Theoretical Test

December 6th, 2022
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.
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.
## GENERAL INFORMATION

<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration due to gravity</td>
<td>$g = 9.81 \text{ m/s}^2$</td>
</tr>
<tr>
<td>Universal gas constant</td>
<td>$R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$</td>
</tr>
<tr>
<td>Refractive index of air</td>
<td>$n = 1$</td>
</tr>
<tr>
<td>Avogadro's constant</td>
<td>$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$</td>
</tr>
<tr>
<td>Speed of light</td>
<td>$c = 2.998 \times 10^8 \text{ m/s}$</td>
</tr>
<tr>
<td>Planck's constant</td>
<td>$h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$</td>
</tr>
<tr>
<td>Specific heat capacity of water</td>
<td>$c_w = 4.18 \text{ kJ/kg} \cdot ^\circ\text{C}$</td>
</tr>
</tbody>
</table>
**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.

   - 30% fertilization:
     
     \[
     \begin{array}{cc}
     B & b \\
     b & b \\
     \end{array}
     \]
     
     \[
     \begin{array}{cc}
     Bb & Bb \\
     bb & bb \\
     \end{array}
     \]

   - 70% fertilization:
     
     \[
     \begin{array}{cc}
     B & b \\
     b & b \\
     \end{array}
     \]

     \[
     \begin{array}{cc}
     BB & Bb \\
     Bb & bb \\
     \end{array}
     \]

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

   - bb 50% upper Punnett square
   - bb 25% down Punnett square

   \[
   15\% + 17.5\% = 32.5\%
   \]
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.

<table>
<thead>
<tr>
<th>Process</th>
<th>Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitosis</td>
<td></td>
</tr>
<tr>
<td>Meiosis stage 1</td>
<td>X</td>
</tr>
<tr>
<td>Meiosis stage 2</td>
<td>X</td>
</tr>
<tr>
<td>Interphase</td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to corn borer</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance to corn leaf blight</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolerates flooding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhibits dormancy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sensitive to high growth temps</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 100 pips per kernel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Day length short for flowering</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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).

<table>
<thead>
<tr>
<th>Cellular Feature</th>
<th>Found in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spores</td>
<td>F</td>
</tr>
<tr>
<td>Chloroplasts</td>
<td>P</td>
</tr>
<tr>
<td>Cell walls of cellulose</td>
<td>P</td>
</tr>
<tr>
<td>Mitochondria</td>
<td>B</td>
</tr>
<tr>
<td>Hyphae</td>
<td>F</td>
</tr>
<tr>
<td>Multi layered cell walls including chitin</td>
<td>F</td>
</tr>
<tr>
<td>Stains blue with iodine</td>
<td>F</td>
</tr>
</tbody>
</table>
6. [0.50 marks] The *Aspergillus flavus* 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)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Occurs when</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid, undifferentiated cell growth</td>
<td>C</td>
</tr>
<tr>
<td>More frequent infections</td>
<td>I</td>
</tr>
<tr>
<td>Fewer immune memory cells</td>
<td>I</td>
</tr>
<tr>
<td>Increased lymphocyte levels</td>
<td>N</td>
</tr>
<tr>
<td>Resisting cell death</td>
<td>C</td>
</tr>
<tr>
<td>Reduced rate of cell division</td>
<td>N</td>
</tr>
<tr>
<td>Increased red blood cell levels in the blood</td>
<td>N</td>
</tr>
</tbody>
</table>

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 organisms or process. 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 *Nitrosomonas*,
x: denitrifying bacteria
y: nitrogen fixing bacteria,
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.

![Image of butterflies and insects]

2. [0.25 marks] Mark with X which of the following is most likely to predate corn borer larvae:
3. [0.25 marks] In a controlled experiment corn borers were grown in an atmosphere with a higher oxygen partial pressure. Taking in account the trachea respiratory system of insects, Predict the appearance of the adult corn borer relative to an adult grown with normal oxygen partial pressures.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger thorax</td>
<td>X</td>
</tr>
<tr>
<td>Smaller antennae</td>
<td></td>
</tr>
<tr>
<td>Longer legs</td>
<td>X</td>
</tr>
<tr>
<td>Smaller wings</td>
<td></td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Option</th>
<th>Possible answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Place 9-hexadecenal lures outside the maize field to attract males away from the maize field</td>
</tr>
<tr>
<td>X</td>
<td>Place 9-hexadecenal lures in the field without females to distract the males from mating.</td>
</tr>
<tr>
<td>X</td>
<td>Place 9-hexadecenal lures in the field together with a powerful contact insecticide to kill all the males</td>
</tr>
</tbody>
</table>

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

a: larva
b: pupa
c: female 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
of the insect eyes (trace black, bottom 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).

Previous research has indicated that:
Previous reports about the quantities of vesicles in these synapses give a total of 3 vesicles available to release in every flash of stimulation. The probability of release of each glutamate vesicle is independent of the release of others. PEPS have discrete values.

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

![Histogram of PEPS events](image)

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

![Frequency of PEPS](image)
Frequency of 1 mV PEPS at pH 9: \( \frac{7}{39} = 18\% \) and of 1 mV PEPS at pH 5: \( \frac{15}{34} = 44\% \)

Frequency of 2 mV PEPS at pH 9: \( \frac{18}{39} = 46\% \) and of 2 mV PEPS at pH 5: \( \frac{15}{34} = 44\% \)

Frequency of 3 mV PEPS at pH 9: \( \frac{14}{39} = 36\% \) and of 3 mV PEPS at pH 5: \( \frac{5}{34} = 14\% \)

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 = \( \frac{39}{40} = 97.5\% \)

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: \( \frac{5}{40} = ___12.5___\% \)

Probability of more than two vesicles being released at pH 9: \( \frac{14}{40} = ___35___\% \)

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

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

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

\[ K_a = \frac{[\text{Receptor-signal molecule complex}]}{[\text{Receptor}][\text{Signal Molecule}]} \]

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

![Figure 5.1](image)

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

| Fungal Fragment FF | 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.
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.

<table>
<thead>
<tr>
<th>Receptor part</th>
<th>Hydrophobic</th>
<th>Hydrophilic</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>II.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>III.</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
3. [1 mark] Mark with X which of the terms apply to figure 5.2

<table>
<thead>
<tr>
<th>Active transport</th>
<th>Facilitated diffusion</th>
<th>Receptor mediated endocytosis</th>
<th>Phagocytosis</th>
<th>Simple diffusion</th>
<th>Co-transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Histatin1?

Answer 297 amino acids + start + stop codons = 299\times3 = 897 base pairs

\[ \% \text{ exons} = \frac{897}{9546} = 9.4\% \]

**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

   \[
   \begin{array}{ccc}
   \text{Agrigro} & \text{NH}_4\text{NO}_3 & 0.8 \\
   \text{Mr} & 80.06 & 0.9 \\
   \text{Happy plants} & \text{KNO}_3 & 5 \\
   \text{Mr} & 101.11 & 0.9 \\
   \end{array}
   \]
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.

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

Mass of Agrigrow 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)

Aqueous ammonia + oxygen = nitrate ions and water
Theoretical Test

Name.................................................................................................................. Code ..............................................

____________________________________
_________________________________________________________
______

Theoretical Test

Questions

20

NH₄⁺ O₂ NO₃⁻

Oxidation states -3 0 0 =5 & -2

Nitrate(v) formation

N₃⁻ ---- N⁵⁺ and

Oxidation reaction 8e⁻-

Reduction reaction O⁰ +2e⁻ ---- O²⁻

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

N₃⁻ ---- N⁵⁻ and

Oxidation reaction 6e⁻-

Reduction reaction O⁰ +2e⁻ ---- O²⁻

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

NH₄OH + 1.5O₂⁻ + OH⁻ === NO₂⁻ + 2H₂O

NH₃ + 1.5O₂⁻ + OH⁻ === NO₂⁻ + 2H₂O

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 NH₄NO₃ 0.85 g

Moles of NH₄NO₃ = mass/ Mr. 0.010617037 moles

Conc of NH₄⁺ = moles/ vol 0.071 M.

Ka = [NH₃]x[H⁺] / [NH₄⁺] = [H⁺]

Assume [NH₄⁺] unchanged

[0.25 marks]
So $[H^+] = \sqrt{K_a \times [NH_4^+]}$

\[
6.29579 \times 10^{-6}
\]

\[
\text{pH} = -\log[H^+]
\]

\[
5.20
\]

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?

<table>
<thead>
<tr>
<th>Na$_2$HPO$_4$</th>
<th>NaH$_2$PO$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>40%</td>
</tr>
<tr>
<td>Mr</td>
<td>142</td>
</tr>
<tr>
<td>%P</td>
<td>22%</td>
</tr>
<tr>
<td>Application rate</td>
<td>150 Kg/Ha</td>
</tr>
<tr>
<td>% Phosphorus required</td>
<td>23%</td>
</tr>
<tr>
<td>Mass P per Ha</td>
<td>34.50 Kg/Ha</td>
</tr>
</tbody>
</table>

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 $K_a$ of dihydrogen phosphate ion is $6.30 \times 10^{-8}$ calculate the pH of this buffer formed in the soil based only on the equilibrium between the mono and dihydrogen phosphate ions.

\[
K_a = 6.30 \times 10^{-8}
\]

\[
pH = pK_a + \log \frac{[\text{salt}]}{[\text{acid}]}
\]

\[
pK_a = 7.200659451
\]

\[
\text{Moles of H}_2\text{PO}_4 = \frac{\text{mass}}{\text{Mr}}
\]

\[
0.00833
\]
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.

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

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

<table>
<thead>
<tr>
<th>Ion</th>
<th>Fe^{3+}</th>
<th>Mg^{2+}</th>
<th>Cl(^-)</th>
<th>Ca^{2+}</th>
<th>Fe^{2+}</th>
<th>NO(_3^-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection of the strongest</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 2.07x10\(^{-33}\) and 9.84x10\(^{-16}\) 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)

<table>
<thead>
<tr>
<th>pH</th>
<th>Ksp</th>
<th>Cation</th>
<th>Phosphate</th>
<th>Phosphate ion conc at equilibrium</th>
<th>Soil A</th>
<th>Soil B</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2.07E-33</td>
<td>3</td>
<td>2</td>
<td>2.28E-07</td>
<td>no marks calculation</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9.84E-16</td>
<td>1</td>
<td>1</td>
<td>3.14E-08</td>
<td>7.26E+00</td>
<td>Multiple</td>
</tr>
</tbody>
</table>

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 m\(^2\). The stock solution of Malathion contains 57g per 100 mL of stock solution. The farmer’s plot is 7 500 m\(^2\). In addition, the farmer adds a wetting agent which should be 5.0
Malathion solutions (57% m/v)

<table>
<thead>
<tr>
<th>Malathion solutions (57% m/v)</th>
<th>Tank (L)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>57%</td>
<td>40</td>
<td>7500</td>
</tr>
</tbody>
</table>

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

Volume of wetting agent = % of malathion volume

32.89 mL

Volume of water

39.31 L

Volume of Malathion_____________________[0.25 marks]
Volume of wetting agent___________________[0.25 marks]
Volume of water_________________________[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:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>E₀(V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu²⁺(aq) + 2e⁻ → Cu(s)</td>
<td>+0.34</td>
</tr>
<tr>
<td>Fe³⁺(aq) + 3e⁻ → Fe(s)</td>
<td>-0.04</td>
</tr>
<tr>
<td>Fe²⁺(aq) + 2e⁻ → Fe(s)</td>
<td>-0.44</td>
</tr>
<tr>
<td>Al³⁺(aq) + 3e⁻ → Al(s)</td>
<td>-1.66</td>
</tr>
</tbody>
</table>

Mark with X all the locations that apply:
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
hydrolysis, fermentation with yeast, centrifugation and finally distillation before molecular filtration. Milled maize kernels have the following composition.

<table>
<thead>
<tr>
<th>Component</th>
<th>% by Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (H₂O)</td>
<td>9.6</td>
</tr>
<tr>
<td>Ash (metal and silicon oxides)</td>
<td>1.7</td>
</tr>
<tr>
<td>Proteins</td>
<td>10.7</td>
</tr>
<tr>
<td>Insoluble Fibres</td>
<td>2.2</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>70.4</td>
</tr>
<tr>
<td>Lipids</td>
<td>5.4</td>
</tr>
</tbody>
</table>

(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.
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 (C₆H₁₂O₆) per second in this reactor. The anaerobic respiration of hydrolysed carbohydrates by yeast can be shown by

\[ \text{C}_6\text{H}_12\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2 \quad \Delta H = -34.5 \text{ kJ/mol of ethanol} \]

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.

<table>
<thead>
<tr>
<th>Microbial rate</th>
<th>2000 mol/sec</th>
<th>Water in (5) °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthalpy change</td>
<td>-34.5 kJ per mole ethanol</td>
<td>Heat capacity of water</td>
</tr>
</tbody>
</table>

\[
\text{Thermal energy from fermentation} = \text{thermal energy removed by cooling water}
\]

\[
-138000 \text{ kJ/sec} = M \times C \times \Delta T
\]

\[
= 104.5 \text{ m}
\]
Flow rate = \(-1321\) kg/sec

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 = 10^{exp-6.80} x 4000 = 0.004 moles
Moles of H+ ions required for pH 2 = 44.88074
Each sulphuric acid molecule produces 2 H+ ions

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

Volume of sulphuric acid required = moles / conc = 8.98 L

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. \((R = 8.314 \text{ J/mol.K})\)?

% carbohydrate converted 86%
Maize meal per 4000L batch 1329.78723 1400 kg
Mass of carbohydrate = mass of maize meal x % carb in maize 
Molecular mass of carb = 6 x (12 +2+16) = 180 g/mol
Moles of carbohydrate = mass / Mr = 5475.55556 moles
Mole ratio of Carb to CO2 = 1:2
Moles of CO2 produced = 9418 moles
Assume ideal gas so V = nRT/P
Pressure = 101000
Temp = 305 K
R = 8.314
Volume = nRT/P = 236 m³

Volume of carbon dioxide emitted ..........236 m³

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/m³ ethanol 789 kg/m³). 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 C₈H₁₈ and C₂H₅OH respectively.

<table>
<thead>
<tr>
<th>%</th>
<th>Hc</th>
<th>Density</th>
<th>Mass in 1 L</th>
<th>Molar mass</th>
<th>Energy released</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane</td>
<td>80%</td>
<td>5470</td>
<td>703</td>
<td>562.4</td>
<td>114.26</td>
</tr>
<tr>
<td>Ethanol</td>
<td>20%</td>
<td>1371</td>
<td>789</td>
<td>157.8</td>
<td>46.08</td>
</tr>
</tbody>
</table>

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

\[
(1 \text{ u} = 1.66 \times 10^{-27} \text{ kg})
\]

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.

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Mass (u)</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{35}\text{Cl})</td>
<td>34.97</td>
<td>(-e)</td>
</tr>
<tr>
<td>(^{37}\text{Cl})</td>
<td>36.97</td>
<td>(-e)</td>
</tr>
<tr>
<td>(^{24}\text{Mg})</td>
<td>23.98</td>
<td>(+2e)</td>
</tr>
<tr>
<td>(^{26}\text{Mg})</td>
<td>25.98</td>
<td>(+2e)</td>
</tr>
</tbody>
</table>
Data:

- Elementary charge $e$: $1.60 \times 10^{-19}$ 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 $v_0$: $1.0 \times 10^5$ 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.

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

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.

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

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:
\[ ma = eE = \frac{eU}{d}. \]

\[ v_y = at. \]

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 \(^{35}\text{Cl}\) 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)

\[ \alpha = 5.9^\circ. \] (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 \(m_2\).

\[ h_1 = h' + h'' = \frac{2eUD^2}{2mdv_0^2} + L \cdot \tan \alpha = \frac{eUD}{m_1dv_0^2} (D + 2L) \]

\[ \frac{h_1}{h_2} = \frac{m_2}{m_1} \]
6. [1.00 marks] How far apart are the marks on the screen of $^{24}\text{Mg}$ and $^{26}\text{Mg}$ 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 $\text{Mg}^{24}$ and 2 to $\text{Mg}^{26}$. Then

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

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 $m_1 v_{0i}^2 = m_2 v_{02}^2 = 4eU$, 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 $^{24}\text{Mg}$ and $^{26}\text{Mg}$ 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.
Data

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

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

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

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

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

Mass of the Earth: $M_{\text{Earth}} = 5.974 \times 10^{24}$ kg
Mass of the Sun: $M_{\text{Sun}} = 1.989 \times 10^{30}$ kg
Universal gravitational constant: $G = 6.674 \times 10^{-11}$ N m$^2$ 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.
Since the $R_* = 1.05R_\odot$

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

\[ \Delta F = 1.6\% \]  
\[ \Delta F = \frac{R_p^2}{R_*^2} = 0.016 \]  
\[ R_p = \frac{\sqrt{0.016}}{1} R_* \]  
\[ R_p = 0.126R_* \]

\[ R_p = 0.132R_\odot \text{ Valid } [0.128 - 0.135] \text{ or } R_p = 13.44R_\oplus \text{ Valid } [13.42 - 13.46] \]

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

Solution is valid with either equation:

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

$$a = 6.777 \cdot 10^9 m \quad (0.1 \text{ marks})$$

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

$$M_p = (155.5M_\odot) = (155.5)(5.9736 \cdot 10^{24} kg) = 9.2889 \cdot 10^{26} kg \quad (0.1 \text{ marks})$$

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

$$\tau = 302333.9915 \text{ s} \quad (0.2 \text{ marks})$$

$$\tau = 3.49 \text{ days} \quad \text{Valid} \ [3.48 \text{ days} - 3.52 \text{ days}] \quad (0.2 \text{ marks})$$

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

\[ v_p = \sqrt{\frac{G M_p}{a}} \]

\[ v_p = \sqrt{\left(6.6738 \cdot 10^{-11} \text{N} \cdot \text{kg}^{-2} \cdot \text{m}^2\right) \frac{2.108 \cdot 10^{30} \text{kg}}{6.777 \cdot 10^8 \text{m}}} \]

\[ v_p = 139.98 \text{ km/s} \quad \text{Valid} \quad [139.95 \text{ km/s} - 140.10 \text{ km/s}] \quad -/+5\% \]

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 \( T \):

\[ L = \sigma A T^4 \]
where $\sigma$ 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

\[
L_* = \varepsilon A = 4\pi R_*^2 \sigma T_*^4
\]  
\(0.3\) marks

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

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

**Note:**

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

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