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# Theoretical Test

**December 6th, 2022**

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## EXAMINATION RULES

1. You are NOT allowed to bring any personal items into the examination room, except for the water bottle, personal medicine or approved personal medical equipment.

2. You must sit at your designated desk.

3. Check the stationery items (pen, calculator, and scrap paper) provided by the organizers.

4. Do NOT start answering the questions before the "START" signal.

5. You are NOT allowed to leave the examination room during the examination except in an emergency in which case you will be accompanied by a supervisor/volunteer/invigilator.

6. If you need to visit the bathroom, please raise your hand.

7. Do NOT disturb other competitors. If you need any assistance, raise your hand and wait for a supervisor to come.

8. Do NOT discuss the examination questions. You must stay at your desk until the end of the examination time, even if you have finished the exam.

9. At the end of the examination time you will hear the "STOP" signal. Do NOT write anything more on the answer sheet after this stop signal. Arrange the exam, answer sheets, and the stationary items (pen, calculator, and scrap paper) neatly on your desk. Do not leave the room before all the answer sheets have been collected.

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# EXAM INSTRUCTIONS

1. After the "START" signal, you will have 4 hours to complete the exam.

2. ONLY use the pen and pencil provided by the organizers.

3. Check if your name, code and country name are filled in your  sheets..

4. You have 37 pages of the exam sheet – including the front page. Raise your hand, if you find any sheets missing.

5. Read the problems carefully and write the correct answers in the corresponding spaces after each question in this document.

6. This paper will be evaluated. Before writing your answers you may use the scrap paper provided to avoid errors on your paper.

7. The number of points that can be obtained is indicated for each question.

8. The total number of questions is 3. Check if you have a complete set of the test questions sheets. Raise your hand, if you find any sheets missing.

9. Useful information for answering the questions is provided on page 4.

10. Always show your calculations. If you do not show your calculations, no points are awarded for the question.

11. You should write your final answers down in the appropriate number of digits.

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GENERAL INFORMATION

| constant | |
|---|---|
| Acceleration due to gravity | $g = 9.81 \text{ m/s}^2$ |
| Universal gas constant | $R = 8.314 \dfrac{J}{mol \cdot K}$ |
| | $R = 0.08206 \text{ L} \cdot \text{atm/mol} \cdot \text{K}$ |
| Refractive index of air | $n = 1$ |
| Avogadro's constant | $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$ |
| Speed of light | $c = 2.998 \times 10^8 \text{ m/s}$ |
| Planck's constant | $h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$ |
| Specific heat capacity of water | $c_w = 4.18 \text{ kJ/kg} \cdot °\text{C}$ |

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## Periodic Table of the Elements



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## QUESTION 1

## PART 1

Maize varieties have been developed for shorter stature. The genotype for shorter stature can be determined by the recessive allele of a single gene B. A farmer growing seed maize had 30% of his seed maize crop fertilized by a wild variant (male) that was short, the remainder of the crop was fertilized by the commercial heterozygous variant (male) that had a tall stature.  All the female plants were heterozygous regarding the allele for stature.

1.  [0.25 marks] Complete the Punnett squares for each of these fertilizations.

|     | b   | b   |
| --- | --- | --- |
| B   | Bb  | Bb  |
| b   | bb  | bb  |

30%

|     | B   | b   |
| --- | --- | --- |
| B   | BB  | Bb  |
| b   | Bb  | bb  |

70%

2.  [0.25 marks] Determine what percentage of this farmer's seed would result in short plants.

bb 50% upper Punett square

bb 25% down Punett square

15% + 17.5% = 32.5%

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3. [0.25 marks] Maize has many high yielding varieties that are triploid. Mark with a cross the box(s) corresponding to the process by which the triploid variety may have developed from the standard diploid maize.

| Process | Selection |
|---|---|
| Mitosis | |
| Meiosis stage 1 | X |
| Meiosis stage 2 | X |
| Interphase | |

4. [0.75 marks] *Maize has six closely related species, some of which have subspecies (ssp). The table below shows their common characteristics. Use this table to construct a phylogenetic tree for these species.*

  I.     *Zea mays -* ssp *mays*
  II.     *Zea mays -* ssp *mexicana*
  III.     *Zea mays -* ssp *parvigluans*
  IV.     *Zea dipliperenis*
  V.     *Zea luxurans*
  VI.     *Zea nicaraguensis*
  VII.     *Zea huehuetengensis*
  VIII.     *Zea perensis*

| SPECIES | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| Resistance to corn borer | | X | | X | | X | | X |
| Resistance to corn leaf blight | | | | X | | X | | |
| Tolerates flooding | | | | | X | | | |
| Exhibits dormancy | X | X | | X | | X | X | X |
| Sensitive to high growth temps | | X | | X | | X | | X |
| More than 100 pips per kernel | | | | X | | | | |
| Day length short for flowering | X | | | | | | | |

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| Tasselling density high | X | X |  | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|



(0.75 marks)
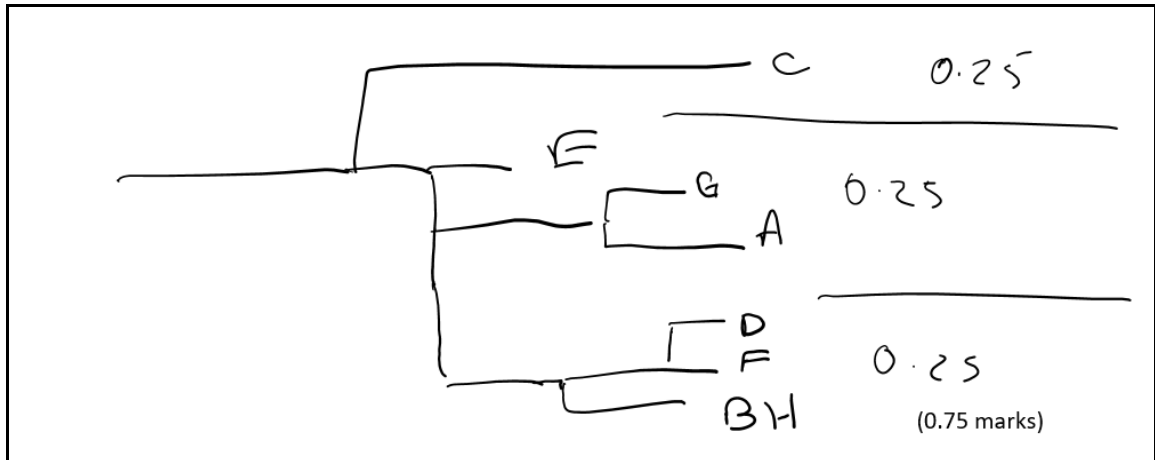
5.  [0.50 marks] The fungus *Aspergillus flavus* can develop on the harvested maize seeds. A sample of maize cells contaminated with this fungus were examined using a light microscope. Indicate which of the following cellular features are only found in maize plants (denote P), or only in *Aspergillus* fungi (denote F) or can be found in both (denote B).

| Cellular Feature | Found in |
|---|---|
| Spores | F |
| Chloroplasts | P |
| Cell walls of cellulose | P |
| Mitochondria | B |
| Hyphae | F |
| Multi layered cell walls including chitin | F |
| Stains blue with iodine | F |

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6. [0.50 marks] The <mark>*Aspergillus flavus*</mark> produces a toxin that can suppress the immune system of children who ingest it or increase the incidence of liver cancer in adults. Which of the following features are consistent with a suppressed immune system (denote I) or a liver cancer (denote C) or neither (denote N)

| Characteristic | Occurs when |
|---|---|
| Rapid, undifferentiated cell growth | C |
| More frequent infections | I |
| Fewer immune memory cells | I |
| Increased lymphocyte levels | N |
| Resisting cell death | C |
| Reduced rate of cell division | N |
| Increased red blood cell levels in the blood | N |

## PART 2

The microbiome in the soil is critical for plant growth.

[1 marks] Fill in the boxes in the diagram below with the corresponding part of the nitrogen cycle by inserting the letter that identifies the <mark>organisms or process</mark>. One letter may be used multiple times or not at all and some boxes may not be filled:

s: lightning,
t: saprophytic fungi,
u: nitrifying bacteria e.g. *Nitrobacter*,  and <mark>*Nitrosomonas.*</mark>
x: denitrifying bacteria
y: nitrogen fixing bacteria,

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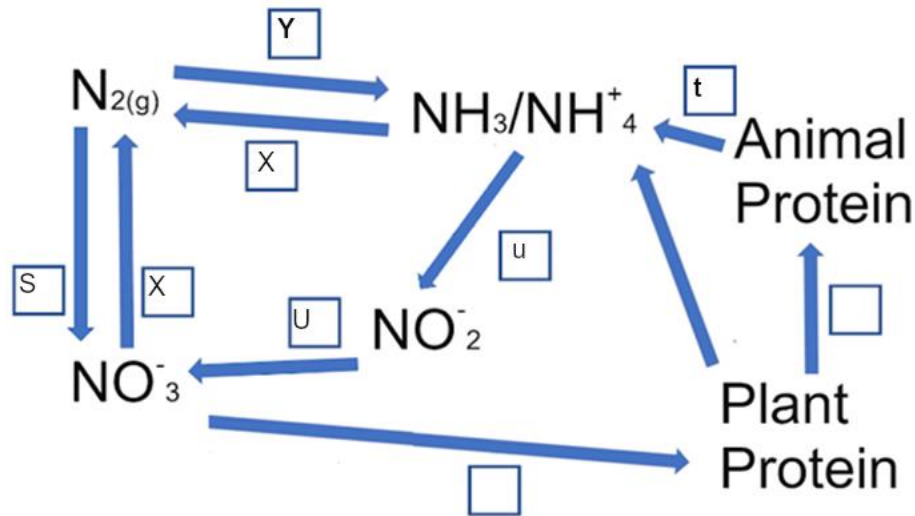


Answer

## PART 3

Lepidopteran insects are a major pest with species such as the Southwestern Corn borer, _Diatraea grandiosella,_ damaging the growth center of the maize plant. Some birds such as the yellow shafted flicker, _Colaptes auratus_, eat stalk borer larvae and reduce this pest.

1. [0.25 marks] Identify an adult lepidopteran most similar to the Corn borer by circling the image.
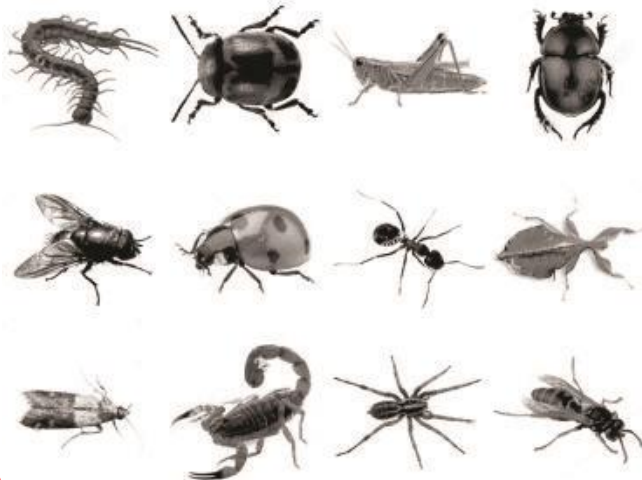


This one

2. [0.25 marks] Mark with X which of the following is most likely to predate corn borer larvae:

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**Name**………………………………………………………………………..          **Code** ……………………………………………….

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| Bats | Spiders | Moths | Snails |
|------|---------|-------|--------|
|      | X       |       |        |

3. [0.25 marks] In a controlled experiment corn borers were grown in an atmosphere with a higher oxygen partial pressure. <mark>Taking in account the trachea respiratory system of insects</mark>, Predict the appearance of the adult corn borer relative to an adult grown with normal oxygen partial pressures.

| Characteristics | Selection |
|-----------------|-----------|
| Larger thorax   | X         |
| Smaller antennae |          |
| Longer legs     | X         |
| Smaller wings   |           |

4. [0.50 marks] The southwestern corn borer males are attracted to the sex pheromone 9-hexadecenal, how could farmers use this to manage this insect pest? Mark with X the appropriate answer(s)

| Option | Possible answers |
|--------|------------------|
| X | Place 9-hexadecenal lures outside the maize field to attract males away from the maize field |
| X | Place 9-hexadecenal lures in the field without females to distract the males from mating. |
| X | Place 9-hexadecenal lures in the field together with a powerful contact insecticide to kill all the males |
|   | Place 9-hexadecenal lures in the field to distract the females and repel them from the field |

5. [0.5 marks] Identify the stages of insect development below by inserting the following letters:

       a: larva
       b: pupa
       c: female adult

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Name………………………………………………………………..        Code …………………………………………….

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d: egg
e: male adult
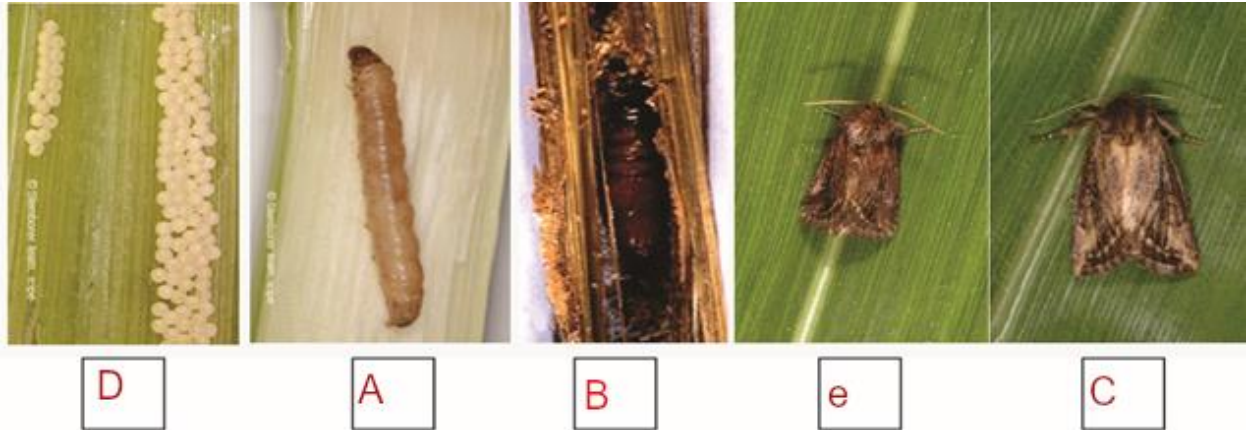


## PART 4

In this experiment the effect of pH on the activation of glutamatergic synapse (figure 4.1)  was tested in insect brains (mushroom bodies)

Then from this type of synapse was recorded the electrical activity as red trace (pH9, Figure 4.2), that represents the post-synaptic excitatory potentials (PEPS) from a neuron localized in the mushroom bodies of corn borer, under stimulation with a flash light of 30 ms in front



_____
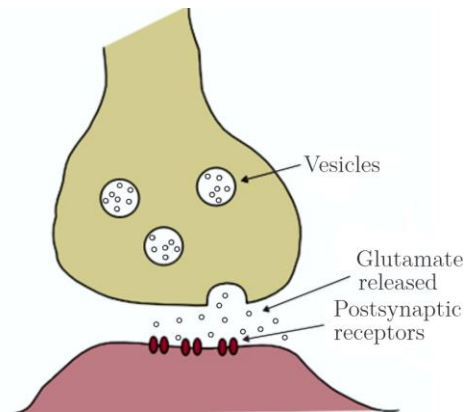
**Name**……………………………..-………………………………..      **Code** …………………………………….
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of          the          insect          eyes          (trace          black,          bottom          Figure          4.2).
Figure 4.1
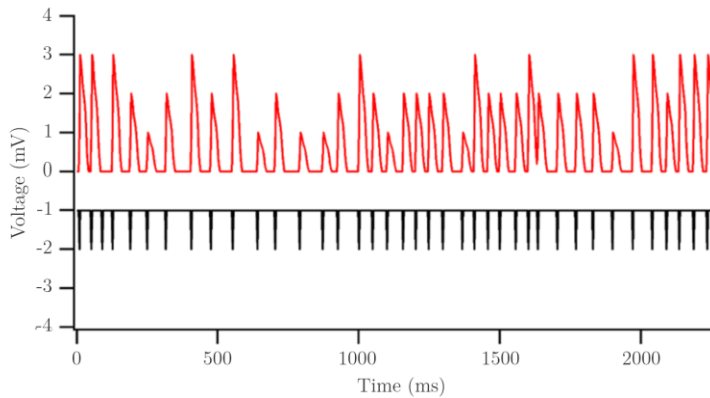


Figure 4.2
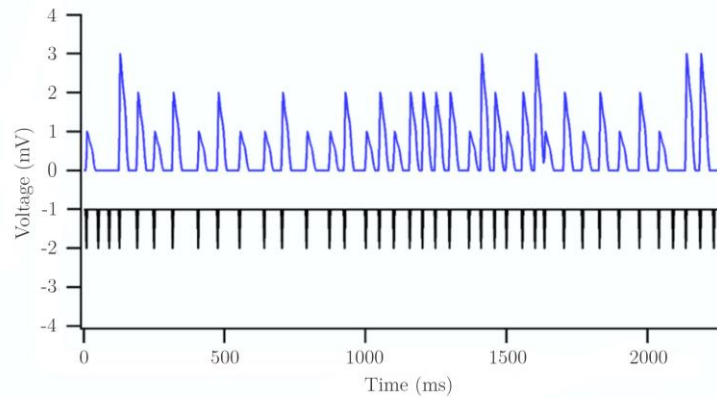
On    the    same … neuron       was
repeated      the … experiment
using the same … turning  on-off
light    stimulation, … but   in   pH5
(blue          trace, … Figure 4.3).

Figure 4.3

Previous research has indicated that:

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1. [0.50 marks] Make a histogram of PEPS events.
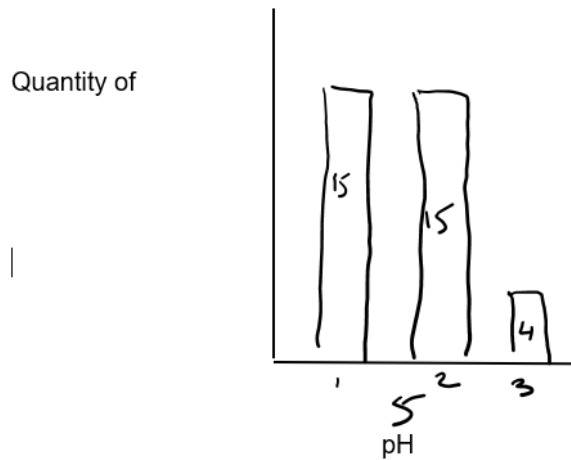


last is 5 events



Correct pH 5
= 0.25

Correct pH 9
= 0.25

(0.5 marks)

2. [1.00 marks] Determine a frequency of each type of PEPS:

_____
_____

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Frequency of 1 mV PEPS at pH 9 : _7/39 = 18%_  and of 1 mV PEPS at pH 5: 15/34 = 44%

Frequency of 2 mV PEPS at pH 9: _18/39 = 46%_ and of 2 mV PEPS at pH 5: _15/34=44%

Frequency of 3 mV PEPS at pH 9: _14/39 = 36%_ and of 3 mV PEPS at pH 5: _5/34 = 14%

0.5 marks for all correct at pH9 and 0.5 marks correct at pH 5 deduct 0.16 marks for each error (1 mark)

3. [0.50 marks] Find the release probability of a glutamate PEPS events.

   Release probability of glutamate PEPS events at pH5 : __87.5%_____at pH9___97.5%__

Each trace has 40 signals so pH 9 has 39 responses so the release probability = 39/40 = 97.5%

   In which condition is this higher? pH: _____9_____

4. [0.25 marks] What is the probability to release more than two vesicles during one flash of stimulation?

   Probability of more than two vesicles being released at pH 5: _5/40=_____12.5%_____

   Probability of more than two vesicles being released at pH 9: _____14/40=__35%_____

5. [0.25 marks] Is the charging vesicle mechanism the same in each vesicle? Mark with an X  your selection(s).

| | |
|---|---|
| | Yes, each glutamate vesicle releases the same quantity of glutamate producing an identical current, that's why the discrete steps in voltage. |
| | No, because a absent response in some stimulations, shows a difference sensitivity of some vesicles to the calcium, which is the event triggering the release. |
| X | Yes, each glutamate molecule opens a channel producing identical current, so then two molecules released from different vesicles explain the discrete changes in voltage. |

## PART 5

Cell surface receptors located on the plasma membrane have a major role initiating cellular signaling. A particular cell surface receptor (RLK), found in maize, plays a role in the plant's immune system. Fragments of the cell wall of fungal hyphae act as a signal molecule (FF) that binds to the receptor. These receptors also bind the plant hormone Abscisic acid (AA).

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The binding affinity of a signaling molecule to the receptor can be quantified by

$$Ka=[Receptor\text{-}signal\ molecule\ complex][Receptor][Signal\ Molecule]$$

Use the results of the binding assays shown in Figure 5.1, below, to answer the question that follows
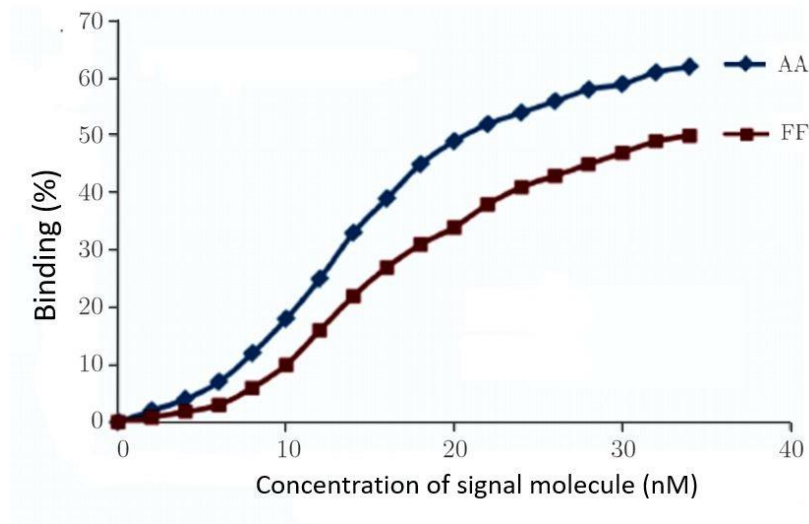


Figure 5.1

1. [0.25 marks] Which signal molecule demonstrates a greater binding affinity for this RLK receptor? Mark with X the appropriate answer.

| Fungal FragmentFF | | Abscisic acid AA | X |
|---|---|---|---|

Binding of the signal molecule to the receptor will also induce a response inside the cell. In Figure 5.2 you can see that molecules move across the membrane in response to binding of the signal molecule.

_____

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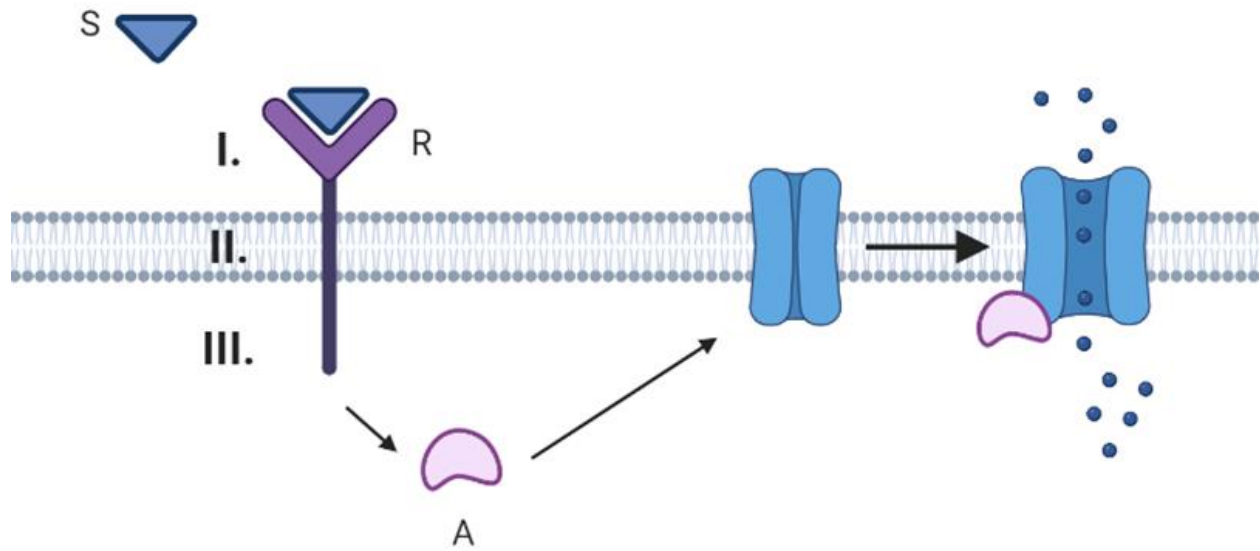


Figure 5.2, S = signal molecule, R = receptor, A = activator

2.      [0.75 marks] The receptor (R) has three parts (labelled I, II, and III in Figure 5.2). Mark with an X in the appropriate box which parts of the receptor are hydrophobic and which are hydrophilic.

| Receptor part | Hydrophobic | Hydrophilic |
|---|---|---|
| I. | | X |
| II. | X | |
| III. | | X |

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3.        [1 mark] Mark with X which of the terms apply to figure 5.2

| Active transport | |
|---|---|
| Facilitated diffusion | ✗ |
| Receptor mediated endocytosis | |
| Phagocytosis | |
| Simple diffusion | |
| Co-transport | |

1. [0.5 marks] The HTN1 gene codes for a small antimicrobial protein, Histatin1, which contains 297 amino acids. The entire HTN1 gene contains 9546 base pairs. Which part (in percentage) of the total gene results in the amino acid sequence of Histatin 1?

Answer 297 amino acids + start + stop codons = 299x3 = 897 base pairs
% exons = 897/9546 = 9.4%

## QUESTION 2

**PART 1**

In Colombia's Orinoco province, maize farmers have a choice of fertilisers to provide the standard requirement of 150 kg/Hectare of NPK 14.0-23.0-14.0 (these numbers refer to the mass percentages of each element). Agrigrow sells 80.0% pure ammonium nitrate(v) for $1.40/kg and Happy plants sells 95.0% pure potassium nitrate(V) for $0.720/kg.

1. [0.50 marks] Determine the cost per kg ($/kg) of nitrogen in each fertilizer

| | | Agrigrow | | | Happy plants | | | 0.95 |
|---|---|---|---|---|---|---|---|---|
| **1a** | w | $NH_4NO_3$ | 0.8 | | | | $KNO_3$ | |
| Mr | | | 80.06 | | | | | 101.11 |

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| | | | |
|---|---|---|---|
| N | 28.02 | | 14.01 |
| % N per pure kg | 0.349987509 | | 0.138562 |
| % N per actual Kg | 0.279990007 | | 0.131633 9 |
| **Price per Kg** | **140** | | **72** |
| Cost per kg of N | **5.00** | | **5.47** |

<mark>(0.25 marks for each Fertilliser)</mark>

<mark>No reduction for incorrect significant figures in any answers</mark>

Agrigrow     __5.00_____.

Happy Plants     ___5.47_____.

2. [0.50 marks] What mass of Agrigrow's fertiliser should be applied per hectare of maize, to achieve the minimum Nitrogen requirements? Express your answer in kilograms.

| **1b** | N | P | K | Application rate | 150 | kg/Ha |
|---|---|---|---|---|---|---|
| | 14 | 23 | 14 | | | |

Mass of N required per Ha      21   kg

Mass of Agrigrow required = mass of pure N / actual % of N per Kg of Agrigrow

                         **75.0**    **Kg**      <mark>0.5 marks</mark>

Mass of Agrigow per hectare _____75.0 Kg_____

3. [0.50 marks] Provide a balanced Redox equation for the conversion of ammonia using dissolved oxygen in alkaline medium into a solution of nitrate(iii) ions. (ignore the state symbols)

**1c**            Aqueous ammonia + oxygen = nitrate ions and water

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|  | NH4+ | O2 | NO3- |
|---|---|---|---|
| Oxidation states |  | -3 | 0    =5 &-2 |

**Nitrate(v) formation**

$N^{3-}$ ---- $N^{5+}$ and

Oxidation reaction          8e-

Reduction reation $O^0$ +2e- ----- $O^{2-}$

To balance electron exchange must have 4 oxygen atoms per nitrogen atom

NH4OH + 2O2 === NO3-  + 2H2O + H+

NH3 + 2O2 === NO3-  + H2O + H+

**Nitrate(iii) formation**

$N^{3-}$ ---- $N3^+$ and

Oxidation reaction          6e-

Reduction reation $O^0$ +2e- ----- $O^{2-}$

To balance electron exchange must have 3 oxygen atoms per nitrogen atom

NH4OH + 1.5O2- + OH-=== NO2-  + 2H2O

$NH_3 + 1.5O_2 + OH- === NO_2^- + 2H_2O$          Will accept this answer with smallest whole integers


Redox equation_____.


4.  [0.50 marks] If a farmer adds 0.85 g of ammonium nitrate(v) to each kg of soil that contains 150 ml of water per kg of topsoil what will be the concentration of the ammonium ions in this water and the pH of the water in this topsoil. Assume the Ka of ammonium ions is 5.60 x $10^{-10}$ and that ammonium ions are the only source of H+ ions, neglect any other source of H+ ions.


| Ka | 5.60E-10 |  | Mass of water |  | 150 | mL |
|---|---|---|---|---|---|---|
| Mass of NH4NO3 |  | 0.85 | g |  |  |  |

| Moles of NH4NO3 | = mass/ Mr. | 0.010617037 | moles |
|---|---|---|---|
| Conc of NH4+ | = moles/ vol | 0.071 | M.   (0.25 marks) |

Ka = [NH3]x[H+] / [NH4+]          [NH3]
Assume [NH4+]          =[H+]
unchanged

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| | | |
|---|---|---|
| So [H+] = SQRT(Ka x [NH4+]) | 6.29579E-06 | |
| pH = -log[H+] | **5.20** | (0.25 marks) |

Concentration of ammonium ions _____0.071_____ mol/L [0.25 marks]

pH of topsoil_____5.20_____ answer to 2 decimal places [0.25 marks]

5. [0.50 marks] Most maize farmers apply hydrogen phosphates(v) to supply the phosphorus needs of the maize plant. A commercial phosphate fertilizer contains 40% by mass of each, of sodium monohydrogen phosphate(v) and sodium dihydrogen phosphate(v). What mass(kg) per hectare should the farmer use this phosphate fertiliser?

| | $Na_2HPO_4$ | $NaH_2PO_4$ | | | |
|---|---|---|---|---|---|
| % | 40% | 40% | | | |
| Mr | 142 | 120 | | | |
| %P | 22% | 26% | Total | 19% | 0.25 marks |
| Application rate | | 150 | Kg/Ha | | |
| % Phosphorus required | | 23% | | | |
| Mass P per Ha | | 34.50 | Kg/Ha | | |
| Phosphate fertiliser requirement | | **181.0** | **Kg/Ha** | | 0.5 marks |

Application mass (kg) per hectare _____181_____.

6. [0.75 marks] This mixture of phosphate creates a buffer solution in the groundwater. If the Ka of dihydrogen phosphate ion is 6.30 x10⁻⁸ calculate the pH of this buffer formed in the soil based only on the equilibrium between the mono and dihydrogen phosphate ions.

Ka =                6.30E-08

pH = pKa + log [salt]/[acid]
pKa        7.200659451
Moles of H2PO4 = mass / Mr                0.00833    **0.25 marks**

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Moles of HPO4 = mass / Mr                        0.00704    **0.25 marks**

pH =                    **7.13**                                **0.75 marks**

        pH of buffer_____7.13_____ (answer to two decimal places)


## PART 2

The soils in the Orinoco province contain essential plant minerals such as calcium and magnesium ions bound ionically to organic decomposing plant matter:

1. [1.00 marks] Identify the types of intermolecular forces between ions and molecules in the soil by inserting the correct letters in the boxes on the diagram below.
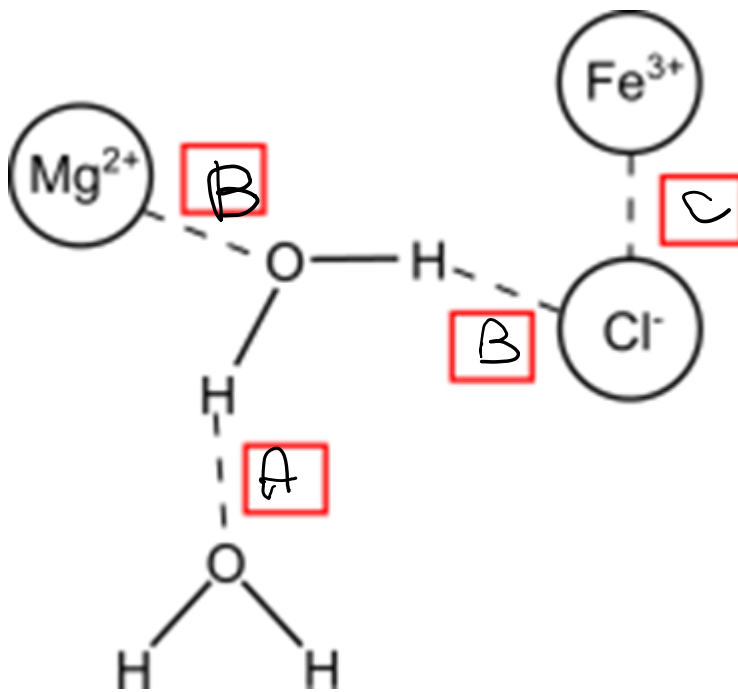


0.25 marks for each correct box of A, B and C


        A = Hydrogen bonds,  B= ion-dipole interactions, C = ion-ion interactions

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2. [0.50 marks] The Cation Exchange capacity (CEC) of the soil is a measure of the capacity of the soil to hold cations available as plant nutrients. Which of the following ion-dipole associations do you predict to be the strongest? Indicate with an X in the box below.

| Ion | $Fe^{3+}$ | $Mg^{2+}$ | $Cl^-$ | $Ca^{2+}$ | $Fe^{2+}$ | $NO_3^-$ |
|---|---|---|---|---|---|---|
| Selection of the strongest | X | | | | | |

3. [1.00 marks] The pH of the soil determines the solubility of phosphate ions. The solubility products of calcium and iron(iii) phosphate(v) are $2.07 \times 10^{-33}$ and $9.84 \times 10^{-16}$ respectively Soil from area A is based upon calcium phosphate(v) and the soil from area B is based on iron(iii) phosphate(v). Determine which soil, at pH of 7.0, will have a greater concentration of phosphate(v) ions in solution in each of these soils at equilibrium and by how many times bigger? (Assume there is no hydrolysis of these iron(iii) or phosphate(v) ions)

| | pH | Ksp | Cation | Phosphate | Phosphate ion conc at equilibr | | |
|---|---|---|---|---|---|---|---|
| Calcium phosphate | 7 | 2.07E-33 | 3 | 2 | 2.28E-07 | Soil A | no marks calculatio |
| iron(iii) phosphate | 7 | 9.84E-16 | 1 | 1 | 3.14E-08 | 7.26E+00 | Multiple |
| | | | | (0.5 marks each) | | total 1 mark | |

Soil with higher concentration_____A_____

How many times bigger_____7.26_____

4. [0.75 marks] Some farmers control maize stalk borer larvae with a chemical insecticide, Malathion, so they need to determine how to dilute the stock solution to achieve the correct field concentration. It is recommended that Malathion should be applied at a rate of 0.050g per m2. The stock solution of Malathion contains 57g per 100 mL of stock solution. The farmer's plot is 7 500 m². In addition, the farmer adds a wetting agent which should be 5.0

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% of the volume of the Malathion stock solution. Identify the volumes of all the chemicals and water the farmer should add to form a full spray tank (40 L).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Malathion solutions (57% m/v) | 57% | % m/v | Tank | 40 | l | | Area | 7500 m2 |
| Application rate | 0.05 | g/m2 | Wetting agent % | | 5% | | | |

| | | | |
|---|---|---|---|
| Total mass of malathion required = area x application rate | **375** | g | |
| Volume of malathion solution required = mass / conc | **657.89** | mL | 0.25 marks |
| Volume of wetting agent = % of malathion volume | **32.89** | ml | 0.25 marks |
| total | **690.79** | mL | |
| Volume of water | **39.31** | L | 0.25 marks |

Volume of Malathion_____658_____[0.25 marks]

Volume of wetting agent_____32.9_____[0.25 marks]

Volume of water_____39.3_____ [0.25 marks]

5. [0.75 marks] The farmer's spray tank is constructed from iron and is repaired with a pair of bolts, one made from aluminum and the second from copper. After several applications of doses of this insecticide the farmer notices corrosion in some of these metals. Identify where the farmer will observe the corrosion.
The standard reduction potential is a measure of the electron-pulling power. The higher the reduction potential, the stronger the pulling. The standard reduction potentials for these metals are:

| Reaction | $E_0(V)$ |
|---|---|
| $Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$ | +0.34 |
| $Fe^{3+}_{(aq)} + 3e^- \rightarrow Fe_{(s)}$ | -0.04 |
| $Fe^{2+}_{(aq)} + 2e^- \rightarrow Fe_{(s)}$ | -0.44 |
| $Al^{3+}_{(aq)} + 3e^- \rightarrow Al_{(s)}$ | -1.66 |

Mark with X all the locations that apply:

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| Selection | Location of corrosion |
|-----------|----------------------|
|  | On the parts of the aluminium bolt that are wetted |
|  | On the wetted parts of the copper bolt |
| X | On the aluminium bolt that is both wetted and rubbed regularly |
|  | On the wetted iron around the aluminium bolt |
|  | On the dry iron near both bolts |
| (x) | On the wetted iron around the copper bolt |

| 2e | Selection | Location of corrosion | |
|----|-----------|----------------------|--|
| | | On the parts of the aluminium bolt that are wetted | Galvanic corrosion wi |
| | | On the wetted parts of the copper bolt | |
| 0.5 marks | x | On the aluminium bolt that is both wetted and rubbed regularly | This is the truly corre |
| | | On the wetted iron around the aluminium bolt | Each incorrect answe |
| | | On the dry iron near both bolts | No negative marks in |
| 0.25 marks | x | On the wetted iron around the copper bolt. | If only select the last |

## PART 3
Fermentation and distillation.

Maize can be consumed directly by humans and animals, but it is also used to produce ethanol as a fuel substitute or processed into corn syrups. Conversion of maize kernels into ethanol involves the following production steps: milling and soaking, boiling, cooling and enzyme

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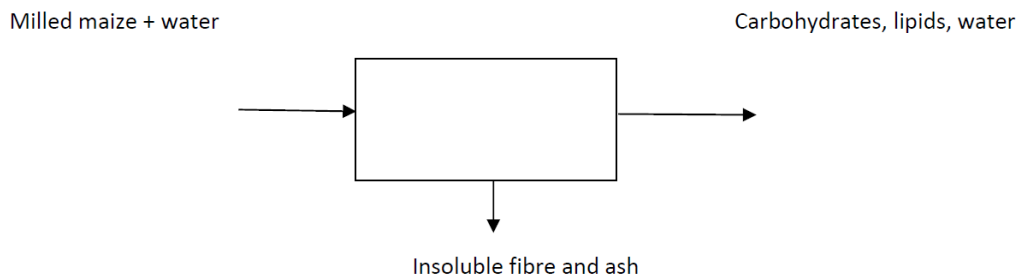**Name…………………………………………………………..**          **Code ………………………………………….**

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hydrolysis, fermentation with yeast, centrifugation and finally distillation before molecular filtration. Milled maize kernels have the following composition.

| Component | % by Mass |
|---|---|
| Moisture ($H_2O$) | 9.6 |
| Ash (metal and silicon oxides) | 1.7 |
| Proteins | 10.7 |
| Insoluble Fibres | 2.2 |
| Carbohydrate | 70.4 |
| Lipids | 5.4 |

(Source: FAO)

1. [0.5 marks] One maize-to-ethanol plant processes 5000 tonnes of milled maize per day by adding 2.50 L of water per kg of milled maize. Identify the mass flow rates (kg/s) in and out of the enzyme digestion process and show these on the diagram below

Milled maize + water                                      Carbohydrates, lipids, water



Insoluble fibre and ash

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| | tonnes | | L/kg | |
|---|---|---|---|---|
| 5000 | per day | 2.758 | maize | |
| | seconds | | | |
| 86400 | per day | 1 | kg/L density of water | |

| **Inputs** | | | | **Outputs** | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Milled | | | | | | |
| **57.87037** | Kg/s | Maize | | **2.257** | Kg/s | Ash and Fibre | **0.25 marks** | |
| | | | | | | Carbohydrate, water | | |
| **159.6065** | Kg/s | Water | | **215.2** | Kg/s | and lipids | **0.25 marks** | With proteins |
| | | | | | | Carbohydrate, water | | |
| 217.4769 | | | | **209.0** | Kg/s | and lipids | **0.25 marks** | Without proteins |

Input maize and water rate …………217 Kg/s……..…………………………
Output fibre and ash rate …………2.257 kg/s……………….…………………
Output carbohydrates, lipids, water rate ………215.2 or 209 Kg/s…………

2. **[0.50 marks]** The mixture of carbohydrates, lipids and water is added to a batch fermenter (4000L) with yeast (Saccharomyces cerevisiae) at 35.0 °C. The yeast grows rapidly and anaerobically respires at a rate of 2000 moles of glucose ($C_6H_{12}O_6$) per second in this reactor. The anaerobic respiration of hydrolysed carbohydrates by yeast can be shown by

$C_6H_{12}O_6$ -------- $2C_2H_5OH + 2CO_2$      **ΔH = -34.5 kJ/mol of ethanol**
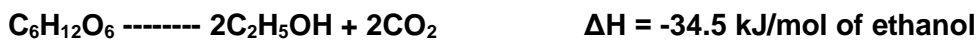
Determine the flow rate (kg/s) of cooling water required to maintain the fermenter at 35.0 °C. You may assume there are no other heat losses, and the specific heat capacity of the cooling water is 4.18 J/g.K with an input temperature of 5.0 °C and an output temp 30.0 °C.

| Microbial rate | | 2000 | mol/sec | Water in | 5 | C |
|---|---|---|---|---|---|---|
| | | | | Water | | |
| Enthalpy change | | -34.5 | kJ per mole ethanol | out | 30 | C |
| Heat capacity of water | | 4.18 | j/g/C | | | |

Thermal energy from fermentation = thermal energy removed by cooling water

| | -138000 | kJ/sec | = | M*C*ΔT |
|---|---|---|---|---|
| | | | = | 104.5   m |

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|  | | **0.5** |
|---|---|---|
| Flow rate = | **-1321**  **kg/sec** | **marks** |

Flow rate of cooling water    ………………1321………………………… kg/s

3. [0.50 marks] During this fermentation one batch becomes contaminated with bacteria which can be killed by lowering the pH from 6.00 to 1.95. The additional acid does not react with carbohydrates or lipids or yeast. Calculate the volume of 2.50 M sulphuric acid which is required to achieve the pH of 1.95 of this batch? Assume the sulphuric acid dissociates completely and this additional acid does not change the total volume significantly.

| | | | |
|---|---|---|---|
| Tank capacity | | 4000 | L |
| Std pH | 6.00  Adj pH | 1.95 | |
| Sulphuric acid | | 2.50 | Mol/L |

| | | |
|---|---|---|
| Moles of H+ ions in fermenter = conc x vol = 10exp-6.80 x 4000 | 0.004 | moles |
| Moles of H+ ions required for pH 2 = | 44.88074 | |
| Each suphuric acid molecule produces | 2  H+ ions | |

Moles of Sulphuric acid required = Final - Original moles /2      22.43837   Mol

| | | | |
|---|---|---|---|
| | | | 0.5 |
| Volume of sulphuric acid required = moles / conc | **8.98** | L | marks |
| Volume if ignores original acid | 8.976148 | L | |

Volume of 2.50M sulphuric acid required_____8.98_____ L

4. [0.75 marks] In an efficient fermentation 86.0% of the soluble carbohydrates($C_6H_{12}O_6$) obtained from maize, are converted by the yeast into ethanol($C_2H_5OH$) and carbon dioxide. Calculate the volume of carbon dioxide that will be emitted by the yeast from a standard 4000 L in which there is 1400kg of milled maize batch at a temperature of 32.0 °C and pressure of 101kPa. (R = 8.314 J/mol.K)?

| | | | |
|---|---|---|---|
| % carbohydrate converted | | 86% | |
| Maize meal per 4000L batch | 1329.78723 | 1400 | kg |

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| Mass of carbohydrate = mass of maize meal x % carb in maize | | | | 985.6 | Kg |

Molecular mass of carb = 6 x (12 +2+16)  180  g/mol

Moles of carbohydrate = mass / Mr  5475.555556  moles

Mole ratio of Carb to $CO_2$ = 1:2

Moles of $CO_2$ produced  9418  moles

Assume ideal gas so V = nRT/P

Pressure  101000  Temp  305  R  8.314

Volume  = nRT/P  **236**  m$^3$  <mark>accept answers with 273 or 273.15</mark>

Volume of carbon dioxide emitted …………236……………………………. m$^3$

5. [0.50 marks] The ethanol produced from distillation is filtered through a molecular sieve to remove the water and added to petrol as a fuel substitute. The enthalpies of combustion are: octane -5470 kJ/mol, ethanol -1371 kJ/mol and the densities of the liquids are: octane 703 kg/m$^3$ ethanol 789 kg/m$^3$). Determine the energy released (assuming no losses) from the combustion of 1.00 L of an 80.0/20.0 v/v octane/ethanol blended fuel. The formulae of octane and ethanol are $C_8H_{18}$ and $C_2H_5OH$ respectively.

| | % | Hc | Density | Mass in 1 L | Molar mass | Energy released | |
|---|---|---|---|---|---|---|---|
| Octane | 80% | 5470 | 703 | 562.4 | 114.26 | 26923.93 | |
| Ethanol | 20% | 1371 | 789 | 157.8 | 46.08 | 4694.961 | |
| | | kJ/mol | kg/m3 | | Sum | **31619** | kJ |
| | | | | | | **31600** | kJ | 0.5 m |

Energy released from the combustion of 1.00L of blended fuel ……31600………kJ

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**Name**........................................................................    **Code** ...........................................................

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## QUESTION 3

### PART 1

When an electrically charged particle enters the space between two electrically charged plates, it is deflected from the direction in which it was originally moving. For a given configuration of the plates, the deflection depends on the mass and the charge of the ion. This is the principle of a simple type of mass spectrometer. To set ideas, consider ionized isotopes of Cl and Mg.
($1 \text{ u} = 1.66 \times 10^{-27}$ kg)

| Isotopes | Mass (u) | Charge |
|----------|----------|--------|
| $^{35}$Cl | 34.97 | $-e$ |
| $^{37}$Cl | 36.97 | $-e$ |
| $^{24}$Mg | 23.98 | $+2e$ |
| $^{26}$Mg | 25.98 | $+2e$ |

Consider an ion of a given substance isotope moving initially with velocity $v_0$ along a line which we take to coincide with the *x*-axis. See the following figure and the data below. For simplicity it is assumed in all subsequent questions that the action of the plates charges is limited to the space between the plates. Under these conditions, the magnitude of the electric field in the space between the plates is $E = U/d$. The deflected ion strikes a screen, leaving a mark.
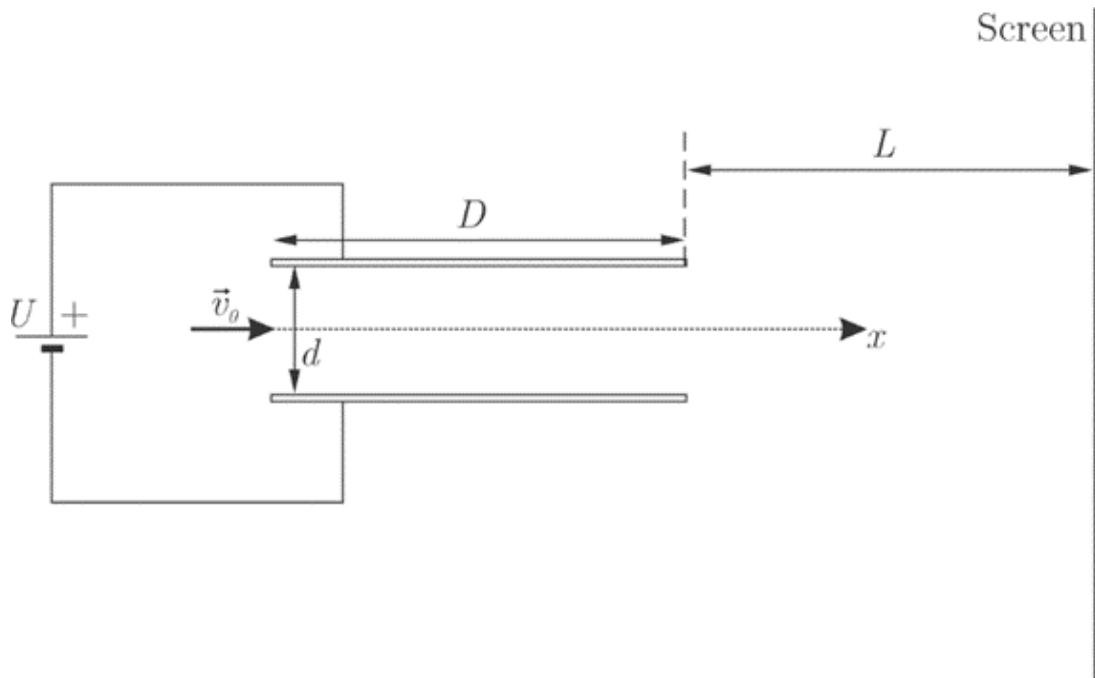
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Data:

| | |
|---|---|
| Elementary charge $e$: | $1.60\times10^{-19}$ C |
| Potential difference between the plates $U$: | 75 V |
| Length of the plates $D$: | 5.0 cm |
| Separation of plates $d$: | 1.0 cm |
| Plates-screen separation $L$: | 10 cm |
| Ion initial velocity $v_0$: | $1.0\times10^5$ m/s |

1. [0.20 marks] Consider a $^{37}$Cl ion with charge $-e$. Calculate the ratio between the gravitational earth force on the ion and the electric force exerted by plates charges on it.

   $eE=$ $1.2\times10^{-15}$ N
   $mg=6.1\times10^{-25}$ N
   $\frac{mg}{eE}=5.1\times10^{-10}$   (0.1 for the expression and 0.1 for the value

   Ratio _____

2. [0.20 marks] Considering the value you find in the question above, is the gravitational force negligible in this problem? Mark the right answer in the table with an X.

   | YES | NO |
   |---|---|
   | X | |

3. [0.50 marks] Calculate how much a $^{35}$Cl ion with charge $-e$ would deviate from the x-axis at the moment it leaves the space between the plates .

   . In the x-direction the motion is uniform:

   $v_x = v_0$

   In the y-direction the motion is uniformly accelerated:

_____

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$$ma = eE = \frac{eU}{d}.$$

$$v_y = at.$$

The time of flight along the condenser is
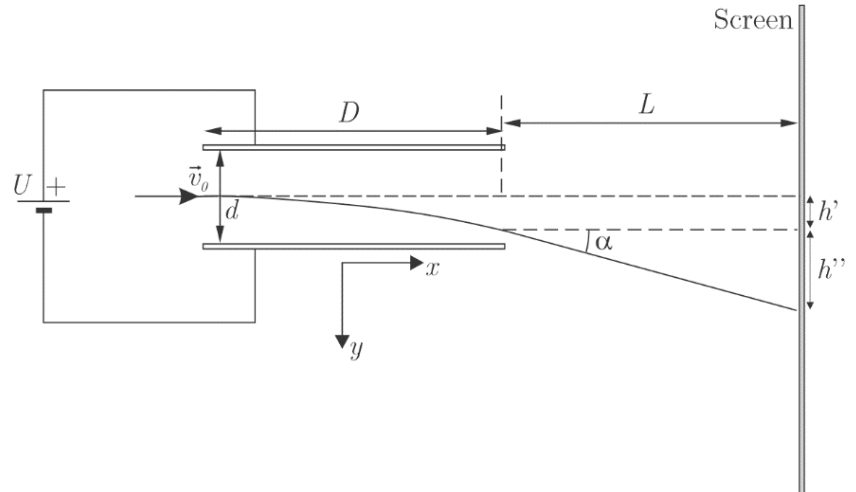
$$t = \frac{D}{v_0}.$$

Hence

$$v_y = \frac{eUD}{mdv_0}.$$

The distance of inclination is

$$h' = \frac{v_y^2}{2a} = \frac{eUD^2}{2mdv_0^2} = 2.6 \text{ mm}$$

(Expression: 0.60 marks. Value: 0.40 marks)

Deviation: _____

4. [0.50 marks] Find the angle that the velocity of a $^{35}$Cl ion with charge *-e* makes with the *x*-axis at the time it leaves the space between the plates.
   We find the angle with the help of the velocity components

$$\tan \alpha = \frac{v_y}{v_x} = \frac{eUD}{mdv_0^2}.$$ (Expression: 0.70 marks)

$\alpha = 5.9°$. (Value: 0.30 marks)

Angle _____

5. [1.60 marks] Express the ratio $h_1/h_2$ between the distances of the marks on the screen from the x-axis of two different ions with the same charge in terms of their masses $m_1$ and $m_2$.

$$h_1 = h' + h'' = \frac{2eUD^2}{2mdv_0^2} + L \cdot \tan \alpha = \frac{eUD}{m_1 dv_0^2}(D + 2L)$$

$$\frac{h_1}{h_2} = \frac{m_2}{m_1}$$

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$h_1/h_2 =$_____

6. [1.00 marks] How far apart are the marks on the screen of $^{24}$Mg and $^{26}$Mg ions with charge *+2e* if they have the same initial velocity $v_0$? Give your answer in mm.

We assign the subscript 1 to the isotope Mg$^{24}$ and 2 to Mg$^{26}$. Then

$$h_1 = h' + h'' = \frac{2eUD^2}{2mdv_0^2} + L \cdot \tan \alpha = \frac{eUD}{m_1 dv_0^2}(D + 2L).$$

For the other isotope we obtain a similar expression.
The distance that then separates the two marks is

$$\Delta h = h_1 - h_2 = \frac{eUD}{dv_0^2}(D + 2L)\left(\frac{1}{m_1} - \frac{1}{m_2}\right) = 1.5 \text{ mm}.$$

e) In this case $m_1 v_{01}^2 = m_2 v_{02}^2 = 4eU$, from which it follows that $\Delta h = 0$.

Distance between the marks in mm: _____

7. [1.00 marks] What would be the answer of the previous question if the $^{24}$Mg and $^{26}$Mg ions were accelerated in x-direction with a potential difference of 1000 V from rest **before** entering into the space between the plates? Give your answer in mm.

Distance between the marks in mm: _____

_____

_____

_____
_____

## PART 2

The James Webb Space Telescope detected an unmistakable signal of a planet orbiting a distant star, taking an important step in the search and characterization of potentially habitable exoplanets beyond Earth. On June 21 2022, the Near-Infrared Imager and Slitless Spectrograph (NIRISS) measured light from the system formed by the star WASP-96 and its planet WASP-96b. As this planet (successive positions, represented by the small gray circle) passed in front of the star (big white circle), scientists extracted the light curve (figure below), showing the overall dimming of the star's brightness (flux) during its transit. The star and the planet are not drawn to scale.



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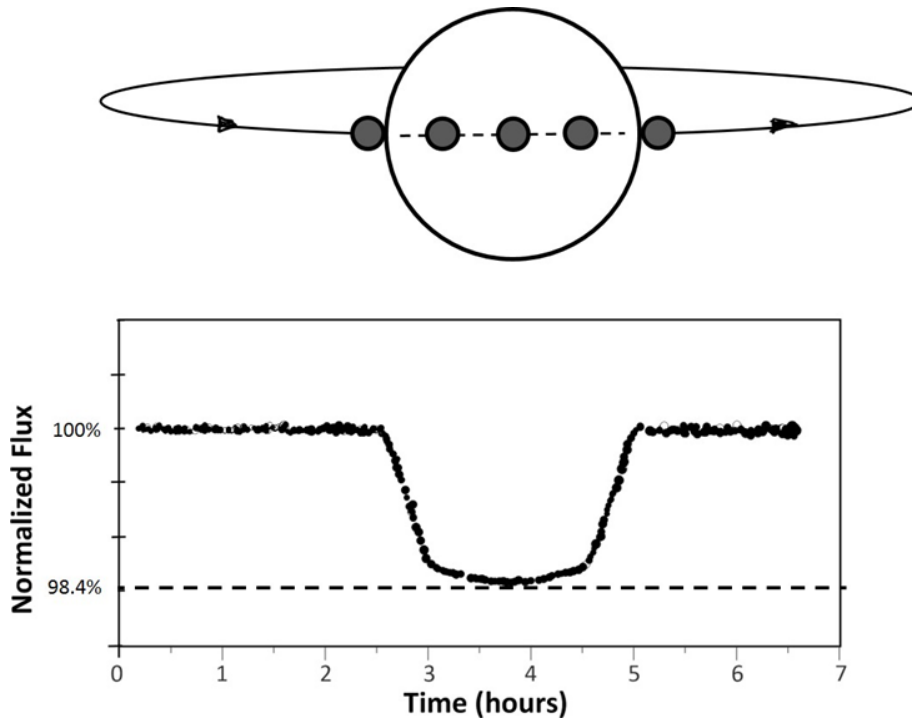
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Data

Mass of the star WASP-96: $M_{star} = 1.06\ M_{Sun}$

Radius of the star WASP-96: $R_{star} = 1.05\ R_{Sun}$

Temperature of the star WASP-96: $T_{star} = 0.9588\ T_{Sun}$

Mass of the planet WASP-96b: $M_{planet} = 155.5\ M_{Earth}$

Star WASP-96 - planet WASP-96b distance: $a = 0.0453$ AU (1 AU $= 1.496 \times 10^{11}$ m)

Mass of the Earth: $M_{Earth} = 5.974 \times 10^{24}$ kg
Mass of the Sun: $M_{Sun} = 1.989 \times 10^{30}$ kg
Universal gravitational constant: $G = 6.674 \times 10^{-11}$ N m² kg⁻²

1. [0.50 marks] Deduce from the graph the transit duration of the planet (in hours).

    Transit        duration        of        the        planet        WASP-96b        (in        hours)

    Transit Time is 2.5 hours Valid $[2.45 - 2.55]$   **(0.5 marks)**

    _____

2. [1.00 marks] Astrophysicists know that the variation of the flux throughout the transit is equal to the ratio between the cross-section area of planet WASP-96b and the cross-section area of star WASP-96. Estimate the radius of planet WASP-96b in terms of solar radius.

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**Name**…………………………………………………………………..                    **Code** ………………………………………..

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Since the $R_* = 1.05R_\odot$

Based on the graph, the flux decreases 1.6%. Using the formula for the planetary radius:

$\Delta F = 1.6\%$                    **(0.3 marks)**

$\Delta F = \frac{R_P^2}{R_*^2} = 0.016$          **(0.3 marks)**

$R_p = \frac{\sqrt{0.016}}{1} R_*$            **(0.1 marks)**

$R_p = 0.126 R_*$                **(0.1 marks)**

$R_p = 0.132 R_\odot$ Valid $[0.128 - 0.135]$ or $R_p = 13.44 R_\oplus$  Valid $[13.42 - 13.46]$ **(0.2 marks)**

The radius of planet WASP-96b in terms of solar radius _____

3. [1.00 marks] Determine the orbital period of planet WASP-96b in days. Assume it describes a circular orbit.

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$$\frac{a^3}{\tau^2} = \frac{GM}{4\pi^2}$$

Solution is valid with either equation:

$\tau^2 = \frac{a^3 4\pi^2}{G(M_* + M_p)}$  or  $\tau^2 = \frac{a^3 4\pi^2}{GM_*}$  **(0.2 marks)**

$a = 6.777 \cdot 10^9 m$  **(0.1 marks)**

$M_* = 1M_\odot + 0.06M_\odot = 2.108 \cdot 10^{30} kg$  **(0.2 marks)**

$M_P = (155.5 M_\oplus) = (155.5)(5.9736 \cdot 10^{24} kg) = 9.2889 \cdot 10^{26} kg$  **(0.1 marks)**

$\tau^2 = 9.1405 \cdot 10^{10} \, s^2$

$\tau = 302333.9915 \, s$  **(0.2 marks)**

$\tau = 3.49 \, days$  Valid $[3.48 \, days - 3.52 \, days]$  **(0.2 marks)**

The orbital period of planet WASP-96b in days_____

4. [1.00 marks] Determine the orbital velocity of planet WASP-96b. Express your answer in km/s.

_____
_____

**Name**……………………………………………………………………………..           **Code** ……………………………………………….

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_____

### option I

$$F_c = F_g \qquad \text{(0.2 marks)}$$

$$\frac{m_p v_p{}^2}{a} = G\frac{m_p M_*}{a^2} \qquad \text{(0.2 marks)}$$

$$v_p = \sqrt{G\frac{M_*}{a}} \qquad \text{(0.2 marks)}$$

$$v_p = \sqrt{(6.6738 \cdot 10^{-11} N kg^{-2} m^2)\frac{2.108 \cdot 10^{30} kg}{6.777 \cdot 10^9 m}} \qquad \text{(0.2 marks)}$$

$$v_p = 139.98\ km/s \ \text{Valid}\ [139.95\ km/s - 140.10\ km/s] \qquad \text{-/+5\%} \qquad \text{(0.2 marks)}$$

### option II

$$v_p = \frac{2\pi a}{\tau} \qquad (0.6\ marks)$$

$$v_p = \frac{(2\pi)(6.777 \cdot 10^9 m)}{302333.9915\ s} \qquad \text{(0.2 marks)}$$

$$v_p = 139.96\ km/s \ \text{Valid}\ [139.95\ km/s - 140.10\ km/s] \quad \text{-/+5\%} \quad \text{(0.2 marks)}$$

The orbital velocity of planet WASP-96b in km/s_____

5.  [1.50 marks] The luminosity $L$ of a star is the electromagnetic power radiated from its surface. According to Stefan-Boltzmann's law, it depends on the surface area $A$ and the temperature $T$:

$$L = \sigma A T^4$$

_____

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**Name……………………………………………………………………..**          **Code ……………………………………………….**

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where σ is a proportionality constant (named Stefan-Boltzmann's constant). Calculate the luminosity (in solar luminosities) of star WASP-96.

$$\frac{L_*}{L_\odot} = \frac{4\pi R_*^2 \sigma T_*^4}{4\pi R_\odot^2 \sigma T_\odot^4}$$          **(0.5 marks)**

$$L_* = EA = 4\pi R_*^2 \sigma T_*^4$$   **(0.3 marks)**

$$\frac{L_*}{L_\odot} = \left(\frac{R_*}{R_\odot}\right)^2 \left(\frac{T_*}{T_\odot}\right)^4$$          **(0.5 marks)**

$$L_* = 0.9317 L_\odot \quad \text{Valid } [0.85 - 0.94] \quad \text{-/+5\%}$$          **(0.2 marks)**

**Note:**

**Units: 0.1 marks will be taken if units are incorrect or missing.**

The luminosity (in solar luminosities) of star WASP-96_____

_____
_____