UNIVERSITY OF CAMBRIDGE

Admissions Testing Service

NATURAL SCIENCES ADMISSIONS ASSESSMENT

SPECIMEN PAPER and ANSWER BOOKLET

40 minutes

SECTION 2

Candidate number	N						Centre number					

	d d		m m		y y y y
Date of Birth		–		–	

First name(s)	

Surname / Family Name	

INSTRUCTIONS TO CANDIDATES

Please read these instructions carefully, but do not open the question paper until you are told that you may do so. This paper is Section 2 of 2.

There are six questions in this paper, of which you should answer any **two**.

There are 25 marks for each question. In total 50 marks are available.

You should write your answers in the spaces provided in this question paper. Please complete this section in black pen. Pencil may be used for graphs and diagrams only.

You can use the blank inside front and back covers for rough working or notes, but no extra paper is allowed. Only answers in the spaces indicated in the paper will be marked.

Calculators may be used in this section. Please record your calculator model in the box below:

Calculator model	

Write the numbers of the questions you answer in the order attempted in the boxes below:

Question number

Please wait to be told you may begin before turning this page.

This question paper consists of 20 printed pages and 4 blank pages

PV11

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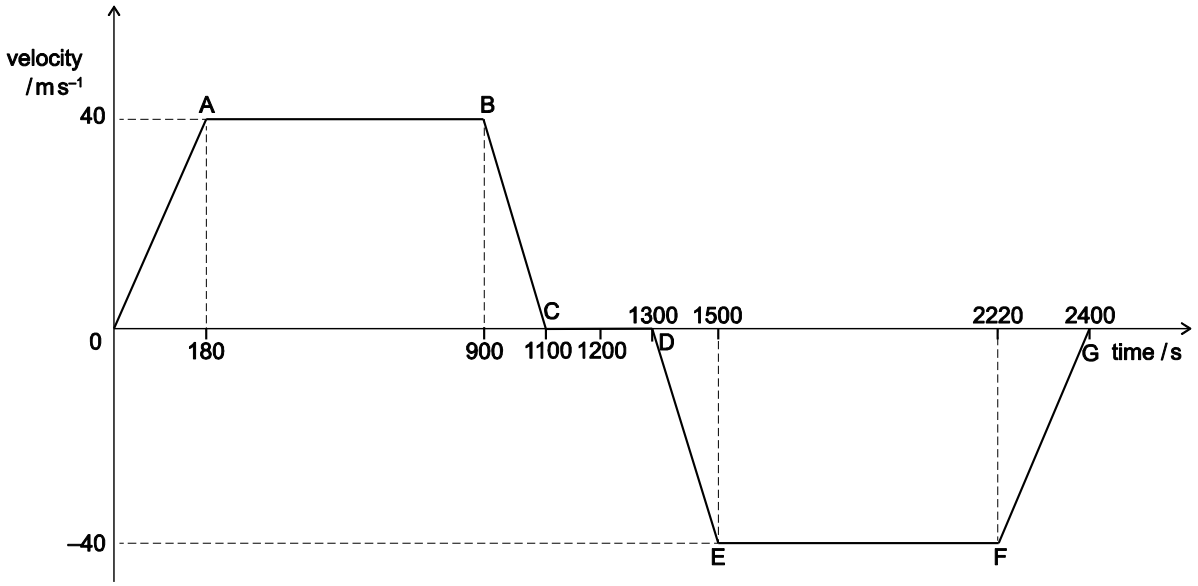
Physics

Question 1

A train of mass 10 000 kg travels from a station on a straight, horizontal track. Its velocity as a function of time is sketched in the graph below.



a) Calculate how far from the station the train is after 40 mins. **[4 marks]**

Answer:……

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b) Find an equation for the velocity of the train between B and C as a function of time. **[4 marks]**

Answer: ……

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c) **(i)** Calculate

$$\int_{1300}^{1500} v(t)\,\mathrm{d}t$$ **[4 marks]**

Answer: ……

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(ii) What quantity does this number represent? **[2 marks]**

Answer: ……

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d) Calculate the force exerted on the train when $t = 1000\,\text{s}$. How does this force arise? **[3 marks]**

Answer: ……

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e) Calculate the mechanical power delivered by the train's engine when $t = 90\,\text{s}$, neglecting the effects of air resistance. **[4 marks]**

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f) Make an annotated plot of the position and acceleration of the train as a function of time over the range $t = 0\,\text{s}$ to $t = 2400\,\text{s}$. **[4 marks]**

Answer:

Question 2

Parts **(c)** and **(d)** can be attempted even if part **(b)** is not completed.

A stone of mass m slides on a horizontal frozen lake. There is no friction between the stone and the ice, but air resistance creates a drag force on the stone equal to bv^3, where v is its horizontal velocity, and b is a constant.

a) Explain why the velocity obeys the equation $ma = -bv^3$, where a is the acceleration. **[2 marks]**

Answer: ……

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b) The acceleration can be written as the derivative of the velocity with respect to time:

$$a = \frac{\mathrm{d}v}{\mathrm{d}t}$$

Using this, the equation for the velocity can be written

$$m\frac{\mathrm{d}v}{\mathrm{d}t} = -bv^3$$

This equation is an example of a differential equation. How the velocity varies with time can be found by solving this equation, which involves evaluating the following (*which you do not need to prove*)

$$\int_{v_0}^{v} \frac{1}{v^3}\,\mathrm{d}v = \int_0^t -\frac{b}{m}\,\mathrm{d}t$$

where v_0 is the velocity at time $t = 0$.

(i) Evaluate the definite integral on the left-hand side, and similarly evaluate the definite integral on the right-hand side. **[8 marks]**

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(ii) By setting the results of the two integrals to be equal to one another and rearranging your expression show that

$$v^2 = \frac{v_0^2 m}{m + 2bv_0^2 t}$$ **[4 marks]**

Answer: ……

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c) After what length of time will the stone's velocity have halved? **[5 marks]**

Answer: ……

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d) Sketch the velocity and acceleration of the stone as a function of time. **[6 marks]**

Answer:

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H 1 1.008																	**He** 2 4.003
Li 3 6.941	**Be** 4 9.012											**B** 5 10.81	**C** 6 12.01	**N** 7 14.01	**O** 8 16.00	**F** 9 19.00	**Ne** 10 20.18
Na 11 22.99	**Mg** 12 24.31											**Al** 13 26.98	**Si** 14 28.09	**P** 15 30.97	**S** 16 32.06	**Cl** 17 35.45	**Ar** 18 39.95
K 19 39.10	**Ca** 20 40.08	**Sc** 21 44.96	**Ti** 22 47.87	**V** 23 50.94	**Cr** 24 52.00	**Mn** 25 54.94	**Fe** 26 55.85	**Co** 27 58.93	**Ni** 28 58.69	**Cu** 29 63.55	**Zn** 30 65.38	**Ga** 31 69.72	**Ge** 32 72.63	**As** 33 74.92	**Se** 34 78.97	**Br** 35 79.90	**Kr** 36 83.80
Rb 37 85.47	**Sr** 38 87.62	**Y** 39 88.91	**Zr** 40 91.22	**Nb** 41 92.91	**Mo** 42 95.95	**Tc** 43	**Ru** 44 101.1	**Rh** 45 102.9	**Pd** 46 106.4	**Ag** 47 107.9	**Cd** 48 112.4	**In** 49 114.8	**Sn** 50 118.7	**Sb** 51 121.8	**Te** 52 127.6	**I** 53 126.9	**Xe** 54 131.3
Cs 55 132.9	**Ba** 56 137.3	**La*** 57 138.9	**Hf** 72 178.5	**Ta** 73 180.9	**W** 74 183.8	**Re** 75 186.2	**Os** 76 190.2	**Ir** 77 192.2	**Pt** 78 195.1	**Au** 79 197.0	**Hg** 80 200.6	**Tl** 81 204.4	**Pb** 82 207.2	**Bi** 83 209.0	**Po** 84	**At** 85	**Rn** 86
Fr 87	**Ra** 88	**Ac^{+}** 89															

symbol
atomic number
mean atomic mass

***Lanthanides**	**Ce** 58 140.1	**Pr** 59 140.9	**Nd** 60 144.2	**Pm** 61	**Sm** 62 150.4	**Eu** 63 152.0	**Gd** 64 157.3	**Tb** 65 158.9	**Dy** 66 162.5	**Ho** 67 164.9	**Er** 68 167.3	**Tm** 69 168.9	**Yb** 70 173.0	**Lu** 71 175.0
$^{+}$Actinides	**Th** 90 232.0	**Pa** 91 231.0	**U** 92 238.0	**Np** 93	**Pu** 94	**Am** 95	**Cm** 96	**Bk** 97	**Cf** 98	**Es** 99	**Fm** 100	**Md** 101	**No** 102	**Lr** 103

Question 3

a) There are two compounds with the formula C_3H_6. Write out the structures of these molecules as a displayed formula and as a skeletal formula. Give the names of the two compounds and identify the particular class of compounds each belongs to. **[4 marks]**

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b) Like every other member in its class, one isomer of C_3H_6, isomer **A**, reacts rapidly with bromine to form a single product, **F**. Draw the structure of **A** as a skeletal formula and also the structure of the product formed when **A** reacts with bromine. **[3 marks]**

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c) The second isomer of C_3H_6, isomer **B**, has a number of unique properties. The other members in the same class of compounds only react with bromine in the presence of light and form HBr as a side product. However, **B** reacts with bromine in the absence of light (but much less rapidly than **A**) and forms a single compound **G**. **F** and **G** are isomers. Draw the structures of **B** and **G** as skeletal formulae. **[4 marks]**

Answer: ……

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d) The table below gives values of the standard enthalpies of combustion, $\Delta_c H^o$, of **A**, **B**, carbon (as graphite) and hydrogen.

	A	***B***	*C(s) (graphite)*	*H_2(g)*
$\Delta_c H^o$ / kJ mol^{-1}	−2058	−2091	−393.5	−241.8

(i) Give the balanced chemical equation for the complete combustion of C_3H_6. **[2 marks]**

Answer: ……

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(ii) Calculate the standard enthalpy of formation, $\Delta_f H^o$, of **A**. **[3 marks]**

Answer: ……

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(iii) Calculate the standard enthalpy of formation of **B**. **[3 marks]**

Answer: ……

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(iv) Calculate the standard enthalpy change for the reaction **B** → **A**. Comment on the value you obtain. **[2 marks]**

Answer: ……

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e) The standard enthalpy of combustion of C_6H_{12} is $-3920\,kJ\,mol^{-1}$. Using this value and the corresponding value for **B**, calculate the average contribution $\Delta_c H^o$ per CH_2 group for the two compounds. Comment on your result. **[4 marks]**

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Question 4

a) Arsenic oxide As_2O_3 is prepared on an industrial scale by roasting arsenic-containing ores such as arsenopyrite, FeAsS, in air. The other products formed are iron(III) oxide and sulfur dioxide.

(i) What is the oxidation state of the arsenic in As_2O_3? **[1 mark]**

Answer: ……

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(ii) Give a balanced chemical equation for the industrial production of As_2O_3 from FeAsS. **[2 marks]**

Answer: ……

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b) As_2O_3 is moderately soluble in water; one dm^3 of a saturated solution at 25 °C contains 20.6 g. When dissolved in water, the oxide reacts to form arsenous acid, H_3AsO_3.

(i) Given that other measurements show all the hydrogen atoms in H_3AsO_3 to be in the same environment, suggest a structure for the acid. What is the geometry around the arsenic atom? **[2 marks]**

Answer: ……

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(ii) Give an equation for the formation of arsenous acid from As_2O_3 when dissolved in water. **[2 marks]**

Answer: ……

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(iii) Calculate the concentration of the arsenous acid, in mol dm^{-3}, in the saturated solution. **[2 marks]**

Answer: ……

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c) Homeopathic medicines are made by preparing an extremely dilute solution of some compound, such as As_2O_3. Typically a saturated solution is diluted by a factor of 10^{30}.

(i) Assuming that the solution referred to in **(b)** is diluted by a factor of 10^{30}, calculate the mass (in g) of As_2O_3 present in a 100 cm^3 of the diluted solution. **[2 marks]**

Answer: ……

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(ii) Given that 0.1 g of As_2O_3 is usually fatal, calculate the volume (in m^3) of the diluted solution that would be needed for a fatal dose of As_2O_3. Also express your answer as a fraction of the volume of the Earth (approximately 1.08×10^{12} km^3). **[4 marks]**

Answer: ……

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(iii) The diluted solution is usually sold in 'one ounce' bottles (1 ounce $= 28\,cm^3$). Calculate how many bottles of the solution need to be bought in order, on average, to purchase one atom of arsenic. **[4 marks]**

Answer: ……

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d) Diluted hydrochloric acid is also sold as a homeopathic medicine. The pH of a solution may be calculated using the following equation:

$$pH = -\log_{10}[H^+]$$

where $[H^+]$ is the total concentration of hydrogen ions, in mol dm^{-3}, in aqueous solution. Rearranging this equation allows us to calculate the total concentration of hydrogen ions from the pH of the solution:

$$[H^+] = 10^{-pH}$$

(i) What is the pH of pure water at room temperature? Calculate $[H^+]$ for pure water. **[3 marks]**

Answer: ……

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(ii) Assuming the original stock solution before dilution has a concentration of $1.0\,mol\,dm^{-3}$, what is the concentration of HCl and pH obtained by the following dilutions of the stock solution: **1)** dilution by a factor of 10^2; **2)** dilution by a factor of 10^6; **3)** dilution by a factor of 10^{10}. **[3 marks]**

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Question 5

Look at the following table.

	320										330										340									
Organism 1	G	C	C	T	A	G	G	C	A	T	T	A	C	G	C	T	A	C	G	T	C	G	C	A	T	T	A	T	A	C
Organism 2	G	C	T	A	A	G	G	C	A	C	T	A	C	G	C	T	A	C	G	T	C	G	C	T	T	A	A	T	A	G
Organism 3	G	C	T	A	A	G	C	A	C	T	A	C	G	C	T	A	C	G	T	C	G	C	T	T	A	A	T	A	G	C
Organism 4	G	C	T	A	A	G	G	C	A	C	T	A	C	G	C	T	A	C	G	T	C	G	C	A	T	T	A	T	A	C
Organism 5	G	C	C	A	A	G	G	C	A	C	T	A	C	G	C	T	A	C	G	T	C	G	C	A	T	T	A	T	A	C
Organism 6	G	C	T	A	A	G	G	C	A	C	T	A	C	G	C	T	A	C	G	T	C	G	C	T	T	T	A	T	A	C
Organism 7	G	C	T	A	A	G	A	G	A	C	T	A	C	G	G	A	A	C	G	C	C	G	C	T	T	A	A	T	A	G

a) What does each horizontal line represent? **[1 mark]**

Answer:……..

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b) If the molecules represented above are transcribed, how would the sequences of the transcripts differ from the original sequences? (Note that you do not need to write out all of the transcripts.) **[3 marks]**

Answer: ……

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c) Which of the sequences is least likely to lead to a functional part of a protein, and why?

[3 marks]

Answer: ……

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d) Each organism in the table belongs to a different species. Based on the sequences, state which organisms are **(i)** the most related to each other, and **(ii)** the least related to each other.

[4 marks]

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e) If organisms 1-6 are all Eukaryotes, which domain(s) of life could organism 7 belong to?

[2 marks]

Answer: ……

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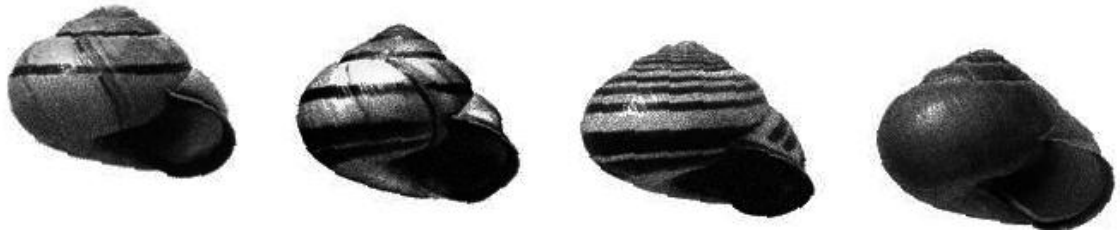
f) Discuss how the differences in these sequences might have arisen, and the possible evolutionary consequences of this variation. **[12 marks]**

Answer: ……

Question 6

Look at the image below.



a) Using experiments, how could you tell if each of these snails belonged to the same species? **[2 marks]**

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b) These snails do in fact belong to the same species, and each of the colour/stripe forms is maintained at very consistent frequencies in the population across time. When such variation is maintained in the population by natural selection, we call it a stable polymorphism. With reference to natural selection, explain why stable polymorphisms are relatively rare in nature. **[3 marks]**

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c) In this case, birds encounter the most abundant forms more frequently and can develop better 'search images', making it easier to find that form in future. Suggest how the variation in snail shells might be maintained in a population. **[2 marks]**

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d) In terms of genetics, the allele for 'unbanded' is dominant to 'banded'. If I breed some homozygous 'unbanded' snails together with homozygous 'banded' snails, what will be the F1 phenotypes and genotypes? **[2 marks]**

Answer: ……

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e) If I breed the F1 generation from the previous cross together, and get 240 offspring, what will be the estimated numbers of each phenotype and genotype in the next generation? **[4 marks]**

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f) Explain how you would conduct a study to compare the proportions of pink, banded snails in two different habitats. Consider how you would avoid bias in your samples. **[12 marks]**

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