planet in terms of its mass M, its radius R and the gravitational constant G. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Use your expression in (b)(i) above to estimate the mass of Jupiter. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

SECTION B

*This section consists of three questions: B1, B2 and B3. Answer **one** question.*

B1. This question is in **two** parts. **Part 1** is about simple harmonic motion and its connection with the greenhouse effect. **Part 2** is about specific heat capacity and heating water for a domestic shower.

Part 1 Simple harmonic motion and the greenhouse effect

(a) A body is displaced from equilibrium. State the **two** conditions necessary for the body to execute simple harmonic motion. *[2]*

1. . . . . .

. . . . . .

2. . . . . .

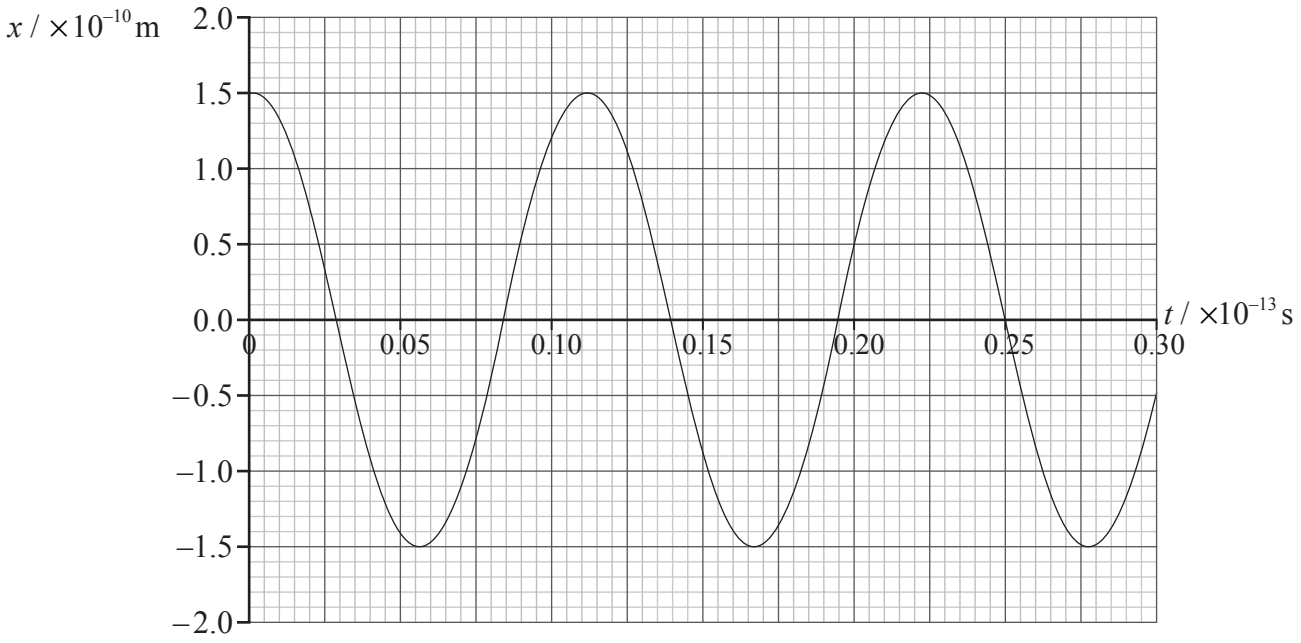
. . . . . .

(This question continues on the following page)

(Question B1, part 1 continued)

(b) In a simple model of a methane molecule, a hydrogen atom and the carbon atom can be regarded as two masses attached by a spring. A hydrogen atom is much less massive than the carbon atom such that any displacement of the carbon atom may be ignored.

The graph below shows the variation with time t of the displacement x from its equilibrium position of a hydrogen atom in a molecule of methane.



The mass of hydrogen atom is 1.7×10^{-27} kg. Use data from the graph above

(i) to determine its amplitude of oscillation. *[1]*

. . . . . .

(ii) to show that the frequency of its oscillation is 9.1×10^{13} Hz. *[2]*

. . . . . .

. . . . . .

(iii) to show that the maximum kinetic energy of the hydrogen atom is 6.2×10^{-18} J. *[2]*

. . . . . .

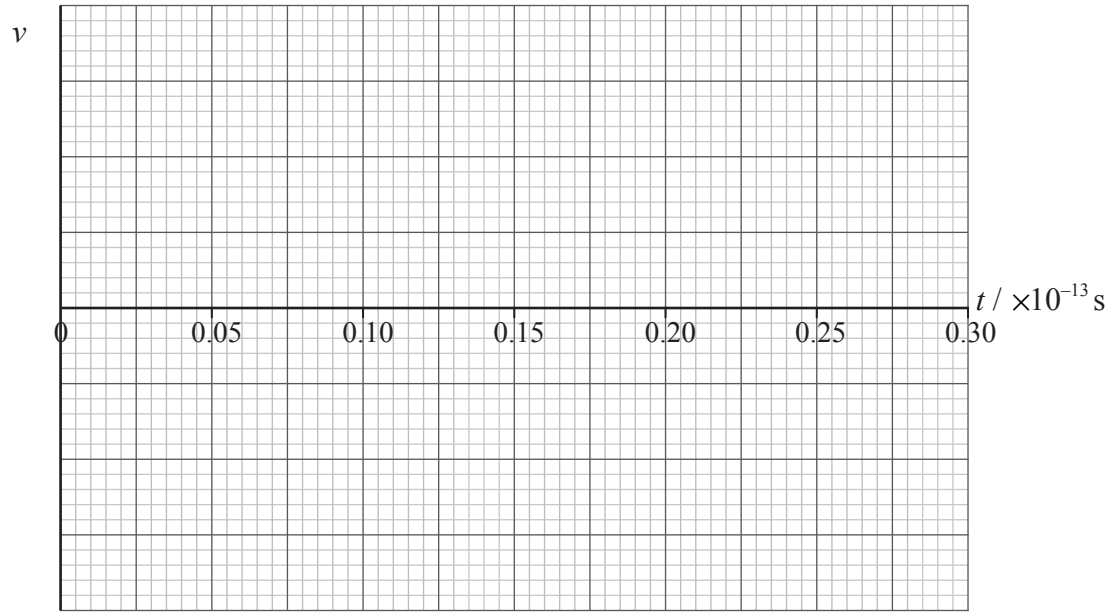
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 1 continued)

(c) On the grid below, sketch a graph to show the variation with time t of the velocity v of the hydrogen atom for one period of oscillation starting at $t = 0$. (There is no need to add values to the velocity axis.) *[3]*



(d) Assuming that the motion of the hydrogen atom is simple harmonic, its frequency of oscillation f is given by the expression

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_p}},$$

where k is the force per unit displacement between a hydrogen atom and the carbon atom and m_p is the mass of a proton.

(i) Show that the value of k is approximately $560\,\text{N m}^{-1}$. *[1]*

. . . . . .

. . . . . .

(ii) Estimate, using your answer to (d)(i), the maximum acceleration of the hydrogen atom. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 1 continued)

(e) Methane is classified as a greenhouse gas.

(i) Describe what is meant by a greenhouse gas. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Electromagnetic radiation of frequency 9.1×10^{13} Hz is in the infrared region of the electromagnetic spectrum. Suggest, based on the information given in (b)(ii), why methane is classified as a greenhouse gas. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1 continued)

Part 2 Specific heat and a domestic shower

(a) Define *specific heat capacity*. *[1]*

. . . . . .

. . . . . .

. . . . . .

(b) Equal masses of two different solid substances A and B are at the same temperature. The specific heat capacity of substance A is greater than the specific heat capacity of substance B. The two substances now have their temperatures raised by the same amount.

Explain which substance will have the greater increase in internal energy assuming both remain in the solid phase. *[2]*

. . . . . .

. . . . . .

. . . . . .

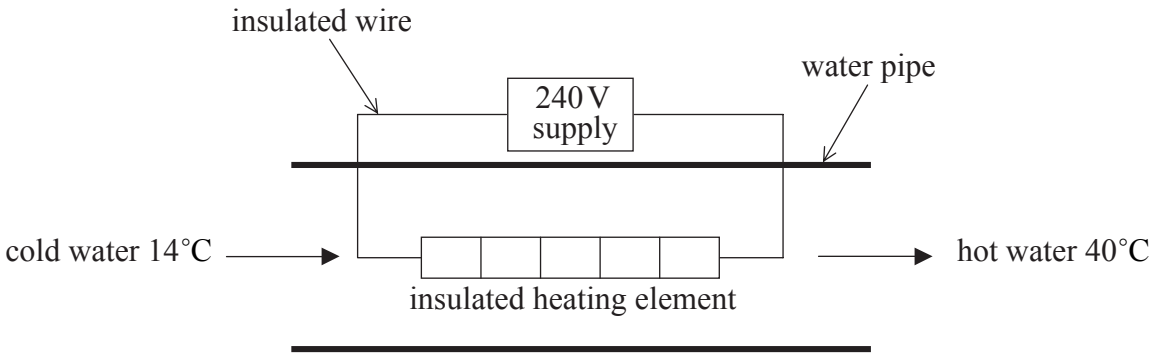
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 2 continued)

(c) The diagram below shows part of the heating circuit of a domestic shower.



Cold water enters the shower unit and flows over an insulated heating element. The heating element is rated at 7.2 kW, 240 V. The water enters at a temperature of 14°C and leaves at a temperature of 40°C. The specific heat capacity of water is $4.2\times10^{3}\,\text{J kg}^{-1}\,\text{K}^{-1}$.

(i) Estimate the flow rate of the water. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

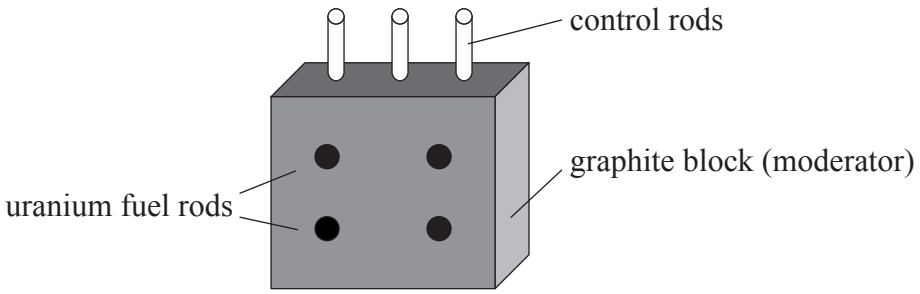
(ii) Suggest **one** reason why your answer to (c)(i) is only an estimate. *[1]*

. . . . . .

. . . . . .

B2. This question is about nuclear power production.

(a) The purpose of a nuclear power station is to produce electrical energy from nuclear energy. The diagram below is a representation of the principal components of a nuclear reactor pile used in a certain type of nuclear power station that uses uranium as a fuel.



The function of the moderator is to slow down the neutrons produced in a reaction such as that described above.

Explain,

(i) why it is necessary to slow down the neutrons. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) the function of the control rods. *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(b) With reference to the concept of fuel enrichment in a nuclear reactor explain,

(i) the advantage of enriching the uranium used in a nuclear reactor. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) from an international point of view, a possible risk to which fuel enrichment could lead. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A particular nuclear reactor uses uranium-235 as its fuel source. When a nucleus of uranium-235 absorbs a neutron, the following reaction can take place.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{144}_{54}\mathrm{Xe} + {}^{90}_{38}\mathrm{Sr} + 2\,{}^{1}_{0}\mathrm{n}$$

The following data are available.

$$\text{rest mass of } {}^{235}_{92}\mathrm{U} = 2.1895 \times 10^{5}\,\mathrm{MeV\,c^{-2}}$$
$$\text{rest mass of } {}^{144}_{54}\mathrm{Xe} = 1.3408 \times 10^{5}\,\mathrm{MeV\,c^{-2}}$$
$$\text{rest mass of } {}^{90}_{38}\mathrm{Sr} = 8.3749 \times 10^{4}\,\mathrm{MeV\,c^{-2}}$$
$$\text{rest mass of } {}^{1}_{0}\mathrm{n} = 939.56\,\mathrm{MeV\,c^{-2}}$$

(i) Show that the energy released in the reaction is approximately 180 MeV. *[1]*

. . . . . .

. . . . . .

(ii) State the form in which the energy appears. *[1]*

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(d) The energy released by 1 atom of carbon-12 during combustion is approximately 4 eV.

(i) Using the answer to (c)(i), estimate the ratio

$$\frac{\text{energy density of uranium-235}}{\text{energy density of carbon-12}}.$$ *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Suggest, with reference to your answer in (d)(i), **one** advantage of uranium-235 compared with fossil fuels. *[1]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(e) When a uranium-238 nucleus absorbs a neutron the following reaction can take place.

$$^{238}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{239}_{92}\mathrm{U}$$

The isotope uranium-239 is radioactive and decays with a half-life of 23 minutes to form an isotope of neptunium-239 (Np-239).

(i) Define *radioactive half-life* and explain what is meant by an isotope. *[2]*

Radioactive half-life:

. . . . . .

. . . . . .

Isotope:

. . . . . .

. . . . . .

(ii) Complete the reaction equation for this decay. *[3]*

$$^{239}_{92}\mathrm{U} \rightarrow$$

(iii) The isotope neptunium-239 undergoes radioactive β^- decay to form an isotope of plutonium. Outline **one** advantage and **one** disadvantage of this decay in relation to nuclear power production. *[4]*

Advantage:

. . . . . .

. . . . . .

. . . . . .

Disadvantage:

. . . . . .

. . . . . .

. . . . . .

B3. This question is in **two** parts. **Part 1** is about mechanical power. **Part 2** is about radioactive decay.

Part 1 Mechanical power

(a) Define *power*. *[1]*

. . . . . .

. . . . . .

(b) A car is travelling with constant speed v along a horizontal straight road. There is a total resistive force F acting on the car.

Deduce that the power P to overcome the force F is $P = Fv$. *[2]*

. . . . . .

. . . . . .

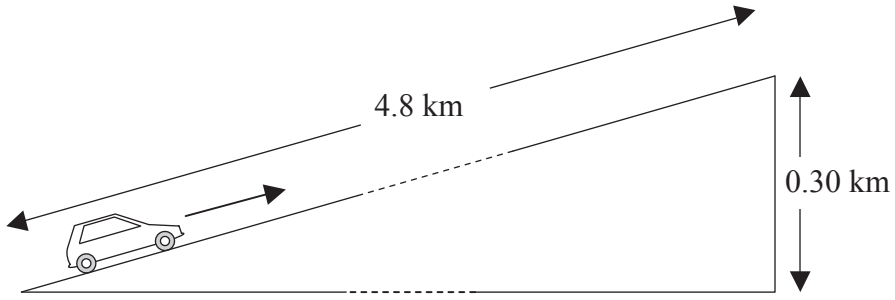
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 1 continued)

(c) A car drives up a straight incline that is 4.8 km long. The total height of the incline is 0.30 km.



The car moves up the incline at a steady speed of $16\,m\,s^{-1}$. During the climb, the average friction force acting on the car is $5.0\times10^{2}\,N$. The total weight of the car and the driver is $1.2\times10^{4}\,N$.

(i) Determine the time it takes the car to travel from the bottom to the top of the incline. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) Determine the work done against the gravitational force in travelling from the bottom to the top of the incline. *[1]*

. . . . . .

(iii) Using your answers to (c)(i) and (c)(ii), calculate a value for the minimum power output of the car engine needed to move the car from the bottom to the top of the incline. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

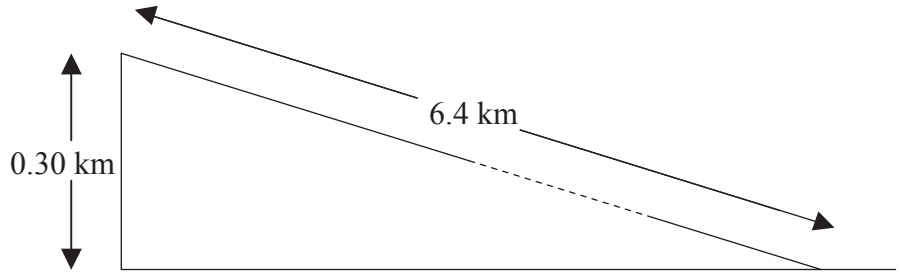
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 1 continued)

(d) From the top of the incline, the road continues downwards in a straight line. At the point where the road starts to go downwards, the driver of the car in (c), stops the car to look at the view. In continuing his journey, the driver decides to save fuel. He switches off the engine and allows the car to move freely down the hill. The car descends a height of 0.30 km in a distance of 6.4 km before levelling out.



The average resistive force acting on the car is 5.0×10^2 N.

Estimate

(i) the acceleration of the car down the incline. *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) the speed of the car at the bottom of the incline. *[2]*

. . . . . .

. . . . . .

(e) In fact, for the last few hundred metres of its journey down the hill, the car travels at constant speed. State the value of the frictional force acting on the car whilst it is moving at constant speed. *[1]*

. . . . . .

(This question continues on the following page)

(Question B3 continued)

Part 2 Radioactive decay

(a) Carbon-14 is a radioactive isotope with a half-life of 5500 years. It is produced in the atmosphere by neutron bombardment of nitrogen. The equation for this reaction is

$$^{14}_{7}\mathrm{N} + ^{1}_{0}\mathrm{n} \rightarrow ^{14}_{6}\mathrm{C} + \mathrm{X}.$$

(i) Explain what is meant by isotopes. *[1]*

. . . . . .

. . . . . .

(ii) Identify the particle X. *[1]*

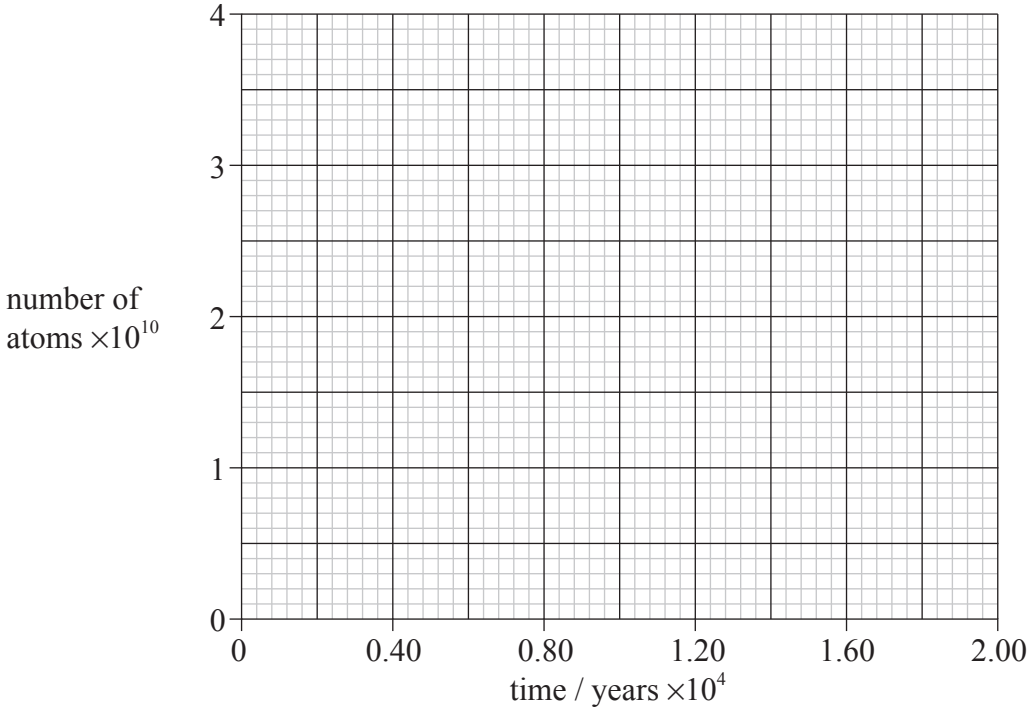
. . . . . .

(This question continues on the following page)

(Question B3, part 2 continued)

(b) Each gram of a living tree contains approximately 4×10^{10} atoms of carbon-14.

On the axes below, draw a graph to show the variation with time of the number of carbon-14 atoms in one gram of wood from a tree. Your graph should indicate the number of atoms for a period of 1.8×10^{4} years after the tree has died. (Half-life of carbon-14 = 5500 years) *[3]*



(c) The activity of a radioactive sample is proportional to the number of atoms in the sample. The activity per gram of carbon from a living tree is 9.6 disintegrations per minute. The activity per gram of carbon in burnt wood found at an ancient campsite is 1.9 disintegrations per minute.

(i) Estimate the number of atoms of carbon-14 in the burnt wood. *[1]*

. . . . . .

. . . . . .

(ii) From the graph you have drawn in (b), estimate the age of the burnt wood. *[1]*

. . . . . .

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

MARKSCHEME

SPECIMEN PAPER

PHYSICS

Standard Level

Paper 2

9 pages

SECTION A

A1. (a) (i) reasonable <u>curve</u> drawn up to $15\,\text{ms}^{-1}$ that does not go through zero; ***[1]***
Expect smooth single-line within one square of each correctly plotted point.

(ii) shape of curve wrong / curve does not go through zero; ***[1]***

(iii) $5\% = \pm 30$;
correct drawing of error bar; ***[2]***

(b) (i) when $v_{\text{in}} = 14\,\text{ms}^{-1}$, $P_{\text{out}} = 570\,(\pm 20)\,\text{kW}$;
$P_{\text{in}} = 1250\,(\pm 50)\,\text{kW}$;
Allow $\pm\frac{1}{2}$ *a square.*
efficiency $= \dfrac{570}{1250} = 0.46$ *or* 46%; ***[3]***

(ii) <u>the efficiency decreases</u>;
for a given increase in velocity the increase in P_{out} gets smaller;
whereas the increase in theoretical P_{in} gets larger;

or

as the P_{out} graph starts to flatten / *OWTTE*;
the P_{in} graph steepens; ***[3]***

(c) *advantage*:
wind is renewable so no resources used up / wind is free / no chemical pollution / carbon dioxide emission / does not add to the enhanced greenhouse effect;

disadvantage:
expensive initial/capital costs / large land area needed / visual / noise pollution / winds unpredictable/not constant / affect on birds; ***[2]***
Award any other suitable advantage or disadvantage.

A2. (a) there are no positions;
the lamp is effectively in series with $100\,\text{k}\Omega$ no matter what the position of S;
this means that the pd across it will always be close to zero (very small) / never reach 6 V;

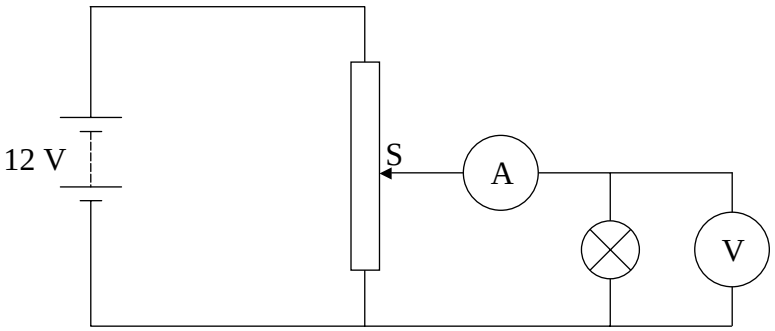
or

the resistance of the filament is much smaller than $100\,\text{k}\Omega$;
so (nearly) all the potential of the battery appears across the variable resistance; ***[3]***
*Award **[0]** for incorrect argument or just the answer without any explanation.*

(b) $I = \frac{V}{R}$;

$= \frac{12}{10^5} = 1.2\times10^{-4}\,\text{A}$; ***[2]***

(c)



correct position of ammeter;
correct position of voltmeter (either to the right or left of the lamp); ***[2]***

A3. (a) the force exerted per unit mass;
on a point (small) mass; ***[2]***

(b) (i) use of $g = \frac{F}{m}$ and $F = G\frac{Mm}{R^2}$;

combine to get $g = G\frac{M}{R^2}$; ***[2]***

(ii) $M = \frac{gR^2}{G}$;

substitute to get $M = 1.9\times10^{27}\,\text{kg}$; ***[2]***

SECTION B

B1. Part 1 Simple harmonic motion and the greenhouse effect

(a) the force acting/accelerating (on the body) is directed towards equilibrium (position);
and is proportional to its/the bodies displacement from equilibrium; ***[2]***

(b) (i) $1.5\times10^{-10}\ \text{m}$; ***[1]***

(ii) $T = 1.1\times10^{-12}\ \text{s}$;

$$f = \left(\frac{1}{1.1\times10^{-12}}\right);$$

$$= 9.1\times10^{13}\ \text{Hz}$$ ***[2]***

(iii) $\omega = (2\pi f) = 5.7\times10^{14}\ (\text{rad s}^{-1})$;

$$E_{\max} = \left(\tfrac{1}{2}m\omega^2 x_0{}^2\right) = \tfrac{1}{2}\times1.7\times10^{-27}\times(1.5)^2\times10^{-20}\times(5.7)^2\times10^{28};$$

$$= 6.2\times10^{-18}\ \text{J}$$ ***[2]***

(c) negative sine;
starting at zero;
with same frequency as displacement; *(allow ± 2 mm square)* ***[3]***

(d) (i) $k = (4\pi^2 f^2 m_p) = 40\times83\times10^{26}\times1.7\times10^{-27}$;

$$\approx 560\ \text{N m}^{-1}$$ ***[1]***

(ii) use of $F = kx$ and $F = ma$;

to give $a = \dfrac{560\times1.5\times10^{-10}}{1.7\times10^{-27}} = 5.0\times10^{19}\ \text{m s}^{-2}$; ***[2]***

(e) (i) infra red radiation radiated <u>from Earth</u> will be absorbed by greenhouse gases;
and so increase the temperature of the atmosphere/Earth; ***[2]***

(ii) the natural frequency of oscillation (of a methane molecule) is equal to $9.1\times10^{13}\ \text{Hz}$;
because of resonance the molecule will readily absorb radiation of this frequency; ***[2]***

Part 2 Specific heat and a domestic shower

(a) the amount of energy/heat required to raise the temperature of 1 kg of a substance through 1K / 1°C; ***[1]***

(b) the internal energy is the total energy of the molecules of a substance;
the greater the specific heat (the more energy required to raise unit mass through 1K) this means that to increase the temperature by the same amount, more energy most be given to substance A than to substance B (so internal energy is greater) / *OWTTE*; ***[2]***

(c) (i) energy supplied by heater in $1\text{s} = 7.2\times10^3\ \text{J}$;
energy per second = mass per second × sp ht × rise in temperature;
$7.2\times10^3 = \text{mass per second}\times4.2\times10^3\times26$;
to give mass per second = 0.066 kg; ***[4]***

(ii) energy is lost to the surroundings;
flow rate is not uniform; ***[1 max]***
Do not allow "the heating element is not in contact with all the water flowing in the unit".

B2. (a) (i) there is more uranium-238 present than uranium-235;
neutron capture is more likely in U-238 with high energy neutrons;
if the neutrons are slowed they are more likely to produce fission in U-235 than neutron capture in U-238; ***[3]***

(ii) control rate at which reactions take place;
by absorbing neutrons; ***[2]***

(b) (i) fuel enrichment means that the amount of uranium-235 present in the fuel is increased / *OWTTE*;
this means that more U-235 available for fission;
therefore the reaction can be sustained; ***[3]***

(ii) enriched fuel can be used in the manufacture of nuclear weapons;
so possibly threatening World peace; ***[2]***

(c) (i) $(\text{energy released}) = 2.1895\times10^{5} - (1.3408 + 0.83749 + 0.0093956)\times10^{5}$;
$= 181.44 \approx 180\,\text{MeV}$ ***[1]***

(ii) kinetic; ***[1]***

(d) (i) number of atoms in 1 kg of carbon $= \dfrac{N_{\text{A}}\times1000}{12}$ and number in 1 kg of U-235 $= \dfrac{N_{\text{A}}\times1000}{235}$;

energy per kg carbon $= \dfrac{4N_{\text{A}}}{12}\,\text{keV}$ and per kg U-235 $= \dfrac{N_{\text{A}}\times1.8\times10^{8}}{235}\,\text{keV}$;

therefore, ratio $= 2.3\times10^{6}$; ***[3]***

(ii) a much higher energy density implies that uranium will produce more energy per kg / smaller quantity of uranium needed to produce same amount of energy / *OWTTE*; ***[1]***

(e) (i) *half-life*:
time for the activity to decrease by half / *OWTTE*;

isotope:
isotopes of elements are chemically identical but have different atomic masses / *OWTTE* / same number of protons in the nucleus but different number of neutrons / *OWTTE*; ***[2]***

(ii) $^{239}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} + \beta^{-} + \bar{\nu}$
$^{239}_{93}\mathrm{Np}$;
β^{-};
$\bar{\nu}$; ***[3]***

(iii) *advantage*:
plutonium is another fissionable element / may be used as nuclear fuel;
and is readily produced in reactors that use uranium as a fuel;

disadvantage:
β-particles are harmful to living organisms / *OWTTE*;
and the plutonium lasts for a very long-time / *OWTTE*; ***[4]***

B3. Part 1 Mechanical power

(a) the rate of working / work ÷ time; ***[1]***
If equation is given, then symbols must be defined.

(b) $P = \frac{W}{t} = \frac{F \times d}{t}$;
$v = \frac{d}{t}$ therefore, $P = Fv$; ***[2]***

(c) (i) $t = \frac{d}{v}$;
$= \frac{4800}{16} = 300\,\text{s}$; ***[2]***

(ii) $W = mgh = 1.2\times10^4 \times 300 = 3.6\times10^6\,\text{J}$; ***[1]***

(iii) work done against friction $= 4.8\times10^3 \times 5.0\times10^2$;
total work done $= 2.4\times10^6 + 3.6\times10^6$;
total work done $= P \times t = 6.0\times10^6$;
to give $P = \frac{6.0\times10^6}{300} = 20\,\text{kW}$; ***[4]***

(d) (i) $\sin\theta = \frac{0.30}{6.4} = 0.047$;
weight down the plane $= W\sin\theta = 1.2\times10^4 \times 0.047 = 5.6\times10^2\,\text{N}$;
net force on car $F = 5.6\times10^2 - 5.0\times10^2 = 60\,\text{N}$;
$a = \frac{F}{m}$;
$\frac{60}{1.2\times10^3} = 5.0\times10^{-2}\,\text{m s}^{-2}$; ***[5]***

(ii) $v^2 = 2as = 2\times5.0\times10^{-2}\times6.4\times10^3$;
to give $v = 25\,\text{m s}^{-1}$; ***[2]***

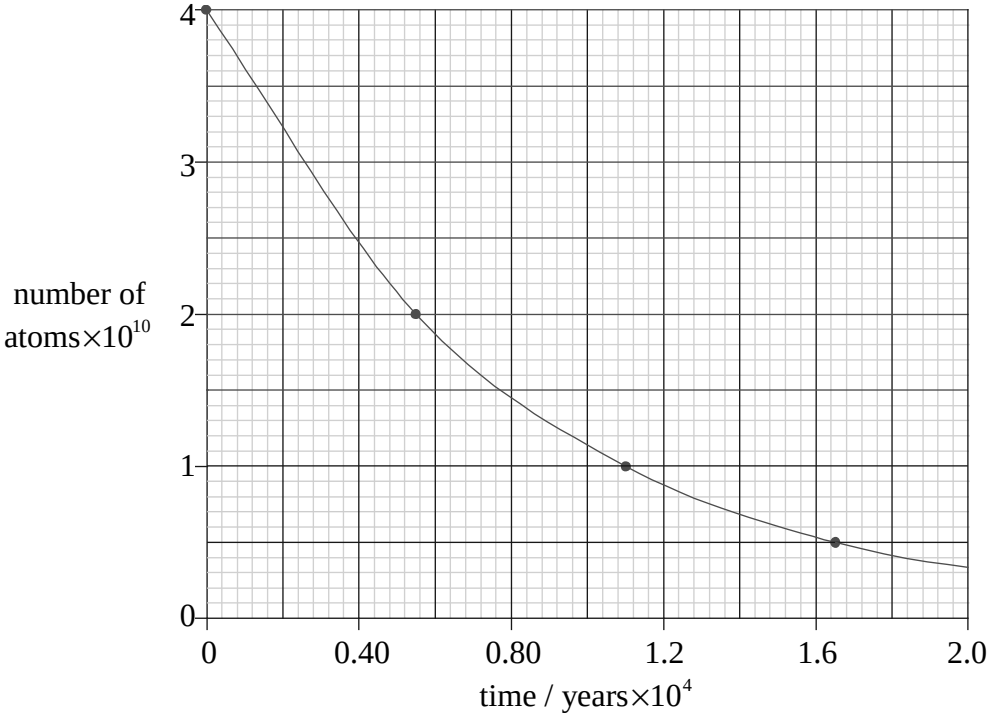
(e) $5.6\times10^2\,\text{N}$; ***[1]***

Part 2 Radioactive decay

(a) (i) isotopes of elements are chemically identical but have different atomic masses / *OWTTE* / same number of protons in the nucleus but different number of neutrons / *OWTTE*; ***[1]***

(ii) proton / ${}^{1}_{1}\mathrm{H}$ / p^{+}; ***[1]***

(b)



four data points covering 3 half-lives; } *The data points at 4×10^{10} and 0.5×10^{10} must be shown.*

correct plotting of data points;
line of best-fit to 1.8×10^{4} years; ***[3]***

(c) (i) number of atoms $= \dfrac{1.9\times4\times10^{10}}{9.6} \approx 0.8\times10^{10}$; ***[1]***

(ii) from the graph age $= 1.3\times10^{4}$ years; ***[1]***
Allow ECF from (b) and from (c)(i).

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/SP3/ENG/TZ0/XX

PHYSICS
STANDARD LEVEL
PAPER 3

SPECIMEN PAPER

1 hour

Candidate session number

0	0							

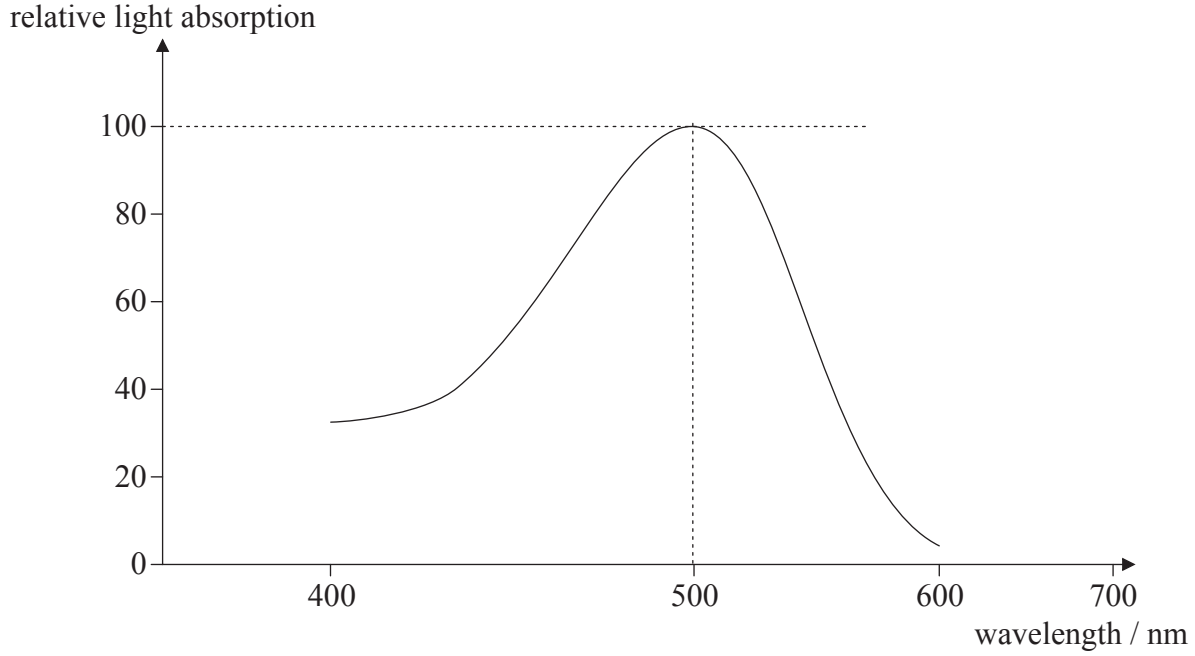
INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet.

26 pages

Option A — Sight and wave phenomena

A1. The graph below shows the overall relative light absorption curve for the light-sensitive cells involved in scotopic vision. The relative light absorption is expressed as a percentage of the maximum.



(a) State the name of the cells involved in **scotopic** vision. *[1]*

. . . . . .

(b) (i) On the axes above, sketch a relative light absorption curve for a cell involved in **photopic** vision. *[2]*

(ii) State the colour to which the cell is most sensitive. *[1]*

. . . . . .

(c) Outline how colour blindness may arise from defects in the retina's light sensitive cells. *[3]*

. . . . . .

. . . . . .

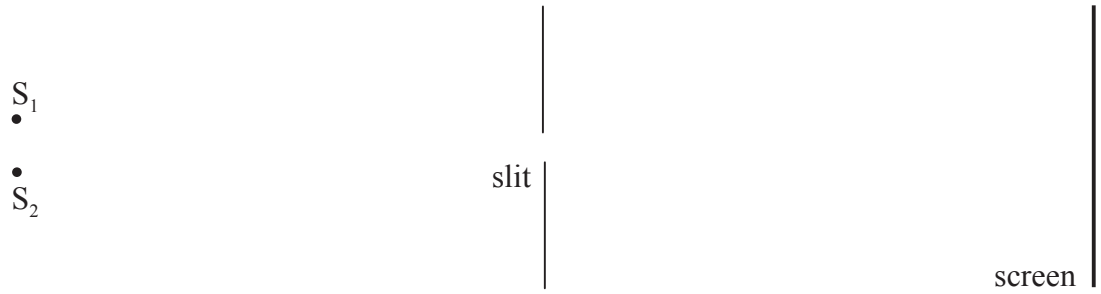
. . . . . .

. . . . . .

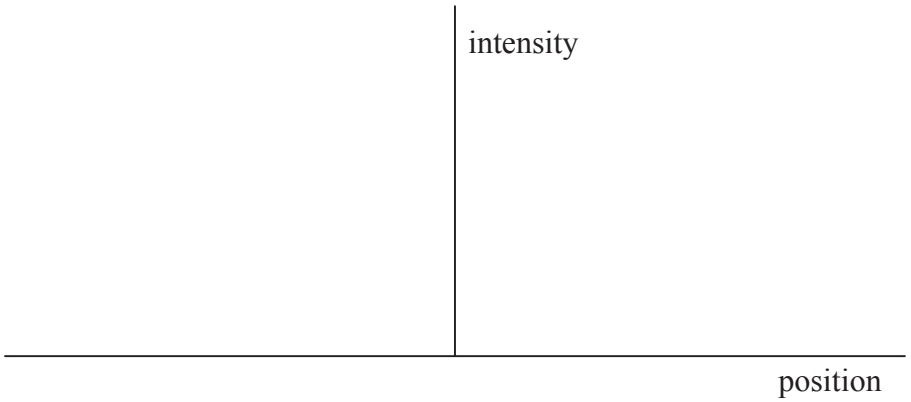
. . . . . .

A2. This question is about the Rayleigh criterion.

(a) Light from two monochromatic distant point sources, S_1 and S_2, is incident on a narrow slit. After passing through the slit, the light is incident on a screen.



On the axes below, draw the intensity distribution of the diffracted light on the screen from each source when the images of S_1 and S_2 are just resolved according to the Rayleigh criterion. *[3]*



(b) A woman views an approaching car at night. The apertures of her eyes are each of diameter 3.0 mm. The headlamps of the car are separated by a distance of 1.2 m and emit light of wavelength 400 nm.

Calculate the distance of the car from the woman at which the images of the two headlamps are just resolved. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

A3. This question is about polarization.

(a) State what is meant by polarized light. *[1]*

. . . . . .

. . . . . .

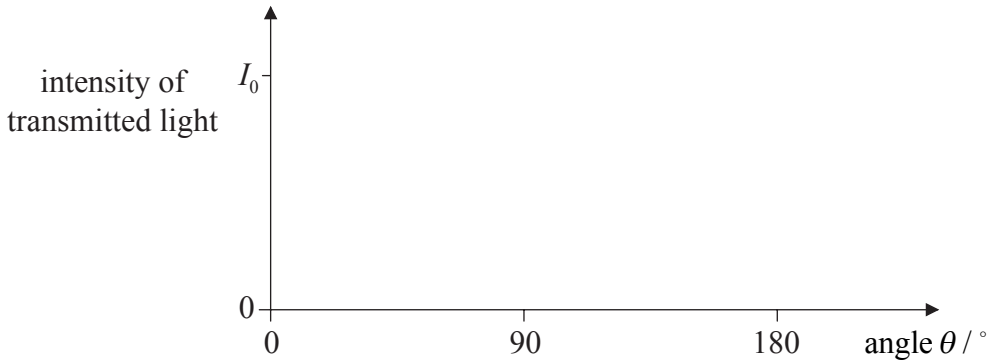
(b) Polarized light of intensity I_0 is incident on an analyser. The transmission axis of the analyser makes an angle θ with the direction of the electric field of the light.

(i) Calculate, in terms of I_0, the intensity of light transmitted through the analyser when $\theta = 60^\circ$. *[1]*

. . . . . .

. . . . . .

(ii) On the axes below, sketch a graph to show the variation with angle θ of the intensity of the transmitted light. *[2]*



(c) Outline how polarizing sunglasses reduce glare from a reflecting surface. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option B — Quantum physics and nuclear physics

B1. This question is about wave-particle duality.

(a) Describe the de Broglie hypothesis. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) An electron is accelerated from rest through a potential difference of 1250 V. Determine the associated de Broglie wavelength of the accelerated electron. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

B2. This question is about line spectra.

(a) Light is emitted from a gas discharge tube. Outline briefly how the visible line spectrum of this light may be obtained. *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(b) The table below gives information relating to three of the wavelengths in the line spectrum of atomic hydrogen.

Wavelength / $\times 10^{-9}$ m	**Photon energy / $\times 10^{-19}$ J**
1880	1.06
656	3.03
486	4.09

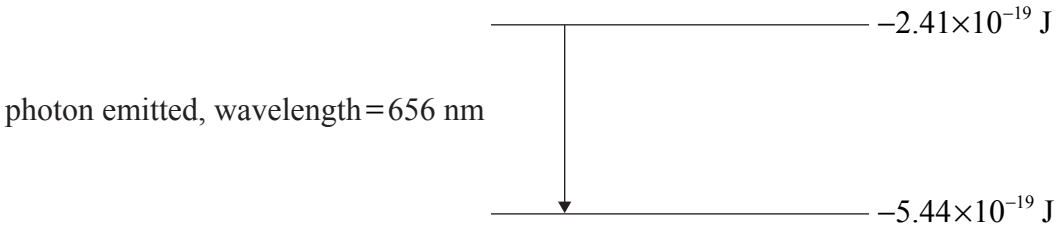
Deduce that the photon energy for the wavelength of 486×10^{-9} m is 4.09×10^{-19} J. *[2]*

. . . . . .

. . . . . .

. . . . . .

(c) The diagram below shows two of the energy levels of the hydrogen atom, using data from the table above. An electron transition between these levels is also shown.

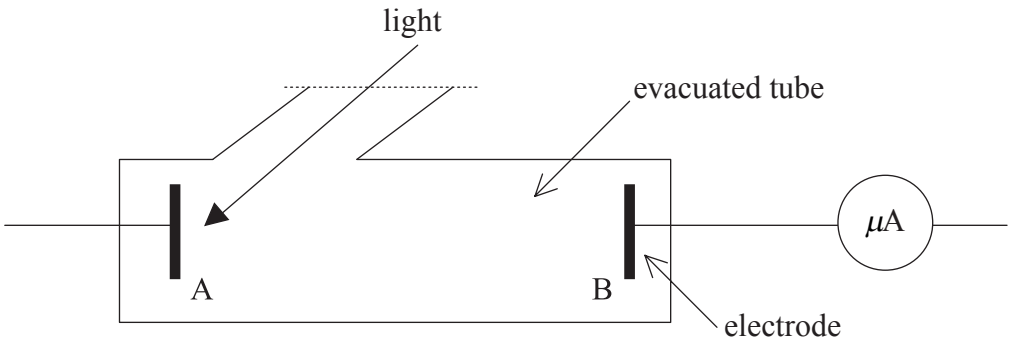


(i) On the diagram above, construct the other energy level needed to produce the energy changes shown in the table above. *[1]*

(ii) Draw labelled arrows to represent the energy changes for the two other wavelengths shown in the table above. *[1]*

B3. This question is about the photoelectric effect.

In an experiment to investigate the photoelectric effect, light of frequency f is incident on the metal surface A shown in the diagram below. A potential difference is applied between A and electrode B. The photoelectric current is measured by the microammeter. *(**Note**: the complete electrical circuit is not shown.)*



(a) Indicate on the diagram the polarity of A and of B. *[1]*

(b) The frequency f of the light is reduced and it is found that there is a frequency f_0, the threshold frequency, below which the microammeter does not indicate a current. Explain how Einstein's photoelectric theory accounts for this observation. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

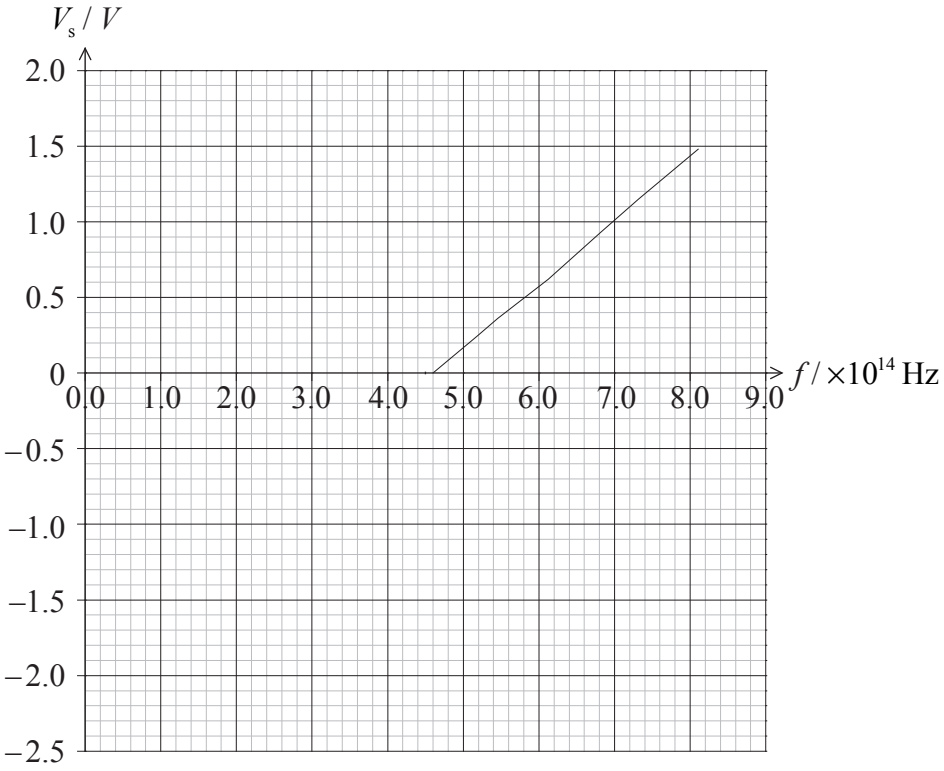
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3 continued)

(c) The potential difference between A and B is now reversed. For a particular frequency of the light, the potential difference is changed until there is zero current in the circuit. The graph below shows the variation of frequency f of the light with the potential difference, V_s, for zero current.



Explaining your working, use the graph to determine the

(i) threshold frequency. *[1]*

. . . . . .

. . . . . .

(ii) work function, in eV, of the metal. *[2]*

. . . . . .

. . . . . .

Option C— Digital technology

C1. In a computer code, text (letters, spaces and punctuation marks) is represented by binary numbers. The letter "E" is represented by the two four bit binary numbers below.

0100 and 0101

(a) Define *least significant bit.* *[1]*

. . . . . .

. . . . . .

(b) Calculate the decimal equivalent for the two four bit binary numbers. *[1]*

0100 . . . . . .

0101 . . . . . .

(c) Using this computer code state how many separate bits would be needed to represent the following phrase. *[1]*

IBO Physics is easy!

. . . . . .

(d) Discuss, in terms of reproducibilty and portability, the disadvantages of storing text in analogue rather than digital form. *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) State **one** environmental implication of storing text in analogue form. *[1]*

. . . . . .

. . . . . .

C2. A digital camera is used to photograph an object. Two points on the object are separated by 0.0020 cm. The charged coupled device (CCD) in the camera has a collecting area of 16 cm^2 and contains 4.0 megapixels. The magnification of the camera is 1.5.

(a) Define *magnification*. *[1]*

. . . . . .

. . . . . .

(b) Deduce that the images of the points can be resolved. *[4]*

. . . . . .

. . . . . .

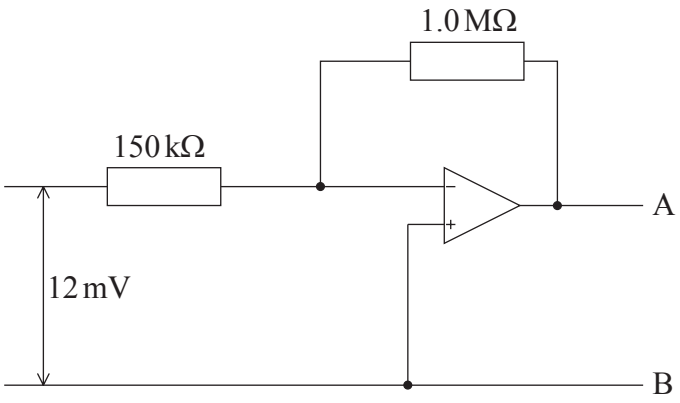
. . . . . .

. . . . . .

. . . . . .

. . . . . .

C3. The diagram below shows an inverting amplifier circuit.



(a) State what is meant by an inverting amplifier circuit. *[1]*

. . . . . .

(b) The input voltage is 12 mV. Calculate

(i) the current in the 150 kΩ resistor. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) the potential difference between A and B. *[1]*

. . . . . .

. . . . . .

(c) Outline any assumptions that you have made in (b). *[2]*

. . . . . .

. . . . . .

. . . . . .

Option D — Relativity and particle physics

D1. This question is about relativistic kinematics.

(a) State what is meant by an inertial frame of reference. *[2]*

. . . . . .

. . . . . .

(b) A spacecraft is moving with a speed of 0.80c with respect to observers on Earth. After 6.0 years of travel, according to the spacecraft clocks, the spacecraft arrives at a distant solar system.

(i) Calculate the time the journey has taken according to an observer on Earth. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Calculate the distance between the Earth and the solar system according to an observer on Earth. *[2]*

. . . . . .

. . . . . .

. . . . . .

(iii) The spacecraft observers send a signal to Earth to announce that they have arrived at the solar system. The spacecraft continues to move. Determine how long it will take the signal to arrive on Earth according to the **spacecraft** observers. *[3]*

. . . . . .

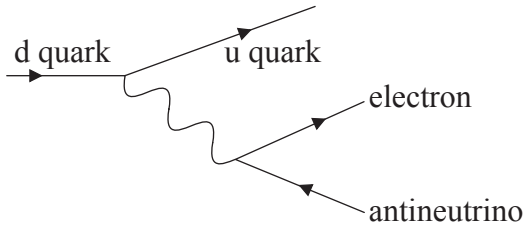
. . . . . .

. . . . . .

. . . . . .

D2. This question is about fundamental interactions.

(a) The Feynman diagram below represents a β^- decay via the weak interaction process.



The exchange particle in this weak interaction is a virtual particle.

(i) State what is meant by a virtual particle. *[1]*

. . . . . .

. . . . . .

(ii) Determine whether the virtual particle in the process represented by the Feynman diagram is a W^+, a W^- **or** a Z^0 boson. *[2]*

. . . . . .

(b) The order of magnitude of the mass of the $W^{\pm}$ and Z^0 bosons is $100\,\text{GeV}\,c^{-2}$. Estimate the range of the weak interaction. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

D3. This question is about a proton.

The proton is made out of three quarks.

(a) Explain why the three quarks in the proton do not violate the Pauli exclusion principle. *[2]*

. . . . . .

(b) Quarks have spin $\frac{1}{2}$. Explain how it is possible for the proton to also have spin $\frac{1}{2}$. *[2]*

. . . . . .

. . . . . .

Option E — Astrophysics

E1. This question is about stars.

Betelgeuse and Rigel are two super giants in the constellation of Orion.

(a) Distinguish between a *constellation* and a *stellar cluster*. *[2]*

Constellation: . . . . . .

. . . . . .

Stellar cluster: . . . . . .

. . . . . .

(b) The star Betelgeuse has a parallax of 0.0077 arc second. Deduce that its distance from Earth is approximately 130 pc. *[1]*

. . . . . .

. . . . . .

(c) State why the Hipparcos satellite which orbits Earth is able to measure stellar parallaxes for stars at considerably greater distances than 130 pc. *[1]*

. . . . . .

(This question continues on the following page)

(Question E1 continued)

(d) The table below gives some information about the types and magnitudes of Betelgeuse and Rigel.

Star	Type	Apparent magnitude	Colour	Apparent brightness
Betelgeuse	M	–0.04		$2.0\times10^{-7}\,\mathrm{W\,m^{-2}}$
Rigel	B	0.12		$3.4\times10^{-8}\,\mathrm{W\,m^{-2}}$

(i) Complete the above table for the colours of the stars. *[2]*

(ii) State why Betelgeuse has a lower apparent magnitude than Rigel. *[1]*

. . . . . .

. . . . . .

(iii) Given that the distance of Betelgeuse from Earth is 130 pc, calculate the luminosity of Betelgeuse. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) The luminosity of Rigel is 2.3×10^{31} W. Without any further calculation, explain whether Rigel is closer or further than Betelgeuse from Earth. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

E2. This question is about Olbers' paradox.

(a) Newton assumed that the universe is static and that the stars are uniformly distributed. State **one** further assumption of the Newtonian universe. *[1]*

. . . . . .

(b) Explain how Newton's assumptions led to Olbers' paradox. *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

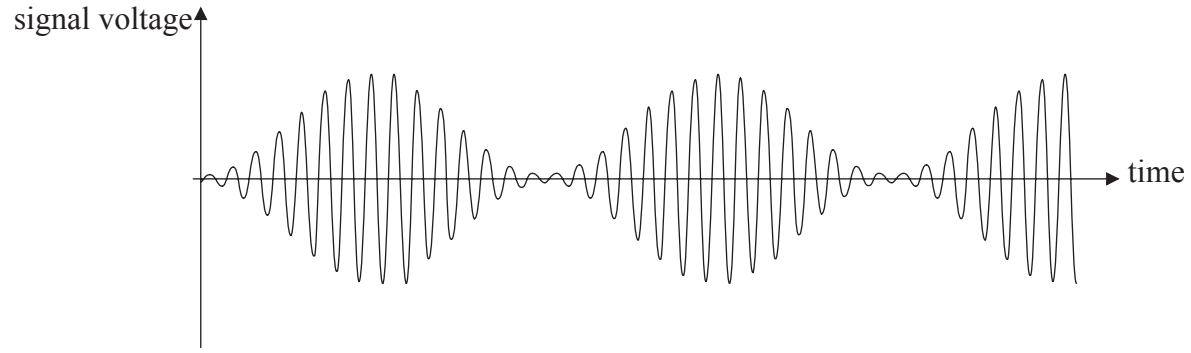
. . . . . .

. . . . . .

Option F— Communications

F1. This question is about amplitude-modulated radio waves.

The diagram below shows a sketch graph of signal voltage against time for an amplitude-modulated radio wave.



(a) The information signal consists of a continuous single frequency sine wave. The frequency of the carrier wave is 18 kHz.

(i) Determine the frequency of the information signal. *[3]*

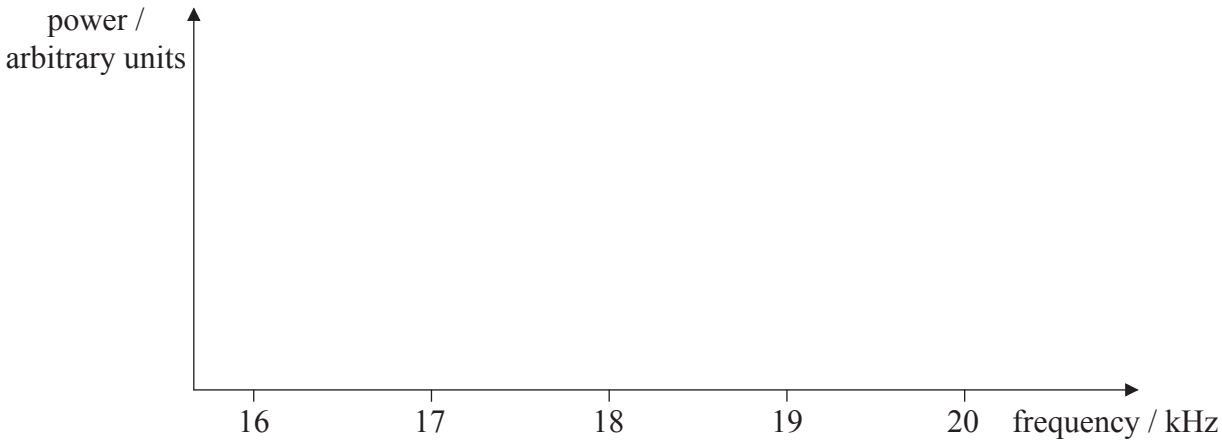
. . . . . .

. . . . . .

. . . . . .

. . . . . .

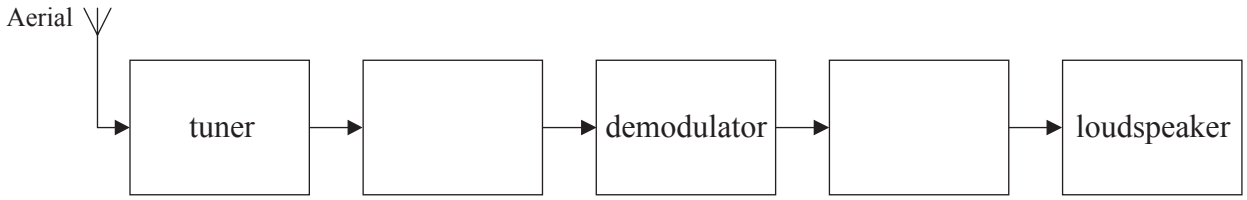
(ii) On the axes below, draw the power spectrum for the amplitude-modulated wave. *(Numerical values are not required on the power axis.)* *[3]*



(This question continues on the following page)

(Question F1 continued)

(b) The block diagram below shows the principal systems in a radio that receives an amplitude-modulated signal. The unlabelled boxes represent amplifiers.



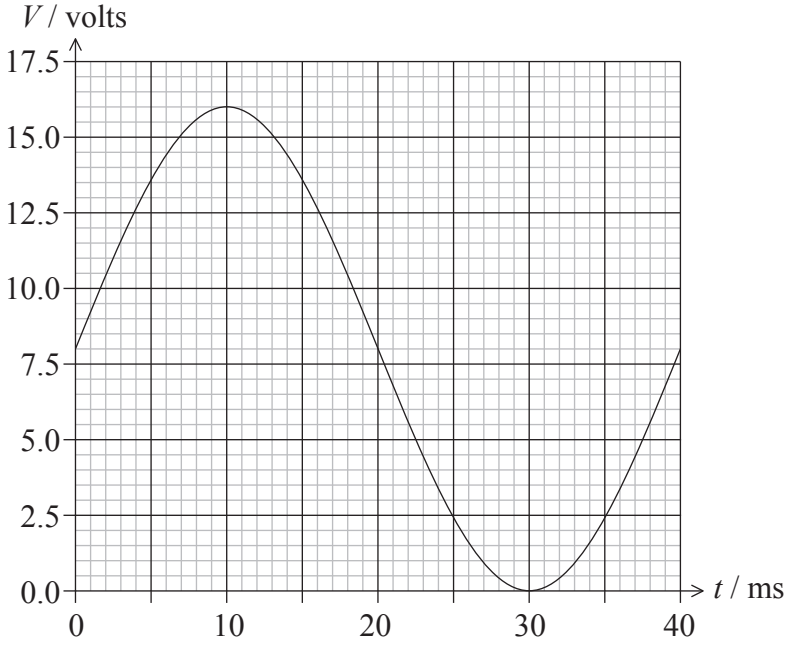
(i) Label the blank boxes with the type of amplifier used. *[1]*

(ii) State the function of the demodulator. *[1]*

. . . . . .

. . . . . .

F2. The graph below shows the variation with time t of the voltage V of an analogue signal.



The signal is sampled at a frequency of 200 Hz and digitized using a three-bit analogue to digital converter (ADC). The first sample is taken at $t = 0$.

The possible outputs of the ADC are given below.

Analogue signal / volts	ADC binary output
	111
14	110
12	101
10	100
8	011
6	010
4	001
2	000
0	

(a) Calculate the time at which the fourth sample is taken. *[2]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question F2 continued)

(b) Determine the binary output of the fourth sample. *[2]*

. . . . . .

. . . . . .

(c) The ADC output is fed into a three-bit digital to analogue converter (DAC). State, and explain, whether the output of the DAC will be a faithful reproduction of the original analogue signal. *[2]*

. . . . . .

. . . . . .

F3. This question is about communication channels.

(a) State the order of magnitude of the frequencies used for communication with geostationary satellites. *[1]*

. . . . . .

(b) A voice communication channel is to be established between a scientific base in the northern hemisphere and its headquarters in the southern hemisphere.

For this communication channel, state and explain **one** advantage of using

(i) a geostationary satellite. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) a polar orbiting satellite. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) State **one** reason why the up-link frequency and the down-link frequency for communication satellites are different. *[1]*

. . . . . .

. . . . . .

Option G — Electromagnetic waves

G1. This question is about laser light.

(a) State **two** differences between the light emitted by a laser and that emitted by a filament lamp. *[2]*

1. . . . . .

2. . . . . .

(b) The production of laser light relies on population inversion. Outline the meaning of the term population inversion. *[2]*

. . . . . .

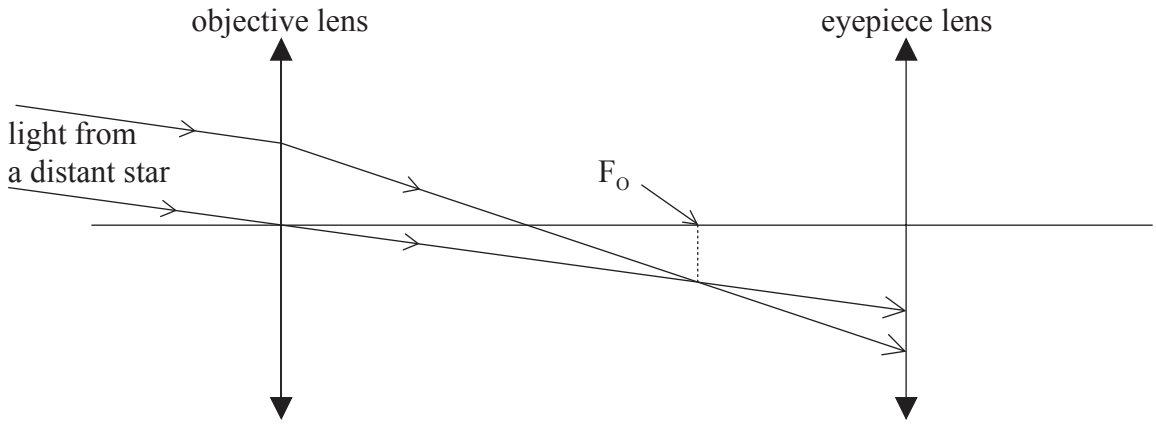
. . . . . .

. . . . . .

. . . . . .

G2. This question is about an astronomical telescope.

(a) The diagram below shows two rays of light from a distant star incident on the objective of an astronomical telescope. The paths of the rays are also shown after they pass through the objective lens and are incident on the eyepiece lens of the telescope.



The principal focus of the objective lens is F_O.

On the diagram above, mark the position of the

(i) principal focus of the eyepiece lens (label this F_E). *[1]*

(ii) image of the star formed by the objective lens (label this I). *[1]*

(b) State where the final image is formed when the telescope is in normal adjustment. *[1]*

. . . . . .

(c) Complete the diagram in (a) to show the direction in which the final image of the star is formed for the telescope in normal adjustment. *[2]*

(This question continues on the following page)

(Question G2 continued)

(d) The eye ring of an astronomical telescope is a device that is placed outside the eyepiece lens of the telescope at the position where the image of the objective lens is formed by the eyepiece lens. The diameter of the eye ring is the same as the diameter of the image of the objective lens. This ensures that all the light passing through the telescope passes through the eye ring.

A particular astronomical telescope has an objective lens of focal length 98.0 cm and an eyepiece lens of focal length 2.00 cm (*i.e.* $f_O = 98.0\,\text{cm}$, $f_E = 2.00\,\text{cm}$). Determine the position of the eye ring. *[4]*

. . . . . .

. . . . . .

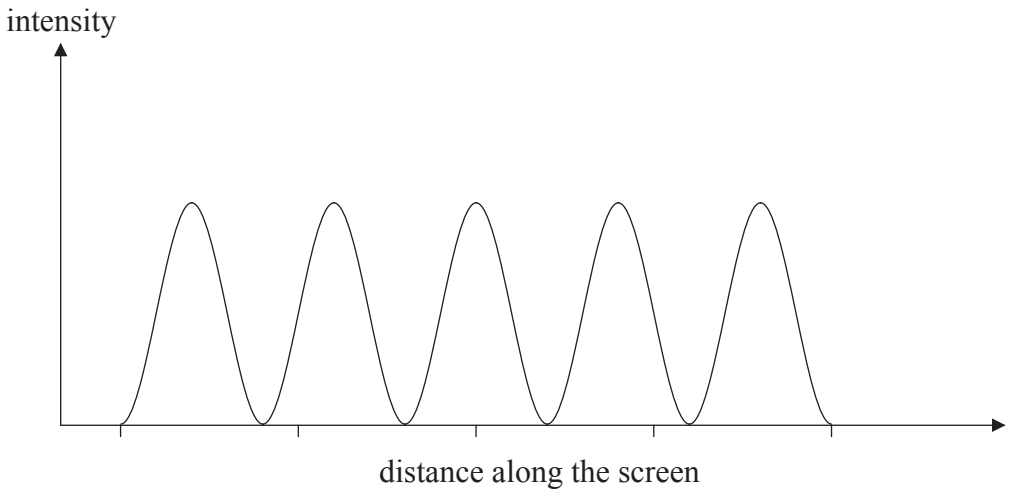
. . . . . .

. . . . . .

. . . . . .

G3. This question is about interference and diffraction.

Light from a laser is incident on two slits of equal width. After passing through the slits, the light is incident on a screen. The diagram below shows the intensity distribution of the light on the screen.



(a) The wavelength of the light from the laser is 633 nm and the angular separation of the bright fringes on the screen is 4.00×10^{-4} rad. Calculate the separation of the slits. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Light from the laser is incident on many slits of the same width as the widths of the slits above. Draw, on the above diagram, a possible new intensity distribution of the light on the screen. *[2]*

(c) The laser is replaced by a source of white light. Describe, if any, the changes to the fringes on the screen. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

SPEC/4/PHYSI/SP3/ENG/TZ0/XX/M

MARKSCHEME

SPECIMEN PAPER

PHYSICS

Standard Level

Paper 3

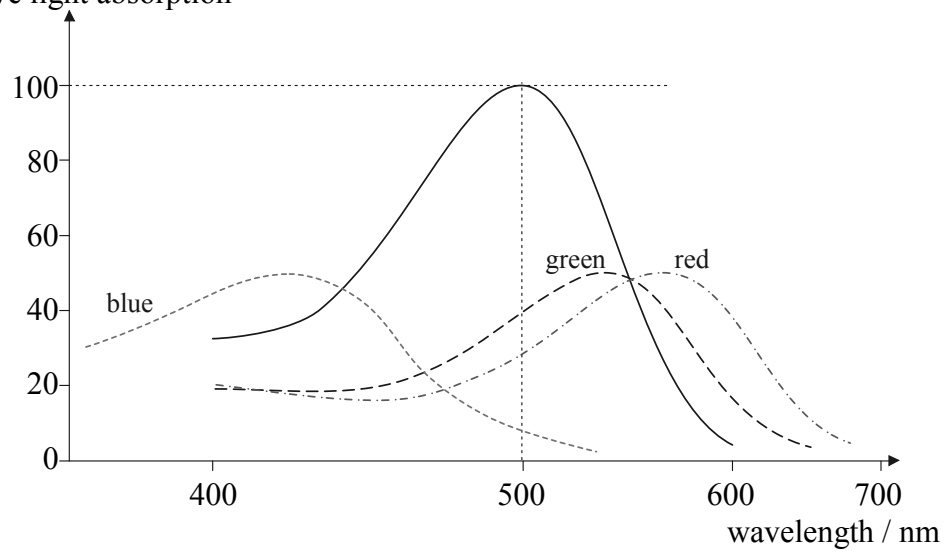
12 pages

Option A — Sight and wave phenomena

A1. (a) rods; ***[1]***

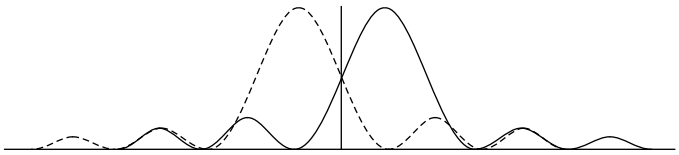
(b) (i) similar shaped curve with different position of maximum;
lower maximum; ***[2]***

(ii) blue, red <u>or</u> green as appropriate to the sketch; ***[1]***



(c) <u>three</u> types of cones/cells involved in part (b)/photopic vision;
each has different frequency response;
normally a shortage/defect of one type / *OWTTE*; ***[3]***

A2. (a) shape of diffraction pattern acceptable;
central maximum of one pattern falls on first minimum of other;
relative heights of central and first maxima realistic for both patterns; ***[3]***



(b) $\theta = \frac{1.22\lambda}{d} = \frac{1.22 \times 400 \times 10^{-9}}{0.003} (= 1.63 \times 10^{-4} \text{ rad})$;

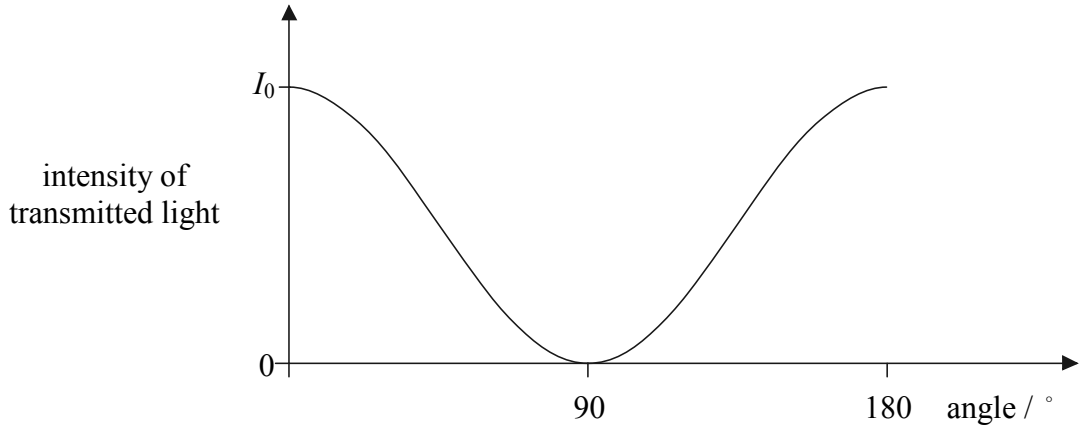
$\text{woman} \rightarrow \text{car distance} = \left(\frac{\text{head lamp separation}}{\tan\theta} \right) = \frac{1.2}{1.63 \times 10^{-4}}$;

$= 7.4 \text{ km}$; ***[3]***

A3. (a) light where the direction of the (electric) field is always/predominantly in the same plane; ***[1]***

(b) (i) $I = \left(I_0 \cos^2 60^\circ\right) = \frac{I_0}{4}$; ***[1]***

(ii)



general $\cos^2$ shape;
max at $\theta = 0$ and curve touches horizontal axis at $\theta = 90^\circ$; ***[2]***

(c) light is (partially) <u>horizontally</u> polarized by reflection;
sunglasses have a transmission axis at 90° to the plane of reflected light;
intensity of reflected light is reduced; ***[3]***
Award full marks for a clearly labelled diagram.

Option B — Quantum physics and nuclear physics

B1. (a) all particles have a wavelength associated with them / *OWTTE*;
given by $\lambda = \frac{h}{p}$, with *h* and *p* explained; ***[2]***

(b) kinetic energy of electron $= qV$;
$= 2.00 \times 10^{-16}$ J;
$E_K = \frac{p^2}{2m}$ *or* $v^2 = \frac{2E}{m}$ and $p = mv$ $(v = 2.1 \times 10^7 \text{ m s}^{-1})$
$p = 1.91 \times 10^{-23}$ N s;
$\lambda = \frac{h}{p}$
$= 3.47 \times 10^{-11}$ m; *(allow 2 or 4 significant digits)* ***[4]***

B2. (a) use of diffraction grating/prism and screen/telescope;
observe diffracted/refracted (as appropriate) light / first/second orders; ***[2]***

(b) $E = \frac{hc}{\lambda}$ *or* $E = hf$ and $c = f\lambda$;
correct substitution into relevant formula clear; ***[2]***
to give energy $= 4.09 \times 10^{-19}$ J
*Award **[0]** for answer alone.*

(c) (i) ——————— -1.35×10^{-19} J
——————— -2.41×10^{-19} J
——————— -5.44×10^{-19} J
level shown in "reasonable" position (spacing of lines not important); ***[1]***
To receive the mark answers must quote -1.35×10^{-19} J.

(ii) transition $-1.35 \times 10^{-19} \rightarrow -5.44 \times 10^{-19}$ (and labelled 486 m)
transition $-1.35 \times 10^{-19} \rightarrow -2.41 \times 10^{-19}$ (and labelled 1880 m); ***[1]***

B3. (a) A negative (–) B positive (+); ***[1]***

(b) *Answers will be open ended but look for these main points.*
light consists of photons;
each photon has energy *hf*;
a certain amount of energy is required to eject an electron from a metal;
if *hf* is less than this energy, then no electrons will be emitted;
and so no current will be registered by the microammeter; ***[4 max]***

(c) (i) intercept of f axis $= 4.6\times10^{14}$ Hz; ***[1]***

(ii) intercept on V_s axis;
$= 1.9(\pm0.2)$ eV;
or
slope of graph $= 4.2\times10^{-15} = \frac{h}{e}$ to give $h = 4.2\times10^{-15}$ eV s;
$W = hf_0 = 4.6\times10^{14}\times4.2\times10^{-15} = 1.9\,(\pm0.2)$ eV; ***[2]***

Option C— Digital technology

C1. (a) represents the smallest decimal number *i.e.* 2^0 of each of the bits / *OWTTE*; ***[1]***

(b) *0100*: 4;
0101: 5; ***[1]***
Need both to receive the mark.

(c) 20 characters = 160 bits; ***[1]***
Allow candidates to make assumptions regarding end of line character or equivalent but do not award mark for those that forget spaces or punctuation mark.

(d) recognition that analogue format means paper/microfiche *etc.*;
accurate reproducibility of analogue form is difficult;
(because of) susceptibility to noise (*e.g.* repeated photocopying);
analogue format could be bulky;
any other sensible comment/example; ***[5]***

(e) using up natural resources *e.g.* trees / large waste / waste disposal / *OWTTE*; ***[1]***

C2. (a) image length / object length; ***[1]***

(b) area corresponding to each pixel $\frac{16\times10^{-4}}{4\times10^{6}} = 4.0\times10^{-10}\ \text{m}^2$;
separation of pixels $\sqrt{4.0\times10^{-10}} = 2.0\times10^{-5}\ \text{m}$;
divided by $1.5 = 0.0013\,\text{cm}$;
the distance between two pixels $< 0.0020\,\text{cm}$; ***[4]***

C3. (a) a circuit whose output (signal) is proportional, and opposite, to the input; ***[1]***

(b) (i) $I = \frac{12\times10^{-3}}{1,5\times10^{5}}$;
$8.0\times10^{-8}\ \text{A}$; ***[2]***

(ii) 80 mV; ***[1]***

(c) junction between resistors is at (about) 0 V / virtual earth;
no current flows into op-amp / very high input resistance;
very high gain; ***[2 max]***

Option D — Relativity and particle physics

D1. (a) observers using rulers and clocks to measure positions and times of events;
these observers are not accelerating; ***[2]***

(b) (i) realization that 6.0 years is the proper time interval;
calculation of gamma factor $\gamma = \frac{1}{\sqrt{1-0.80^2}} = \frac{5}{3} (= 1.67)$;
time on Earth $\gamma \times 6.0 = 10 \text{ yrs}$; ***[3]***

(ii) realization that spacecraft has been travelling for 10 years at 0.80c;
so distance is $0.80\text{c} \times 10 = 8.0 \text{ ly}$; ***[2]***

(iii) let t be the time according to the spacecraft observers, then in this time Earth will move a distance of $0.80\text{c} \times t$ according to spacecraft;
Earth and spacecraft are already separated by $0.80\text{c} \times 6 = 4.8 \text{ ly}$ according to spacecraft;
and so $\text{c}t = (0.80\text{c} \times t) + 4.8 \Rightarrow t = \frac{4.8}{0.20} = 24 \text{ years}$; ***[3]***

D2. (a) (i) a particle that appears as an intermediate particle in a Feynman diagram / a particle that is not observed and may violate energy and momentum conservation at a vertex; ***[1]***

(ii) W^-;
applying charge conservation at either vertex;
e.g. $-\frac{1}{3} = \frac{2}{3} + x \Rightarrow x = -1$ *or* $x = -1 + 0 = -1$ ***[2]***

(b) conversion of mass into kg
$100 \text{ GeVc}^{-2} = \frac{100 \times 10^9 \times 1.6 \times 10^{-19}}{9 \times 10^{16}} = 1.78 \times 10^{-25} \text{ kg}$;
correct substitution in $R = \frac{6.63 \times 10^{-34}}{4\pi(1.78 \times 10^{-25})(3 \times 10^8)}$;
to get $9.9 \times 10^{-19} \text{ m} \approx 10^{-18} \text{ m}$; ***[3]***

D3. (a) (The Pauli exclusion principle states:) it is impossible for two identical fermions/half integral spin particles to occupy the same quantum state / it is impossible for two fermions with the same quantum numbers to be in the same quantum state;
the three quarks are distinguished by an additional quantum number, colour; ***[2]***

(b) there are two states of spin;
and so one can make a spin $\frac{1}{2}$ particle out of three spin $\frac{1}{2}$ objects by having two parallel and one opposite / up + up + down / $+\frac{1}{2} + \frac{1}{2} - \frac{1}{2}$; ***[2]***

Option E — Astrophysics

E1. (a) *constellation*: pattern of stars;
Candidates must indicate that stars are not close together.

stellar cluster: group of stars bound by gravitation / in same region of space; ***[2]***

(b) $d = \frac{1}{0.0077}$;
$= 130\,\text{pc}$ ***[1]***

(c) no atmospheric turbulence / irregular refraction; ***[1]***

(d) (i) red/red-orange; *(not orange)*
blue / blue-white / white; ***[2]***

(ii) Betelgeuse looks brighter; ***[1]***

(iii) $L = 4\pi bd^2$;
Rearrangement of formula on data sheet required.
$d = 4.0 \times 10^{18}\,\text{m}$;
$L = 4\pi \times 2.0 \times 10^{-7} \times (4.0 \times 10^{18})^2$;
$L = 4.0 \times 10^{31}\,\text{W}$; ***[4]***

(iv) $L = 4\pi bd^2$
luminosity of Rigel is about half that of Betelgeuse; *(or ECF from (iii))*
brightness of Rigel is about 0.1 times that of Betelgeuse;
so Rigel is more distant; { *(must be a consistent conclusion from statements about luminosity and brightness)* } ***[3]***
Do not allow mark for fallacious or no argument.
*Award **[1 max]** for a mere statement that luminosity and brightness are less so Rigel is more distant.*

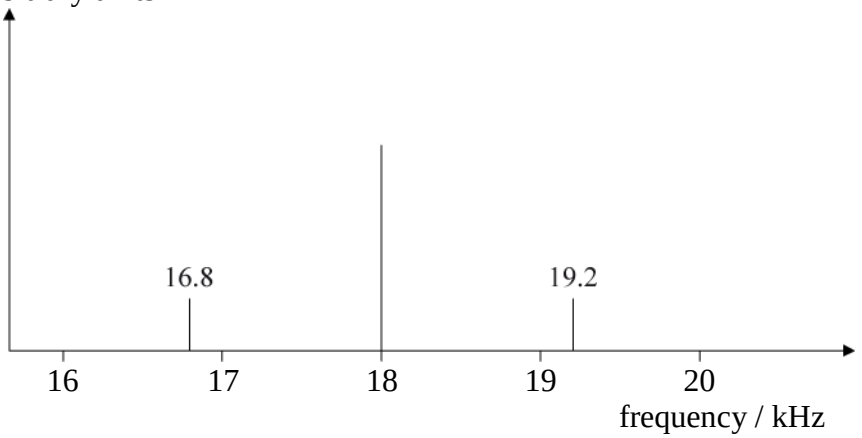
E2. (a) universe is infinite; ***[1]***

(b) number of stars in shell increases as R^2;
intensity decreases as $\frac{1}{R^2}$;
brightness of shell is constant;
adding all shells to infinity;
sky would be as bright as Sun / uniformly bright; ***[5]***
*Award **[2 max]** for argument based on any line of sight lands on a star.*

Option F— Communications

F1. (a) (i) 15 (±1) carrier cycles = 1 information cycle;
so information frequency = 18000 ÷ 15 (±1); *(condone 18000 ÷ 30)*
1200 (±100) Hz ; (condone 600 (±20) Hz) ; ***[3]***

(ii) centre frequency;
sidebands placed about 1200 Hz by eye each side of centre;
correct relative power (centre larger than sidebands); ***[3]***



(b) (i) radio frequency/RF amplifier between tuner and demodulator and audio frequency/AF amplifier between demodulator and loudspeaker; ***[1]***

(ii) separates information signal from carrier signal; ***[1]***

F2. (a) $T = \frac{1}{f} = 5\,\text{ms}$;
fourth sample is at 15 ms; ***[2]***

(b) $V = 13.6$;
(output is) 110; ***[2]***

(c) it will not be a faithful reproduction;
the sampling frequency is (far) too low compared to the frequency of the signal / quantization error large compared to amplitude of the signal; ***[2]***

F3. (a) $0.1-10\,\text{GHz}$; ***[1]***
i.e. accept 0.1/1/10 GHz.

(b) (i) needs no tracking system / always available;
always above same point on Earth's surface; ***[2]***

(ii) polar closer;
so signal stronger / required transmission power lower;
communication possible with all points in both hemispheres (at some time); ***[2 max]***

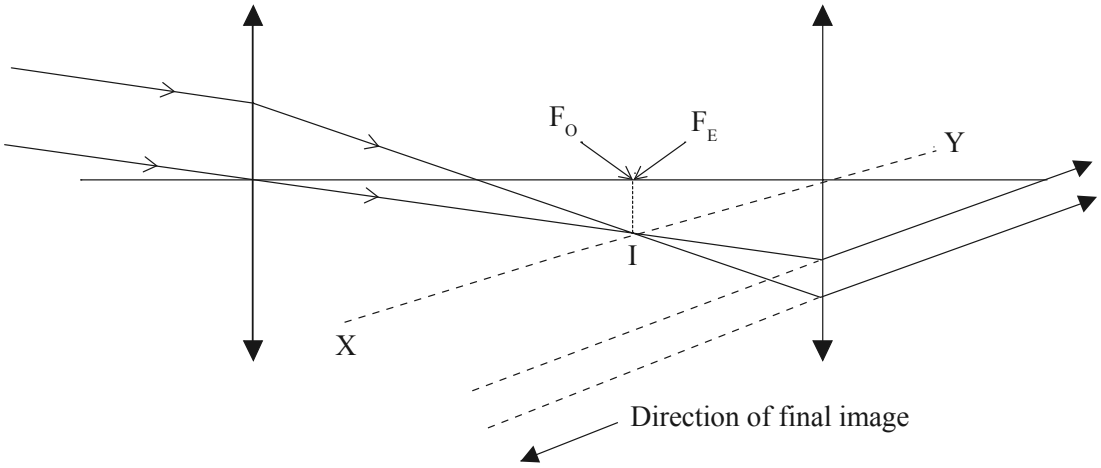
(c) to avoid feedback / resonance / outgoing signal swamping incoming / *OWTTE*; ***[1]***

Option G — Electromagnetic waves

G1. (a) coherent;
monochromatic / single frequency; ***[2]***

(b) <u>normally electrons occupy lowest available energy levels</u>;
to produce laser light a large number of electrons are promoted to a higher energy level / *OWTTE*;
any other valid point; ***[2 max]***

G2. (a)



(i) at F_O; ***[1]***

(ii) as shown on diagram; ***[1]***

(b) at infinity; ***[1]***

(c) two rays parallel to XY; *(judge by eye)*
extrapolated to show direction of final image; ***[2]***

(d) object distance $u = f_O + f_E = 100\,\text{cm}$;
$\frac{1}{v} + \frac{1}{100} = \frac{1}{f_E} = \frac{1}{2}$;
$\frac{1}{v} = \frac{1}{2} - \frac{1}{100}$ to give $v = 2.04\,\text{cm}$;
beyond eyepiece lens / between eyepiece lens and eye;

or

scale drawing: *(not a good idea!)*
suitable scale;
object distance;
rays to locate image;
image distance 2 cm beyond eyepiece lens; ***[4]***

G3. (a) $d = \frac{\lambda D}{s}$;

$= \frac{\lambda}{\theta}$;

$= \frac{6.33\times10^{-7}}{4.00\times10^{-4}} = 1.58\,\text{mm}$;

or

accept use of $d\sin\theta = n\lambda$ with $n = 1$;

$\sin\theta = \theta$;

$d = \frac{6.33\times10^{-7}}{4.00\times10^{-4}} = 1.58\,\text{mm}$; ***[3]***

(b) same number of maxima at the same place but much sharper;
greater intensity than double slit; ***[2]***

(c) fringes are coloured;
blue on the inside / red on the outside;

also accept:
no fringes will be seen;
light is not coherent; ***[2 max]***