UNIVERSITY OF CAMBRIDGE

Admissions Testing Service

NATURAL SCIENCES ADMISSIONS ASSESSMENT

D568/12

Wednesday 2 November 2016

40 minutes

SECTION 2

0094210358

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 pages inside this booklet 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 35 printed pages and 9 blank pages.

PV2

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Physics

Question 1

a) A narrow beam of molecules with a range of different speeds passes through a molecular velocity selector.

The selector comprises two discs rotating in the same direction at the same frequency of rotation f on a common axis in an evacuated container.

The selector allows molecules with particular speeds to pass through.

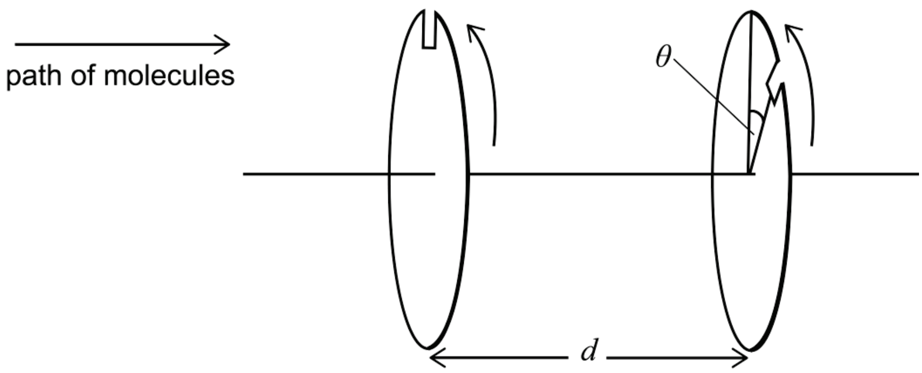

Fig. 1.1

The speeds of the molecules, v, entering the selector vary over a very broad range. The molecules can pass through a very narrow slit on each of the two discs, as shown in Fig. 1.1. The slit on the right-hand disc is displaced by angle θ relative to the slit on the left-hand disc. The horizontal separation of the discs is d.

(The effects of gravity may be ignored and the speed of a molecule within the container remains constant.)

(i) For $f = 160$ revolutions s^{-1}, how long does it take for the discs to rotate through 1.0°? **[2 marks]**

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(ii) If $\theta = 30.0°$, $d = 24.0\,\text{cm}$ and $f = 160$ revolutions s^{-1}, what is the highest speed of a molecule that will pass through both slits? **[3 marks]**

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(iii) When the speeds of the molecules are measured after they have passed through the two narrow slits, it is found that other molecular speeds are present. Explain why there is more than one speed in the outgoing beam. **[3 marks]**

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(iv) For the arrangement described in **(ii)**, calculate the molecular speed, closest to your value in **(ii)**, that will pass through both slits. **[3 marks]**

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(v) Each slit has an angular width of 0.3° either side of its centre, with the centres of the slits being θ apart. What is the range of speeds ($v_{max} - v_{min}$) for the set of molecules referred to in **(ii)** that pass through both slits? **[3 marks]**

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b) A particle of mass m falls through height h on to a thin disc rotating at a rate f revolutions s^{-1}. The particle will just fit through a hole in the rotating disc (Fig. 1.2).

(The effects of air resistance may be ignored; take the acceleration due to gravity as $9.81\,m\,s^{-2}$.)

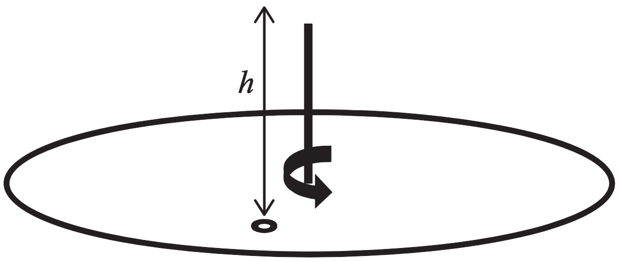

Fig. 1.2

(i) The disc is rotating at frequency f revolutions s^{-1} when the particle is released from rest. Working in degrees, write down an expression for the angle θ through which the disc will have turned by the time the particle reaches it. **[3 marks]**

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(ii) If $f = 20$ revolutions s^{-1} and a particle, initially at rest, is released at the moment that the hole is vertically below it, what is the minimum height (greater than zero) from which the particle can be dropped so that it will pass through the hole? **[2 marks]**

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(iii) An identical disc with a similar hole is fixed to the same axis, but at a distance $h' = 0.15\,\text{m}$ below it. The two holes are aligned. When the particle is released from rest at a height $h = 0.10\,\text{m}$ above the top disc, it is able to fall through both holes in succession. What is the minimum frequency of rotation (greater than zero) of both discs which will allow this to occur? **[6 marks]**

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Question 2

a) Calculate the readings shown on the voltmeter and on ammeters A_1 and A_2 in the circuits shown in Fig. 2.1 **(i)** and **(ii)**.

(You may assume that the ammeters and voltmeters are ideal and that the cells have negligible internal resistance.)

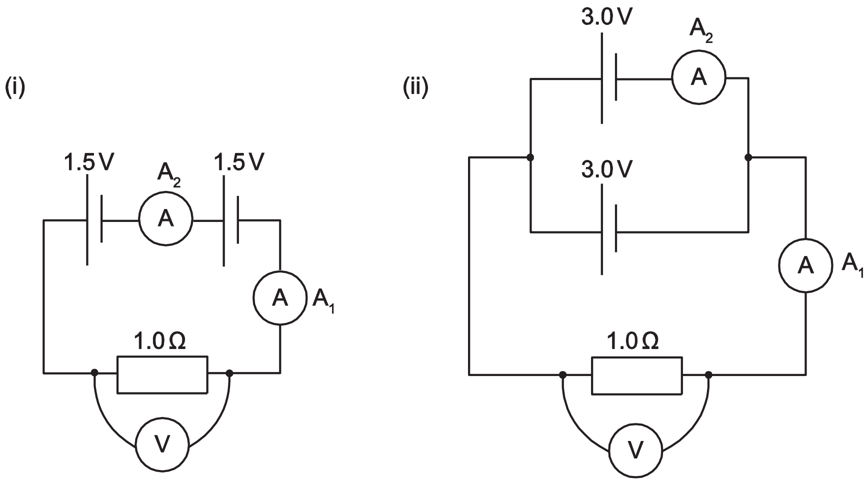

Fig. 2.1 **[5 marks]**

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b) In a more realistic model, the 1.5 V cell has an internal resistance of 0.10 Ω and the 3.0 V cell also has an internal resistance of 0.10 Ω. Calculate the new readings on the voltmeter and on the ammeters for the circuits shown in Fig. 2.1 **(i)** and **(ii)**. **[5 marks]**

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c) The 1.5 V and 3.0 V cells each store the same amount of energy. In which of the four arrangements described in **a)(i)** and **(ii)** and **b)(i)** and **(ii)** do the cells take the longest time to transfer all their energy into heat? Explain your reasoning. **[2 marks]**

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d) A solar cell can be modelled as an ideal cell of 0.50 V in series with an internal resistor of 0.10 Ω. We want to operate a fan that consumes 0.96 W of power and requires a potential difference of 2.4 V. There are 10 identical solar cells available and all must be used. They are arranged as *n* identical parallel sections with each section consisting of *N* cells in series. How must they be arranged in the circuit, and what is the current in each solar cell? In both cases explain your reasoning. **[4 marks]**

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e) A cell with a potential of 1.5 V and zero internal resistance is connected to two resistors in parallel, with values $R_1 = 1.0\,\Omega$ and $R_2 = 2.0\,\Omega$, as shown in Fig. 2.2.

(i) Calculate the current through the cell. **[2 marks]**

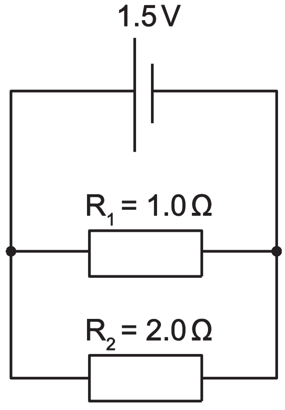

Fig. 2.2

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(ii) If the 1.5 V cell in the circuit shown in Fig. 2.2 is replaced with a 1.5 V cell with an internal resistance $r = 0.10\,\Omega$, how much power is dissipated in R_2? **[2 marks]**

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(iii) A third resistor $R_3 = 4.0\,\Omega$ is now added in parallel with the first two resistors with the cell from **e(ii)**, as shown in Fig. 2.3. Calculate the current through the cell (which has an internal resistance of $0.10\,\Omega$). **[2 marks]**

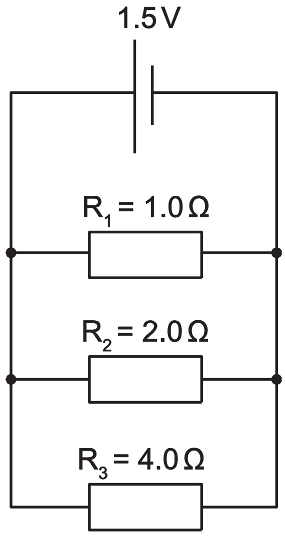

Fig. 2.3

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(iv) More and more resistors are now added, one by one, in parallel with the existing ones, each with double the resistance of the previous one. The final circuit consists of resistors with values of 1 Ω, 2 Ω, 4 Ω, 8 Ω, 16 Ω, 32 Ω, 64 Ω, … connected in parallel with the cell. Calculate the total current through the cell if the number of resistors is infinite.

[3 marks]

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Chemistry

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															

Key:

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

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Question 3

Parts **a)**, **b)** and **c)** can be answered independently of one another.

a) Draw two alternative 'dot and cross' diagrams to describe the bonding in the linear thiocyanate anion SCN^-. In one diagram place the negative charge on the sulfur, and in the other place the negative charge on the nitrogen. **[5 marks]**

Answer:

b) Breakfast cereals frequently have elemental iron added to them as a dietary supplement. A method for making a quantitative measurement of the amount of iron is to use the reaction between Fe^{3+}(aq) and thiocyanate, SCN^{-}(aq), which gives the deep red complex $FeSCN^{2+}$(aq).

$$Fe^{3+}(aq) + SCN^{-}(aq) \longrightarrow FeSCN^{2+}(aq)$$

The depth of the colour can be measured using a *spectrophotometer* which gives a value for the *absorbance* that is proportional to the concentration of the complex:

$$\text{absorbance} = \text{constant} \times [FeSCN^{2+}]$$ **Equation 1**

The constant can be found by measuring the absorbance of a solution of known concentration.

(i) The absorbance of a solution of the complex with concentration 2.5×10^{-4} mol dm^{-3} was measured to be 1.85; determine the value of the constant in Equation 1. **[2 marks]**

Answer: ....

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100 g of breakfast cereal was mixed with sufficient dilute acid to dissolve all of the iron. The solution was carefully filtered and mixed with sufficient oxidising agent to convert all of the iron to Fe^{3+}. The solution was made up to a total volume of 250 cm^3. 10.0 cm^3 of this solution was mixed with 10.0 cm^3 of a solution of thiocyanate; you may assume that all of the iron is converted to the complex. The absorbance of the resulting solution was measured as 0.519.

(ii) Using the value of the constant found in **(i)**, calculate the concentration of Fe^{3+} in the solution for which the absorbance was measured. **[2 marks]**

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(iii) Hence calculate the concentration of Fe^{3+} in the solution prepared from the cereal.
[2 marks]

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(iv) Hence calculate the mass of iron present in the 100 g of breakfast cereal (A_r: Fe = 55.85).
[4 marks]

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c) Hydrogen peroxide, H_2O_2, is used as the oxidising agent to convert Fe^{2+} to Fe^{3+} in the assay described in **b)(ii)**.

(i) Determine the oxidation state of oxygen in H_2O_2. **[2 marks]**

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(ii) When H_2O_2 acts as an oxidising agent in acidic solution, what is the oxygen-containing species that is produced and what is the oxidation state of oxygen in this species? **[4 marks]**

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(iii) Write a balanced chemical equation describing the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$ by H_2O_2 in acidic solution. **[4 marks]**

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Question 4

There are six isomers with the formula C_5H_{10} that are alkenes. The alkenes all have different enthalpies of formation, all of which are negative.

a) Draw the structures of the six alkenes (skeletal or displayed structures are acceptable).

[6 marks]

Answer:

Samples of the six alkenes, in a random order, are labelled **P**, **Q**, **R**, **S**, **T**, and **U**. You will be able to identify which isomer *some* of these correspond to using the information and data throughout the rest of the question.

Alkenes **P**, **Q**, and **R** react with hydrogen gas and a metal catalyst to give the same alkane **A**; alkenes **S**, **T**, and **U** react under the same conditions to give a different alkane **B**.

Both alkanes **A** and **B** react with chlorine gas under UV light to form chloroalkanes with the formula $C_5H_{11}Cl$. Under such conditions, alkane **A** forms *four* different structural isomers, whereas **B** gives *three*.

b) Draw the structures of alkanes **A** and **B**. Also draw the structures of the four isomers arising from the chlorination of **A**, and the three isomers arising from the chlorination of **B**. **[6 marks]**

Answer:

The alkenes react with HBr to form bromoalkanes with the formula $C_5H_{11}Br$; the reaction proceeds via a carbocation intermediate. Alkenes **S** and **T** give a mix of *two* structural isomers, whereas alkene **U** gives only one.

c) Give the structure of alkene **U**. **[4 marks]**

Answer:

A general rule for isomeric alkenes is that the more carbon atoms directly bonded to the double bond (or the lower the number of hydrogen atoms directly bonded), the more negative (that is, the more exothermic) the enthalpy of formation of the alkene.

d) Out of **P**, **Q** and **R**, **R** has the most negative (most exothermic) enthalpy of formation. Give the structure of **R**. **[1 mark]**

Answer:

Consider the following thermodynamic data:

	value / $kJ\,mol^{-1}$
standard enthalpy change of hydrogenation for alkene **P**	–113
standard enthalpy change of hydrogenation for alkene **Q**	–119
standard enthalpy change of combustion for alkane **A**	–3528
standard enthalpy change of formation of $H_2O(l)$	–286

e) Use the data to deduce the structure of: **(i)** alkene **P**; and **(ii)** alkene **Q**. **[4 marks]**

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f) Use the data to calculate the standard enthalpy change of combustion of alkene **P**.

[4 marks]

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Biology

Question 5

*Eco*RI is a restriction enzyme that cuts bacterial DNA into pieces at specific sequences.

a) What type of biological molecule is *Eco*RI? **[1 mark]**

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b) Name the type of bond between adjacent nucleotides that is cut by *Eco*RI. **[1 mark]**

Answer: ………………………………………………………………………………………….....

c) *Eco*RI cuts at specific sites in the DNA, characterised by the sequence GAATTC. Other restriction enzymes cut at specific sequences like GGATCC or AGCT. What characteristic do these sequences have in common and how might this characteristic aid in cutting?

[3 marks]

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d) *Eco*RI is produced by bacteria. What role might it have in a bacterial cell? **[1 mark]**

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e) We can use different restriction enzymes to cut DNA at different sites. Another restriction enzyme is *Bam*HI. By studying the fragments produced by different combinations of restriction enzymes we can produce a map of the cutting sites of these enzymes.

Use the data in the table below to produce a map of the cutting sites of restriction enzymes. This map should be drawn onto a circle of bacterial plasmid DNA, the total length of which is 18 kb. Distances between the cut sites should be identified. **[4 marks]**

enzyme used	*fragment sizes produced* / kb
*Eco*RI alone	6, 12
*Bam*HI alone	7.5, 10.5
*Eco*RI and *Bam*HI together	3, 3, 4.5, 7.5

Answer:

f) Suggest how enzymes like *Eco*RI could be used in genetic engineering. **[3 marks]**

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g) *Eco*RI is produced by bacteria that often live harmlessly inside the human body. Explain how temperature and pH might affect the activity of *Eco*RI in bacterial cells, using diagrams if necessary. **[12 marks]**

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Question 6

Below are images of three species of organism, all of which are vermiform (worm-like) in appearance.

A

B

C

a) What is the approximate length of each species in mm? **[3 marks]**

Answer: …………………………………………………………………………………………......

A……………………………………………………………………………………………….

B……………………………………………………………………………………………….

C……………………………………………………………………………………………….

b) What type of microscope has been used to produce the images of organisms B and C? **[2 marks]**

Answer: …………………………………………………………………………………………....

B………………………………………………………………………………………………

C………………………………………………………………………………………………

c) For organism A, treating it as a tube, estimate the surface area:volume ratio, working in mm.
Show your working. **[4 marks]**

Answer: ……………………………………………………………………………………………….....

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d) How will the surface area:volume ratio differ between the three organisms? **[2 marks]**

Answer: ……………………………………………………………………………………………….....

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e) Identify four substances that organism A may need to exchange with the external environment. **[2 marks]**

Answer: ……………………………………………………………………………………………….....

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f) Discuss how the size of organisms affects their ease of exchange of substances with the external environment. You should highlight at least two adaptations that help overcome the constraints of size. **[12 marks]**

Answer: ……………………………………………………………………………………………

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N