UNIVERSITY OF CAMBRIDGE

NATURAL SCIENCES ADMISSIONS ASSESSMENT **D568/12**

Wednesday 30 October 2019 **40 minutes**

SECTION 2

2201816059

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 20 marks for each question. In total 40 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 30 printed pages and 10 blank pages.

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Physics

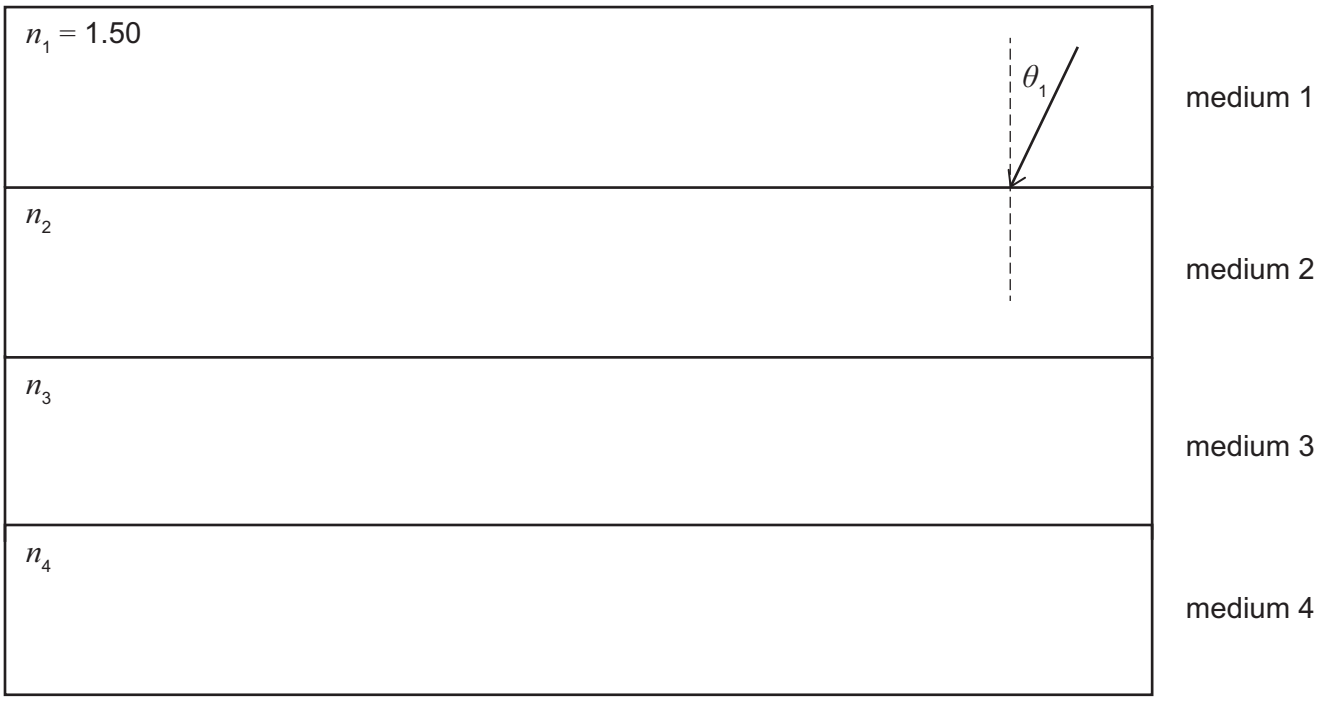
Question P1

a) Four sheets of transparent material are placed on top of each other. A ray of light propagates through medium 1 and is incident at the boundary between medium 1 and medium 2 at an angle θ_1 to the normal. The refractive index of medium 1 is $n_1 = 1.50$.

(i) Given that $n_1 > n_2 > n_3 > n_4$ and n_4 is such that the ray of light **does not** enter medium 4, complete the diagram to show the path of a ray of light through the different mediums. Label the angles to the normal at the boundaries between medium 1 and 2, medium 2 and 3, and medium 3 and 4.

[2 marks]

Answer:



(ii) If the angle at which the light meets the normal to the boundary between medium 3 and medium 4 is the critical angle, find an expression for θ_1 in terms of n_1 and n_4.

[3 marks]

Answer: ……

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(iii) If the refractive index of each medium is given by $n_m = 1.50 \times (0.99)^{m-1}$, where m has values 1, 2, 3, and 4, find the minimum value of θ_1 for total internal reflection to occur at the boundary between medium 3 and medium 4.

[2 marks]

Answer: ……

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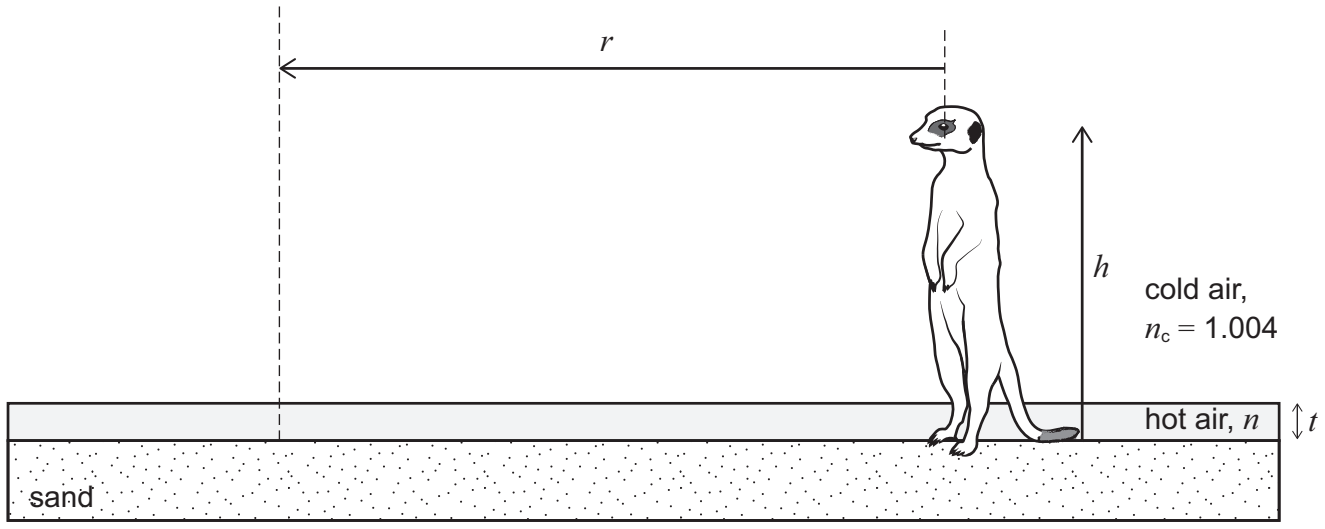
b) A meerkat is in a desert on a hot day with a clear blue sky above the sand. A thin layer of air, of thickness t, above the sand is so hot that it has a lower refractive index, n, than the cold air directly above it. The cold air has a refractive index, $n_c = 1.004$. The meerkat has height h where $h \gg t$. The meerkat believes that he is standing on an "island" of sand of radius r, with what appears to be water all around him. He thinks that there is water because at distances greater than r away from him he sees a reflection of the blue sky when he is looking below the horizon towards the ground.

(i) On the diagram, draw rays to show how light reaches the meerkat's eyes from the sky, by reflection, and from the sand, by refraction.

[2 marks]

Answer:



(ii) Add to the diagram a critical ray showing the path of the light reaching the meerkat's eye from the edge of the "island".

Find an expression for the angle this ray makes with the normal in terms of n_c and n.

[3 marks]

Answer: ……

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(iii) A giraffe stands at the same position as the meerkat. The giraffe has height *H*, where $H \gg h \gg t$. The giraffe thinks the edge of the "island" is at a distance *R*.

Find an expression for $\frac{R}{r}$ in terms of *H* and h.

[1 mark]

Answer: ……

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(iv) Using your result from **(ii)**, show that the radius of the meerkat's "island" is given by $r = \frac{anh}{\sqrt{bn_c^2 + kn^2}}$ and find the integer values of a, b and k.

[3 marks]

Answer: ……

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(v) As the day progresses the hot air warms up and its refractive index n reduces, but the cold air remains at the same temperature and with the same refractive index, n_c. By considering the expression for r from **(iv)**, explain what happens to r as the hot air warms up. Does the meerkat think that the water is **getting closer, staying the same, or getting further away**?

[2 marks]

Answer: ……

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c) The camera that took this photograph was placed at the bottom of a swimming pool. The area labelled A is a window above the pool. The area labelled B is the top surface of a step.

Describe the path that the light has taken to reach the camera from A and from B.

[2 marks]

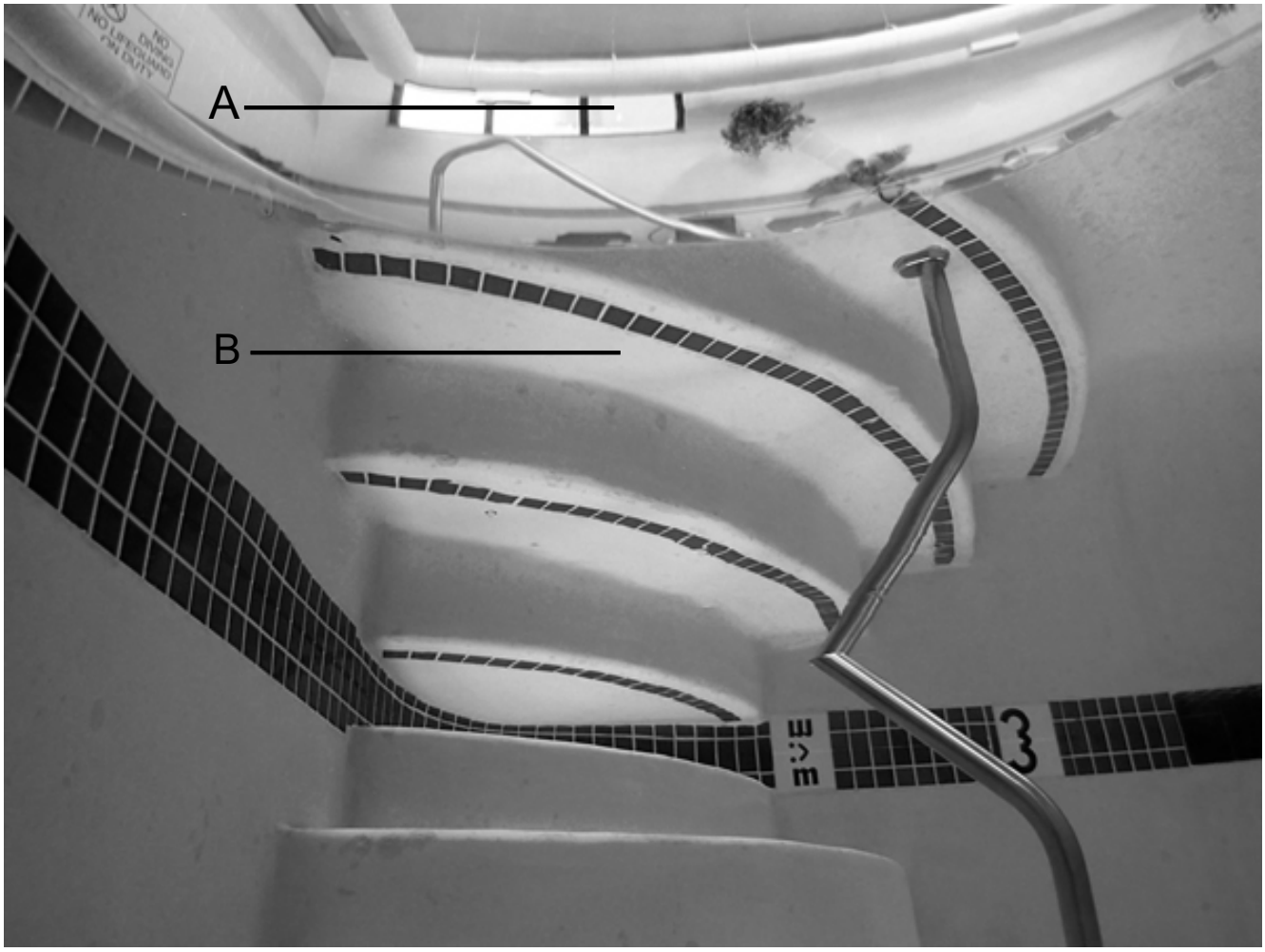

Image used with permission of the High School Physics Photo Contest © 2019 American Association of Physics Teachers

Answer: ……

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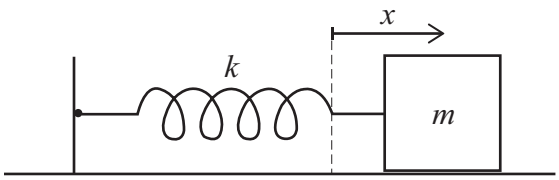
Question P2

A mass m is placed on a frictionless horizontal surface and attached to the end of a light spring of spring constant k, and the spring is attached to a wall as shown in the diagram.



When displaced from equilibrium the mass oscillates with a frequency f. At time t the mass is at a displacement, x, from equilibrium and is moving with velocity, v.

a) Write down an expression for the elastic potential energy, E_p, stored in the spring at time t.

[1 mark]

Answer: ……

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b) Write down an expression for the kinetic energy, E_k, of the mass-spring system.

[1 mark]

Answer: ……

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c) The rate of change of displacement, $\frac{\mathrm{d}x}{\mathrm{d}t} = v$ and the rate of change of velocity, $\frac{\mathrm{d}v}{\mathrm{d}t} = a$.

Using the formula $\frac{\mathrm{d}E_\mathrm{p}}{\mathrm{d}t} = \frac{\mathrm{d}E_\mathrm{p}}{\mathrm{d}x} \times \frac{\mathrm{d}x}{\mathrm{d}t}$ show that $\frac{\mathrm{d}E_\mathrm{p}}{\mathrm{d}t} = kxv$.

Using a similar method, find an expression for $\frac{\mathrm{d}E_\mathrm{k}}{\mathrm{d}t}$ in terms of m, v and a.

Show all of your working.

[3 marks]

Answer: ……

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d) Give the physical reason in words why $\frac{\mathrm{d}(E_\mathrm{k} + E_\mathrm{p})}{\mathrm{d}t} = 0$

[1 mark]

Answer: ……

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e) A formula for the acceleration of the mass is $a = -(2\pi f)^2 x$. Using your answers from part **c)**, the expression given in part **d)** and this formula, find an expression for the frequency of the oscillation, f, in terms of m and k.

Show all of your working.

[3 marks]

Answer: ……

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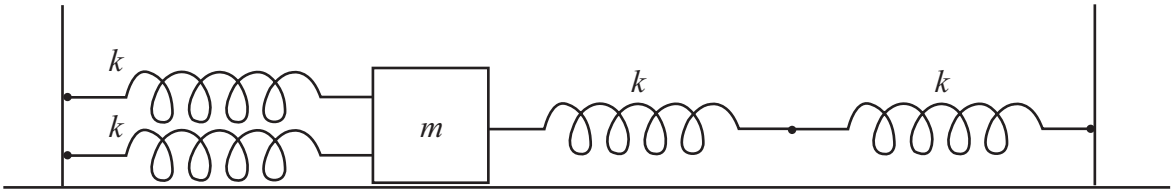
The mass is now placed on a frictionless surface between two walls. It is attached to the left wall by **two** identical, light springs in **parallel**, each of spring constant k and to the right wall by **two** identical springs in **series**, each of spring constant k.



f) What is the new oscillation frequency, f_{new}, of this new system?

[2 marks]

Answer: ……

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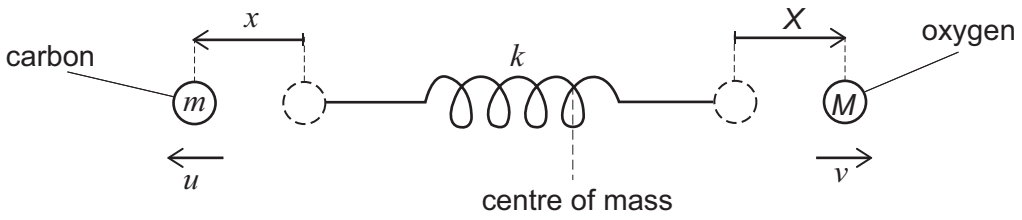
A carbon monoxide molecule can be modelled as two different masses, m and M, each on one end of a light spring of spring constant, k.

When the molecule vibrates it does so such that the centre of mass of the molecule does not move. At time t the spring is extended and the masses are displaced from their equilibrium positions as shown in the diagram. The carbon atom, mass m, has moved a distance x to the left and is moving with a speed u to the left. The oxygen atom, mass M, has moved a distance X to the right and is moving with a speed v to the right.



g) What is the total elastic potential energy stored in the spring in terms of k, x and X?

[1 mark]

Answer: ……

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h) What is the total kinetic energy of the whole system in terms of m, u, M and v?

[1 mark]

Answer: ……

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i) Explain in words why $MX = mx$. Hence deduce an expression for the acceleration, a_M, of mass M, in terms of the acceleration, a_m, of mass m.

[2 marks]

Answer: ……

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j) Given that the total energy of the carbon monoxide molecule is constant, find an expression for the acceleration, a_m, of mass m, in terms of k, m, M and x.

Hence deduce the frequency of the oscillation, f.

[3 marks]

Answer: ……

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k) Calculate the frequency f of the vibration of the carbon monoxide molecule if the mass of the carbon atom is $12\,m_u$, the mass of the oxygen atom is $16\,m_u$ and $k = 2.0 \times 10^3\,\text{N m}^{-1}$.

If this vibration was caused by an electromagnetic wave incident on the molecule, which part of the electromagnetic spectrum would this wave correspond to?

($m_u = 1.66 \times 10^{-27}$ kg. The wavelength of visible light ranges from 400 nm to 700 nm.)

[2 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
relative atomic mass (A_r)

***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

[Turn over

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Chemistry

Question C1

Data: Assume that the molar gas volume = 24.0 $dm^3 mol^{-1}$ at room temperature and pressure (rtp).

This question concerns the chemistry of tellurium, an element in Group 16 of the Periodic Table.

a) What do you expect will be the maximum and minimum oxidation states of tellurium? Briefly explain your answer.

[3 marks]

Answer: ……

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b) How do the electronegativities of the elements vary on descending Group 16?

[1 mark]

Answer: ……

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c) Which hydride, H_2O or H_2Te, has the higher boiling point? Briefly explain your answer.

[2 marks]

Answer: ……

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Tellurium reacts directly with fluorine gas to form a dense gas, **A**, in which each molecule contains a single tellurium atom bonded to several fluorine atoms. In an experiment, 50 cm^3 of gas **A** is formed from 150 cm^3 of fluorine and a certain mass of tellurium, with all measurements made at room temperature and pressure.

d) Calculate the formula of the gas **A**.

[2 marks]

Answer: ……

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e) Predict the value(s) of the F–Te–F bond angles in **A**.

[1 mark]

Answer: ……

f) Calculate the minimum mass of tellurium needed to produce 50 cm^3 of **A**.

[2 marks]

Answer: ……

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g) Calculate the density of gas **A** in g cm^{-3} at room temperature and pressure.

[2 marks]

Answer: ……

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h) Calculate how many times denser gas **A** is than oxygen gas at room temperature and pressure.

[1 mark]

Answer: ……

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In another experiment, 5.0 g of tellurium is oxidised and dissolved in water to form 9.0 g of an acid with general formula H_mTeO_n. On neutralisation with aqueous KOH, 18 g of a salt is formed with general formula K_mTeO_n.

i) Give an expression, in terms of m and n, for the oxidation state of the tellurium in the acid H_mTeO_n.

[1 mark]

Answer: ……

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j) Calculate the relative molecular mass of the acid H_mTeO_n.

[1 mark]

Answer: ……

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k) Calculate the values of m and n, and hence the formulae of the acid H_mTeO_n and the salt formed on neutralisation.

[2 marks]

Answer: ……

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l) Calculate the volume of a 2.0 mol dm^{-3} aqueous solution of KOH that would be needed to neutralise the 9.0 g of acid formed from 5.0 g of tellurium.

[2 marks]

Answer: ……

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Question C2

Trifluoroethanoic acid, TFEA, is a carboxylic acid often used in organic chemistry and has the formula CF_3COOH. The density of TFEA is $1.489\,g\,cm^{-3}$.

a) Draw the structure for trifluoroethanoic acid (TFEA). Indicate on your structure the approximate bond angles around each carbon.

[2 marks]

Answer:

An aqueous solution of TFEA is made up by mixing 0.0700 mol of the pure acid with water and making the solution up to $100.0\,cm^3$.

b) Calculate the volume of pure TFEA needed to make the solution.

[3 marks]

Answer: ……

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c) Give an equation for the ionisation of TFEA in water.

[1 mark]

Answer: ……

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d) Give an expression for the equilibrium constant for the ionisation of TFEA in water.

[2 marks]

Answer: ……

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e) Given that the measured concentration of H^+ ions is $0.4119\,mol\,dm^{-3}$, calculate the value of the equilibrium constant. You may ignore the self-dissociation of water.

[3 marks]

Answer: ……

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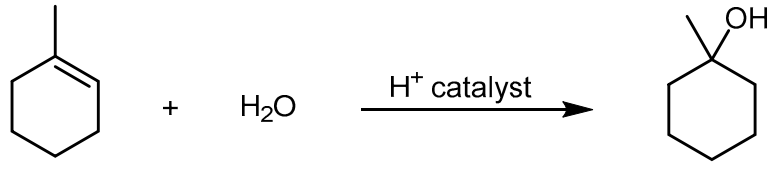
A mixture of TFEA and trifluoroethanoic anhydride, $CF_3COOCOCF_3$, was used as the solvent system in a series of experiments to determine the standard enthalpy changes of hydration of various alkenes.

1-methylcyclohexene, **A**, may be hydrated in an acid-catalysed reaction as shown below:



A **B**

f) How may this reaction be classified? Choose from: *addition*, *elimination*, *substitution*, *oxidation*, *addition polymerisation*.

[1 mark]

Answer: ……

g) Draw the structure of the intermediate initially formed when the H^+ catalyst reacts with alkene **A**.

[1 mark]

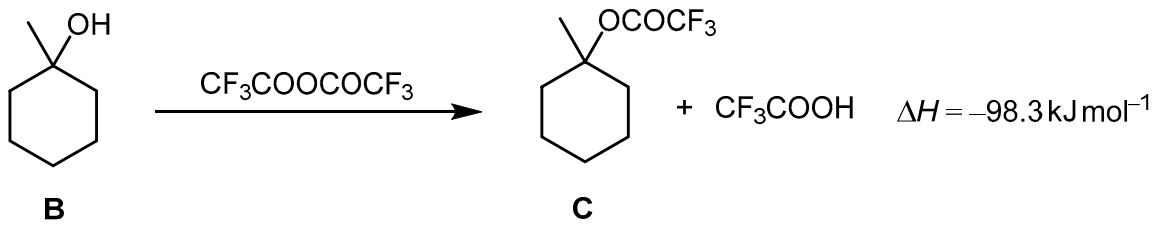
Answer:

h) The same product **B** is formed when an alkene isomer of **A** is treated under identical conditions. Suggest a structure for this isomer.

[1 mark]

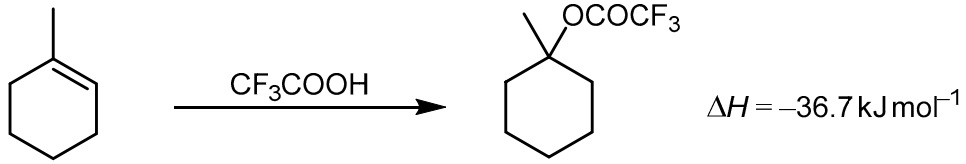
Answer:

In a mixture of TFEA and trifluoroethanoic anhydride, **B** reacts with the trifluoroethanoic anhydride to form **C** and TFEA as shown below. The standard enthalpy change for this reaction is $-98.3\,kJ\,mol^{-1}$.



B **C**

Compound **C** may also be formed in the same mixture of TFEA and trifluoroethanoic anhydride from the reaction between 1-methylcyclohexene and TFEA. The standard enthalpy change for this reaction is $-36.7\,kJ\,mol^{-1}$.



A **C**

The standard enthalpy change for the reaction between one mole of water and one mole of trifluoroethanoic anhydride is $-75.6\,kJ\,mol^{-1}$.

i) Draw the structure of trifluoroethanoic anhydride.

[1 mark]

Answer:

j) Give the equation for the reaction between one mole of water and one mole of trifluoroethanoic anhydride.

[1 mark]

Answer: ……

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k) By constructing an appropriate energy cycle, calculate the standard enthalpy change for the hydration of alkene **A**.

[4 marks]

Answer: ……

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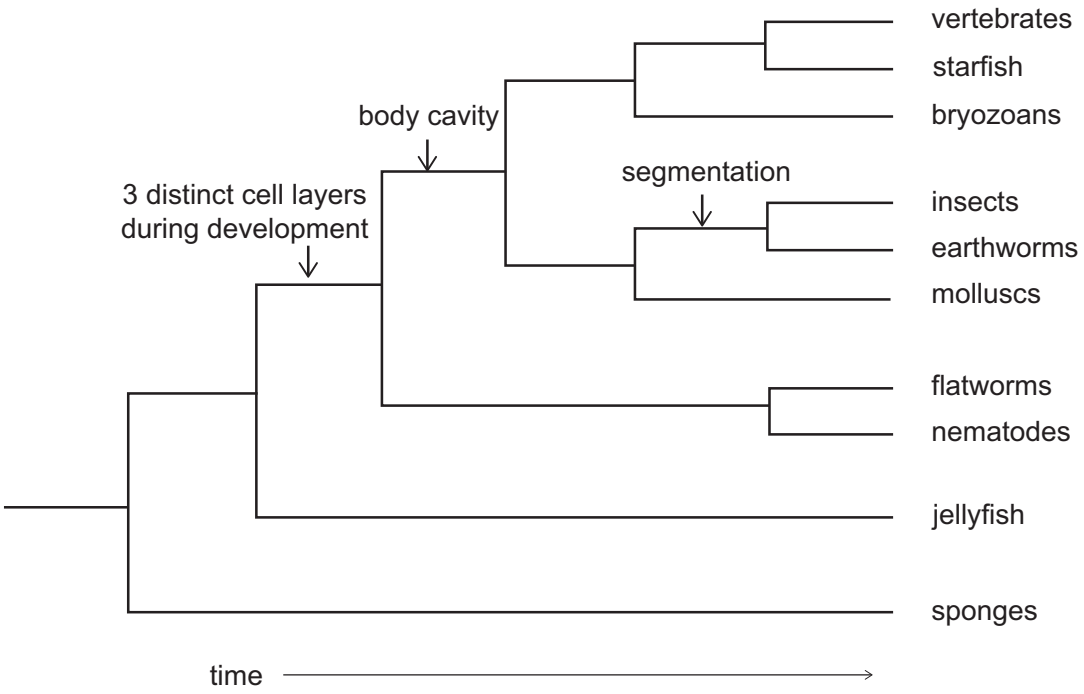
Biology

Question B1

The diagram shows an evolutionary tree for a kingdom of organisms. This tree was constructed over 20 years ago using shared observable features to group these organisms into smaller groups. The time at which three of these shared features first appeared is shown on the evolutionary tree. Each branching point in the tree indicates the time at which groups of organisms diverged from a common ancestor.



a) Identify the kingdom represented in this evolutionary tree.

[1 mark]

Answer: ……

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b) Recently, molecular evidence has changed our understanding of these relationships. Based upon each of the three findings below, what conclusions about evolution can you draw?

(i) Insects and earthworms are not closely related to each other.

[1 mark]

Answer: ……

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(ii) Nematodes and insects, both of which undergo moulting, are very closely related.

[2 marks]

Answer: ……

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(iii) Flatworms, which all lack a true body cavity, are not actually a single group. Some diverged at the base of the tree, some are related to the molluscs, and some are related to starfish and vertebrates.

[2 marks]

Answer: ……

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c) Briefly describe two benefits of using molecular evidence, rather than visible characteristics, to construct trees.

[2 marks]

Answer: ……

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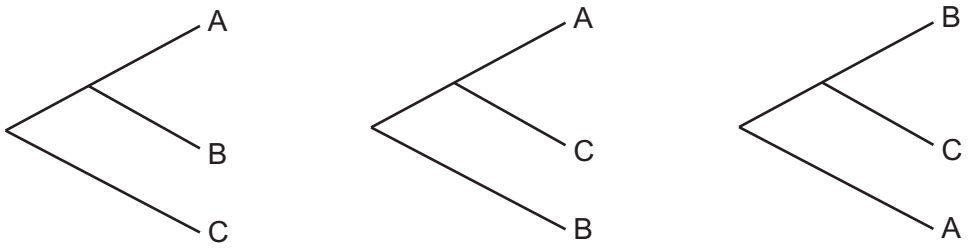
d) The following three tree diagrams show **all** of the possible relationships between 3 different organisms.



How many possible tree diagrams are there with 4 organisms?

[2 marks]

Answer:

e) Using examples, discuss the different ways by which we can measure biodiversity.

[10 marks]

Answer: ……

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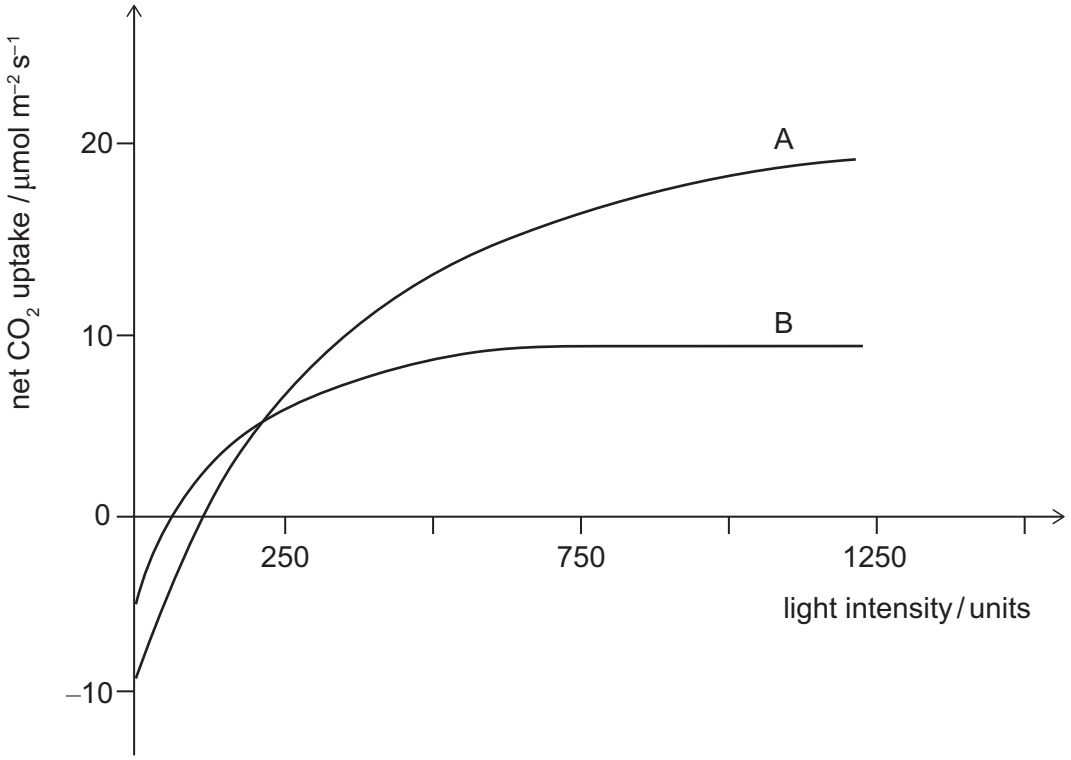
Question B2

The graph shows net CO_2 uptake of two different plants, A and B, when exposed to increasing light levels.



a) Name two physiological processes that affect the net CO_2 uptake in plants.

[1 mark]

Answer: ……

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b) State what can be concluded when the net CO_2 uptake in each plant is zero.

[1 mark]

Answer: ……

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c) For plant B, estimate the value at which increasing light intensity no longer affects CO_2 uptake.

[1 mark]

Answer: ……

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d) Estimate the number of micromoles of CO_2 that would be taken up by a 50 cm^2 leaf of plant B in one minute at light intensity of 750 units.

[2 marks]

Answer: ……

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e) Propose two explanations for the existence of a plateau in the curve for plant B.

[2 marks]

Answer: ……

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f) Describe the differences in the curves for plants A and B and suggest why these differences might occur.

[3 marks]

Answer: ……

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g) Discuss how temperature might affect net CO_2 uptake in plants, with reference to the effects of temperature on enzymatic activity. Use graphs to illustrate your answer.

[10 marks]

Answer:

UNIVERSITY OF CAMBRIDGE

NATURAL SCIENCES ADMISSIONS ASSESSMENT **D568/12**

Wednesday 30 October 2019 **40 minutes**

SECTION 2

2201816059

Candidate Number	N						Centre Number					

	d	d		m	m		y	y	y	y
Date of birth			–			–				

First name(s)	

Surname / Family name	

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Physics

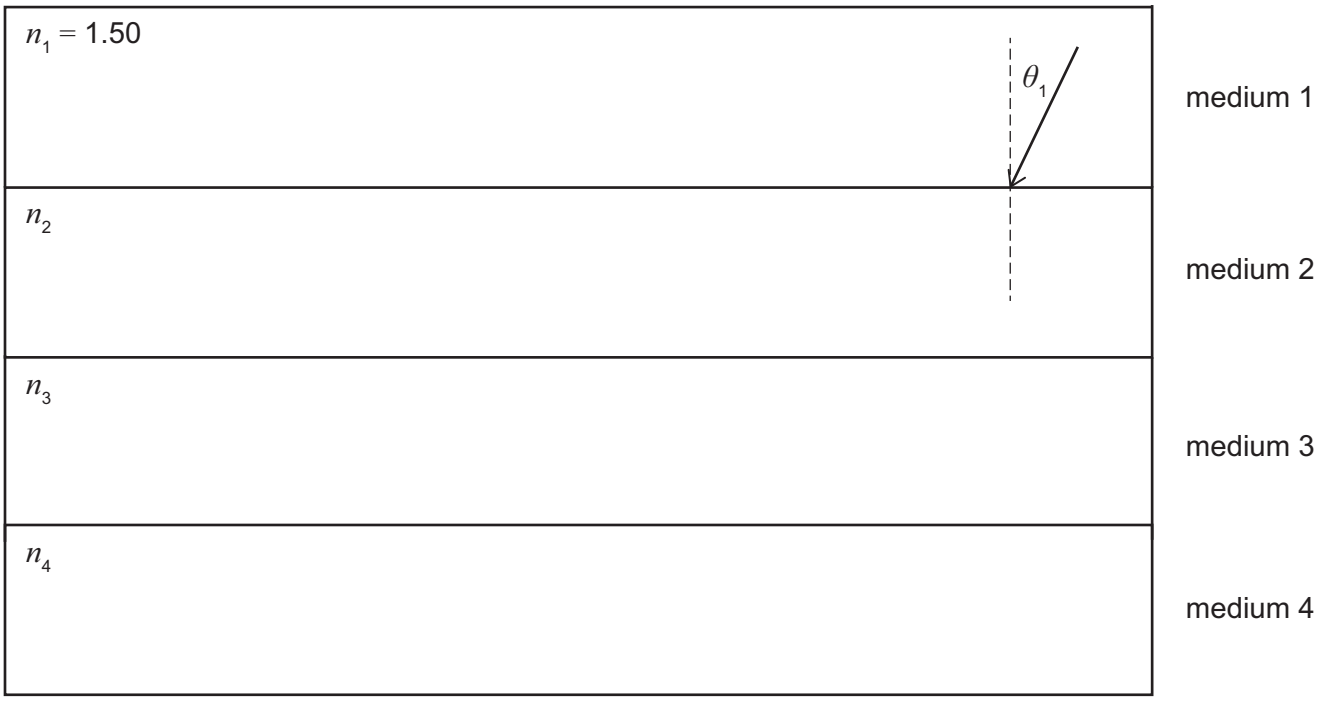
Question P1

a) Four sheets of transparent material are placed on top of each other. A ray of light propagates through medium 1 and is incident at the boundary between medium 1 and medium 2 at an angle θ_1 to the normal. The refractive index of medium 1 is $n_1 = 1.50$.

(i) Given that $n_1 > n_2 > n_3 > n_4$ and n_4 is such that the ray of light **does not** enter medium 4, complete the diagram to show the path of a ray of light through the different mediums. Label the angles to the normal at the boundaries between medium 1 and 2, medium 2 and 3, and medium 3 and 4.

[2 marks]

Answer:



(ii) If the angle at which the light meets the normal to the boundary between medium 3 and medium 4 is the critical angle, find an expression for θ_1 in terms of n_1 and n_4.

[3 marks]

Answer: ……

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(iii) If the refractive index of each medium is given by $n_m = 1.50 \times (0.99)^{m-1}$, where m has values 1, 2, 3, and 4, find the minimum value of θ_1 for total internal reflection to occur at the boundary between medium 3 and medium 4.

[2 marks]

Answer: ……

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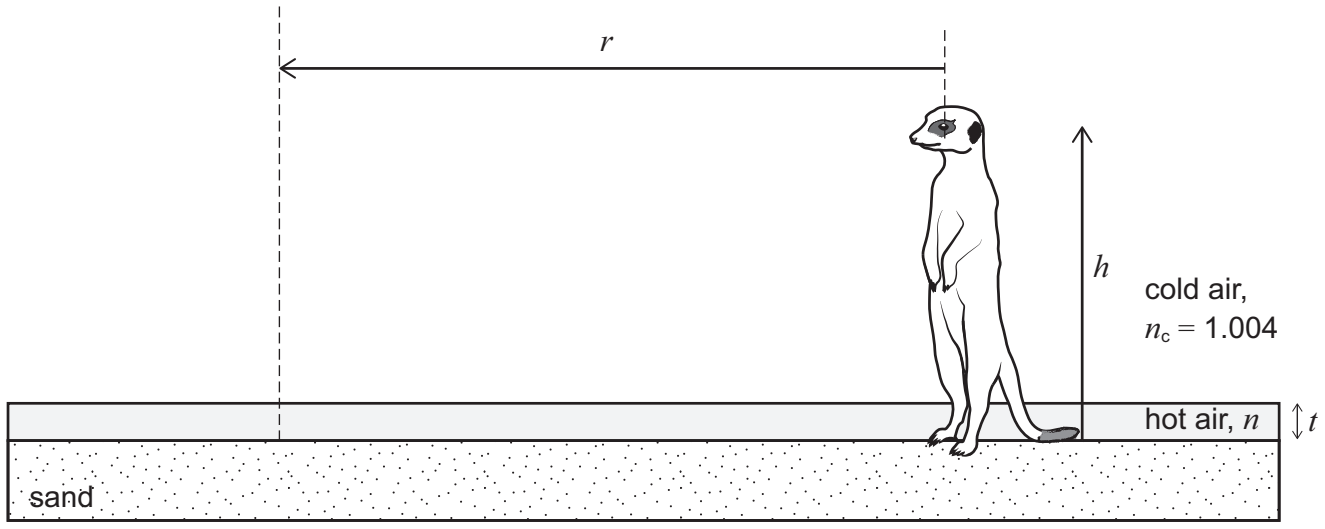
b) A meerkat is in a desert on a hot day with a clear blue sky above the sand. A thin layer of air, of thickness t, above the sand is so hot that it has a lower refractive index, n, than the cold air directly above it. The cold air has a refractive index, $n_c = 1.004$. The meerkat has height h where $h \gg t$. The meerkat believes that he is standing on an "island" of sand of radius r, with what appears to be water all around him. He thinks that there is water because at distances greater than r away from him he sees a reflection of the blue sky when he is looking below the horizon towards the ground.

(i) On the diagram, draw rays to show how light reaches the meerkat's eyes from the sky, by reflection, and from the sand, by refraction.

[2 marks]

Answer:



(ii) Add to the diagram a critical ray showing the path of the light reaching the meerkat's eye from the edge of the "island".

Find an expression for the angle this ray makes with the normal in terms of n_c and n.

[3 marks]

Answer: ……

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(iii) A giraffe stands at the same position as the meerkat. The giraffe has height *H*, where $H \gg h \gg t$. The giraffe thinks the edge of the "island" is at a distance *R*.

Find an expression for $\frac{R}{r}$ in terms of *H* and h.

[1 mark]

Answer: ……

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(iv) Using your result from **(ii)**, show that the radius of the meerkat's "island" is given by $r = \frac{anh}{\sqrt{bn_c^2 + kn^2}}$ and find the integer values of a, b and k.

[3 marks]

Answer: ……

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(v) As the day progresses the hot air warms up and its refractive index n reduces, but the cold air remains at the same temperature and with the same refractive index, n_c. By considering the expression for r from **(iv)**, explain what happens to r as the hot air warms up. Does the meerkat think that the water is **getting closer, staying the same, or getting further away**?

[2 marks]

Answer: ……

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c) The camera that took this photograph was placed at the bottom of a swimming pool. The area labelled A is a window above the pool. The area labelled B is the top surface of a step.

Describe the path that the light has taken to reach the camera from A and from B.

[2 marks]

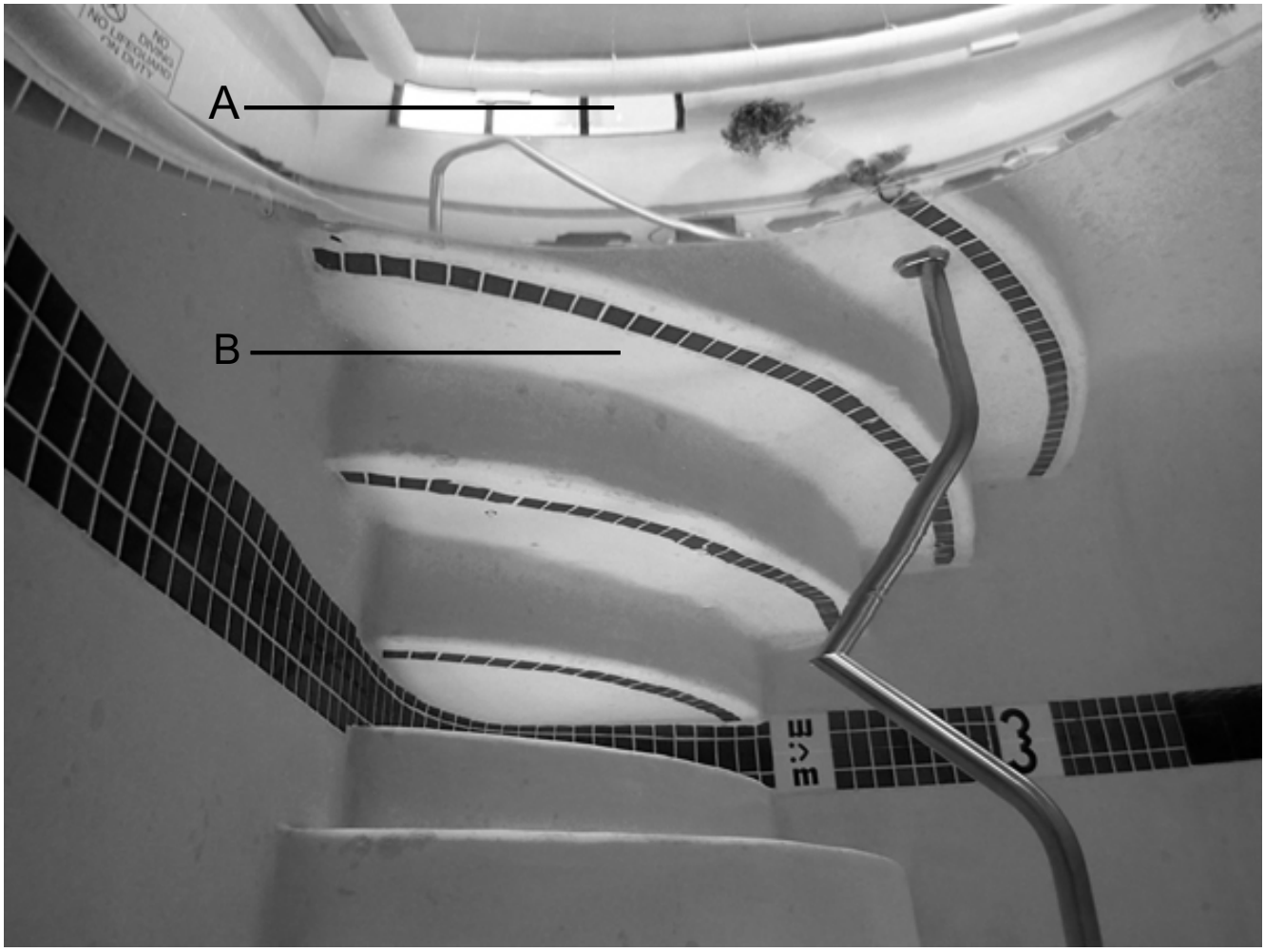

Image used with permission of the High School Physics Photo Contest © 2019 American Association of Physics Teachers

Answer: ……

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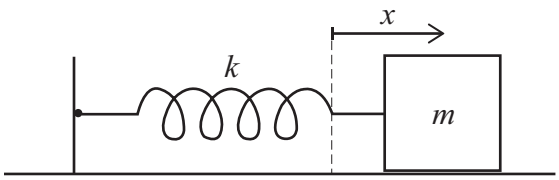
Question P2

A mass m is placed on a frictionless horizontal surface and attached to the end of a light spring of spring constant k, and the spring is attached to a wall as shown in the diagram.



When displaced from equilibrium the mass oscillates with a frequency f. At time t the mass is at a displacement, x, from equilibrium and is moving with velocity, v.

a) Write down an expression for the elastic potential energy, E_p, stored in the spring at time t.

[1 mark]

Answer: ……

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b) Write down an expression for the kinetic energy, E_k, of the mass-spring system.

[1 mark]

Answer: ……

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c) The rate of change of displacement, $\frac{\mathrm{d}x}{\mathrm{d}t} = v$ and the rate of change of velocity, $\frac{\mathrm{d}v}{\mathrm{d}t} = a$.

Using the formula $\frac{\mathrm{d}E_\mathrm{p}}{\mathrm{d}t} = \frac{\mathrm{d}E_\mathrm{p}}{\mathrm{d}x} \times \frac{\mathrm{d}x}{\mathrm{d}t}$ show that $\frac{\mathrm{d}E_\mathrm{p}}{\mathrm{d}t} = kxv$.

Using a similar method, find an expression for $\frac{\mathrm{d}E_\mathrm{k}}{\mathrm{d}t}$ in terms of m, v and a.

Show all of your working.

[3 marks]

Answer: ……

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d) Give the physical reason in words why $\frac{\mathrm{d}(E_\mathrm{k} + E_\mathrm{p})}{\mathrm{d}t} = 0$

[1 mark]

Answer: ……

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e) A formula for the acceleration of the mass is $a = -(2\pi f)^2 x$. Using your answers from part **c)**, the expression given in part **d)** and this formula, find an expression for the frequency of the oscillation, f, in terms of m and k.

Show all of your working.

[3 marks]

Answer: ……

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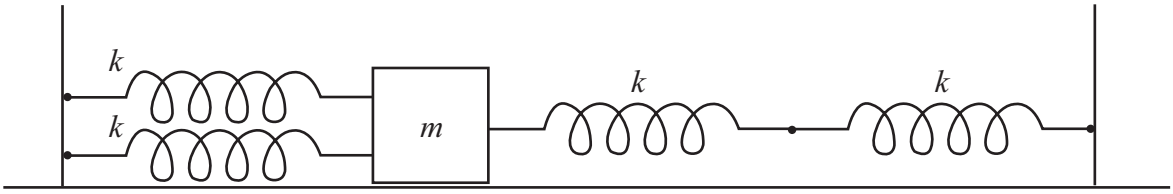
The mass is now placed on a frictionless surface between two walls. It is attached to the left wall by **two** identical, light springs in **parallel**, each of spring constant k and to the right wall by **two** identical springs in **series**, each of spring constant k.



f) What is the new oscillation frequency, f_{new}, of this new system?

[2 marks]

Answer: ……

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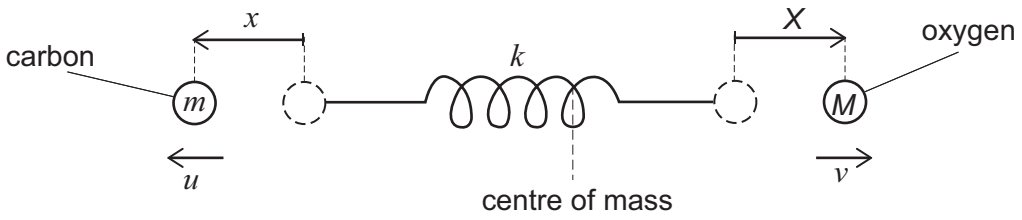
A carbon monoxide molecule can be modelled as two different masses, m and M, each on one end of a light spring of spring constant, k.

When the molecule vibrates it does so such that the centre of mass of the molecule does not move. At time t the spring is extended and the masses are displaced from their equilibrium positions as shown in the diagram. The carbon atom, mass m, has moved a distance x to the left and is moving with a speed u to the left. The oxygen atom, mass M, has moved a distance X to the right and is moving with a speed v to the right.



g) What is the total elastic potential energy stored in the spring in terms of k, x and X?

[1 mark]

Answer: ……

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h) What is the total kinetic energy of the whole system in terms of m, u, M and v?

[1 mark]

Answer: ……

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i) Explain in words why $MX = mx$. Hence deduce an expression for the acceleration, a_M, of mass M, in terms of the acceleration, a_m, of mass m.

[2 marks]

Answer: ……

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j) Given that the total energy of the carbon monoxide molecule is constant, find an expression for the acceleration, a_m, of mass m, in terms of k, m, M and x.

Hence deduce the frequency of the oscillation, f.

[3 marks]

Answer: ……

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k) Calculate the frequency f of the vibration of the carbon monoxide molecule if the mass of the carbon atom is $12\,m_u$, the mass of the oxygen atom is $16\,m_u$ and $k = 2.0 \times 10^3\,\text{N m}^{-1}$.

If this vibration was caused by an electromagnetic wave incident on the molecule, which part of the electromagnetic spectrum would this wave correspond to?

($m_u = 1.66 \times 10^{-27}$ kg. The wavelength of visible light ranges from 400 nm to 700 nm.)

[2 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
relative atomic mass (A_r)

***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

[Turn over

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Chemistry

Question C1

Data: Assume that the molar gas volume = 24.0 $dm^3 mol^{-1}$ at room temperature and pressure (rtp).

This question concerns the chemistry of tellurium, an element in Group 16 of the Periodic Table.

a) What do you expect will be the maximum and minimum oxidation states of tellurium? Briefly explain your answer.

[3 marks]

Answer: ……

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b) How do the electronegativities of the elements vary on descending Group 16?

[1 mark]

Answer: ……

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c) Which hydride, H_2O or H_2Te, has the higher boiling point? Briefly explain your answer.

[2 marks]

Answer: ……

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Tellurium reacts directly with fluorine gas to form a dense gas, **A**, in which each molecule contains a single tellurium atom bonded to several fluorine atoms. In an experiment, 50 cm^3 of gas **A** is formed from 150 cm^3 of fluorine and a certain mass of tellurium, with all measurements made at room temperature and pressure.

d) Calculate the formula of the gas **A**.

[2 marks]

Answer: ……

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e) Predict the value(s) of the F–Te–F bond angles in **A**.

[1 mark]

Answer: ……

f) Calculate the minimum mass of tellurium needed to produce 50 cm^3 of **A**.

[2 marks]

Answer: ……

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g) Calculate the density of gas **A** in g cm^{-3} at room temperature and pressure.

[2 marks]

Answer: ……

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h) Calculate how many times denser gas **A** is than oxygen gas at room temperature and pressure.

[1 mark]

Answer: ……

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In another experiment, 5.0 g of tellurium is oxidised and dissolved in water to form 9.0 g of an acid with general formula H_mTeO_n. On neutralisation with aqueous KOH, 18 g of a salt is formed with general formula K_mTeO_n.

i) Give an expression, in terms of m and n, for the oxidation state of the tellurium in the acid H_mTeO_n.

[1 mark]

Answer: ……

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j) Calculate the relative molecular mass of the acid H_mTeO_n.

[1 mark]

Answer: ……

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k) Calculate the values of m and n, and hence the formulae of the acid H_mTeO_n and the salt formed on neutralisation.

[2 marks]

Answer: ……

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l) Calculate the volume of a 2.0 mol dm^{-3} aqueous solution of KOH that would be needed to neutralise the 9.0 g of acid formed from 5.0 g of tellurium.

[2 marks]

Answer: ……

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Question C2

Trifluoroethanoic acid, TFEA, is a carboxylic acid often used in organic chemistry and has the formula CF_3COOH. The density of TFEA is $1.489\,g\,cm^{-3}$.

a) Draw the structure for trifluoroethanoic acid (TFEA). Indicate on your structure the approximate bond angles around each carbon.

[2 marks]

Answer:

An aqueous solution of TFEA is made up by mixing 0.0700 mol of the pure acid with water and making the solution up to $100.0\,cm^3$.

b) Calculate the volume of pure TFEA needed to make the solution.

[3 marks]

Answer: ……

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c) Give an equation for the ionisation of TFEA in water.

[1 mark]

Answer: ……

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d) Give an expression for the equilibrium constant for the ionisation of TFEA in water.

[2 marks]

Answer: ……

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e) Given that the measured concentration of H^+ ions is $0.4119\,mol\,dm^{-3}$, calculate the value of the equilibrium constant. You may ignore the self-dissociation of water.

[3 marks]

Answer: ……

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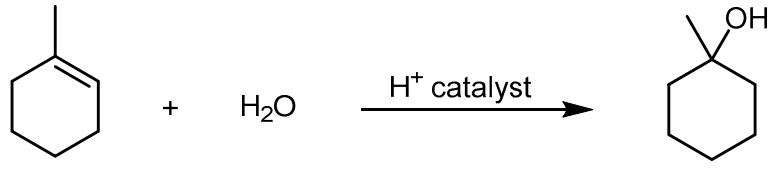
A mixture of TFEA and trifluoroethanoic anhydride, $CF_3COOCOCF_3$, was used as the solvent system in a series of experiments to determine the standard enthalpy changes of hydration of various alkenes.

1-methylcyclohexene, **A**, may be hydrated in an acid-catalysed reaction as shown below:



A **B**

f) How may this reaction be classified? Choose from: *addition*, *elimination*, *substitution*, *oxidation*, *addition polymerisation*.

[1 mark]

Answer: ……

g) Draw the structure of the intermediate initially formed when the H^+ catalyst reacts with alkene **A**.

[1 mark]

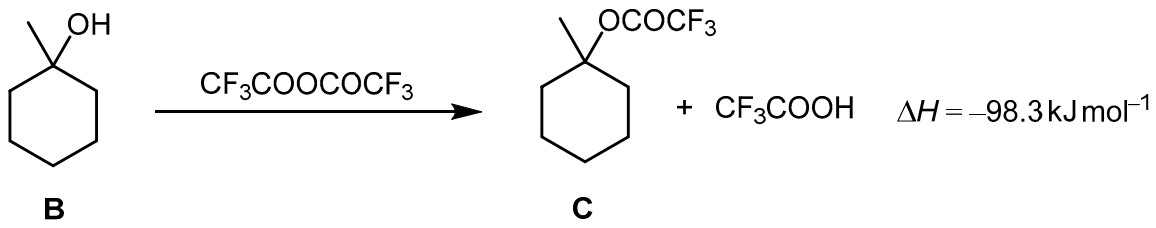
Answer:

h) The same product **B** is formed when an alkene isomer of **A** is treated under identical conditions. Suggest a structure for this isomer.

[1 mark]

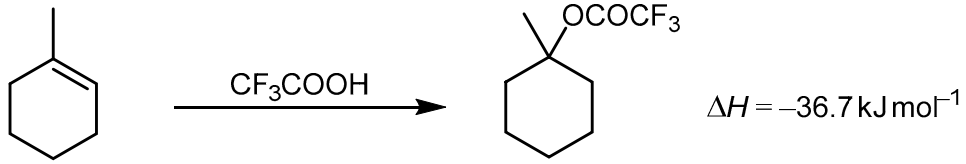
Answer:

In a mixture of TFEA and trifluoroethanoic anhydride, **B** reacts with the trifluoroethanoic anhydride to form **C** and TFEA as shown below. The standard enthalpy change for this reaction is $-98.3\,kJ\,mol^{-1}$.



B **C**

Compound **C** may also be formed in the same mixture of TFEA and trifluoroethanoic anhydride from the reaction between 1-methylcyclohexene and TFEA. The standard enthalpy change for this reaction is $-36.7\,kJ\,mol^{-1}$.



A **C**

The standard enthalpy change for the reaction between one mole of water and one mole of trifluoroethanoic anhydride is $-75.6\,kJ\,mol^{-1}$.

i) Draw the structure of trifluoroethanoic anhydride.

[1 mark]

Answer:

j) Give the equation for the reaction between one mole of water and one mole of trifluoroethanoic anhydride.

[1 mark]

Answer: ……

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k) By constructing an appropriate energy cycle, calculate the standard enthalpy change for the hydration of alkene **A**.

[4 marks]

Answer: ……

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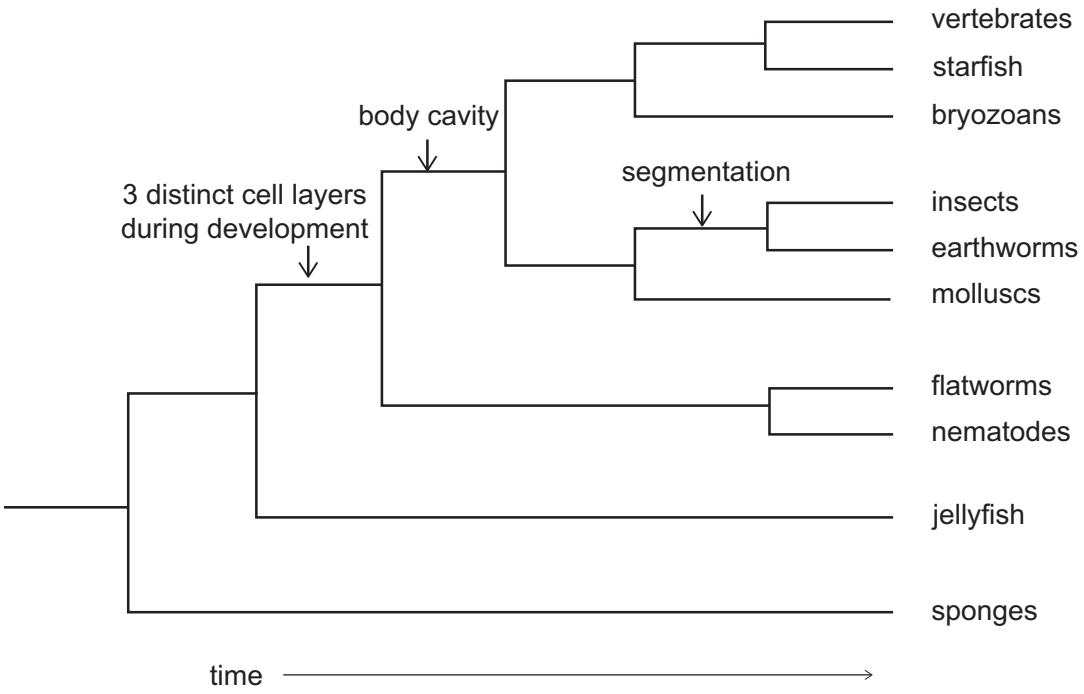
Biology

Question B1

The diagram shows an evolutionary tree for a kingdom of organisms. This tree was constructed over 20 years ago using shared observable features to group these organisms into smaller groups. The time at which three of these shared features first appeared is shown on the evolutionary tree. Each branching point in the tree indicates the time at which groups of organisms diverged from a common ancestor.



a) Identify the kingdom represented in this evolutionary tree.

[1 mark]

Answer: ……

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b) Recently, molecular evidence has changed our understanding of these relationships. Based upon each of the three findings below, what conclusions about evolution can you draw?

(i) Insects and earthworms are not closely related to each other.

[1 mark]

Answer: ……

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(ii) Nematodes and insects, both of which undergo moulting, are very closely related.

[2 marks]

Answer: ……

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(iii) Flatworms, which all lack a true body cavity, are not actually a single group. Some diverged at the base of the tree, some are related to the molluscs, and some are related to starfish and vertebrates.

[2 marks]

Answer: ……

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c) Briefly describe two benefits of using molecular evidence, rather than visible characteristics, to construct trees.

[2 marks]

Answer: ……

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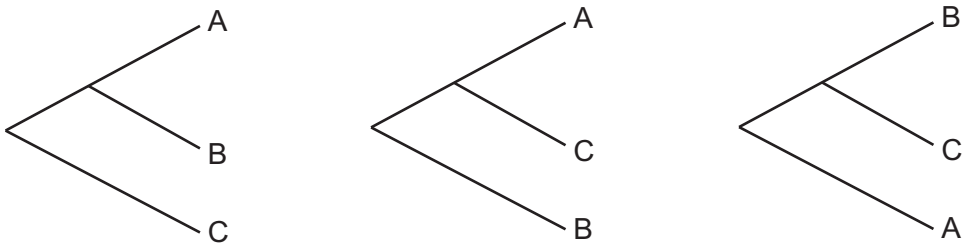
d) The following three tree diagrams show **all** of the possible relationships between 3 different organisms.



How many possible tree diagrams are there with 4 organisms?

[2 marks]

Answer:

e) Using examples, discuss the different ways by which we can measure biodiversity.

[10 marks]

Answer: ……

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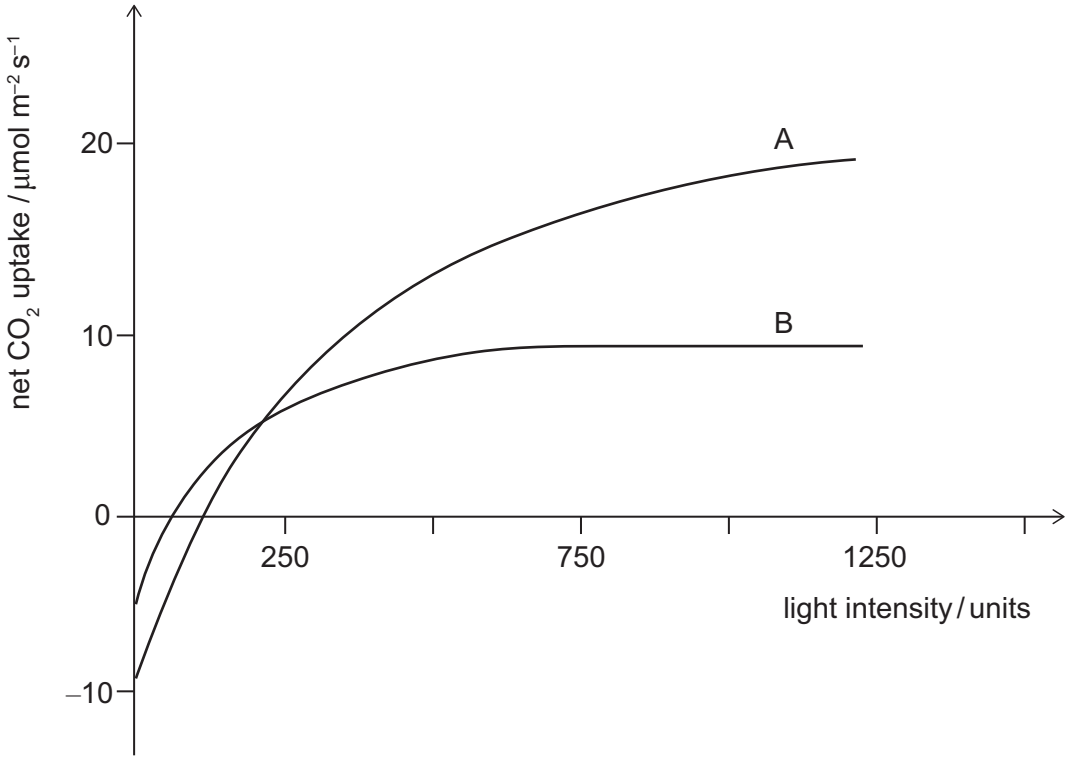
Question B2

The graph shows net CO_2 uptake of two different plants, A and B, when exposed to increasing light levels.



a) Name two physiological processes that affect the net CO_2 uptake in plants.

[1 mark]

Answer: ……

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b) State what can be concluded when the net CO_2 uptake in each plant is zero.

[1 mark]

Answer: ……

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c) For plant B, estimate the value at which increasing light intensity no longer affects CO_2 uptake.

[1 mark]

Answer: ……

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d) Estimate the number of micromoles of CO_2 that would be taken up by a 50 cm^2 leaf of plant B in one minute at light intensity of 750 units.

[2 marks]

Answer: ……

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e) Propose two explanations for the existence of a plateau in the curve for plant B.

[2 marks]

Answer: ……

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f) Describe the differences in the curves for plants A and B and suggest why these differences might occur.

[3 marks]

Answer: ……

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g) Discuss how temperature might affect net CO_2 uptake in plants, with reference to the effects of temperature on enzymatic activity. Use graphs to illustrate your answer.

[10 marks]

Answer:

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