

Name.....

Code



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	$R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$
	$R = 0.08206 \text{ L} \cdot \text{atm/mol} \cdot \text{K}$
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	$c_w = 4.18 \text{ kJ/kg} \cdot ^\circ\text{C}$

Periodic Table of the Elements

1 H Hydrogen 1.01																	2 He Helium 4.00																
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18																
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95																
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 84.80																
37 Rb Rubidium 84.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.25																
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides		72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.09	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium [208.98]	85 At Astatine 209.99	86 Rn Radon 222.02															
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides		104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [293]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown															
																			57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.06	71 Lu Lutetium 174.97
																			89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium [254]	100 Fm Fermium 257.10	101 Md Mendelevium 258.1	102 No Nobelium 259.10	103 Lr Lawrencium [262]

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**DO NOT turn to next page before the
“START SIGNAL”**

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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.

	MALE	
FEMALE		

	MALE	
FEMALE		

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

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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	
Meiosis stage 2	
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							
Tasselling density high	X	X		X	X	X	X	X

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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	
Chloroplasts	
Cell walls of cellulose	
Mitochondria	
Hyphae	
Multi layered cell walls including chitin	
Stains blue with iodine	

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Code

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)

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

PART 2

Name.....

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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:

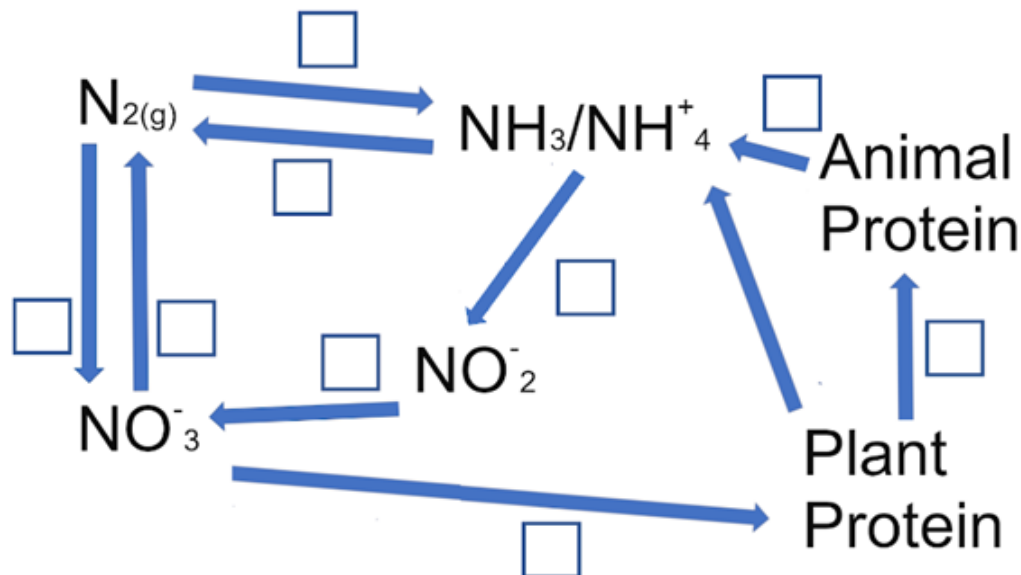
s: lightning,

t: saprophytic fungi,

u: nitrifying bacteria e.g. *Nitrobacter*, and *Nitrosomonas*.

x: denitrifying bacteria

y: nitrogen fixing bacteria,



PART 3

Name.....

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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.



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

Bats	Spiders	Moths	Snails

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.

Characteristics	Selection
Larger thorax	
Smaller antennae	
Longer legs	
Smaller wings	

Name.....

Code

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
☐	Place 9-hexadecenal lures outside the maize field to attract males away from the maize field
☐	Place 9-hexadecenal lures in the field without females to distract the males from mating.
☐	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 Corn borer stages of development below by inserting the following letters:

- a: larva
b: pupa
c: adult female
d: egg
e: adult male



PART 4

Name.....

Code

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

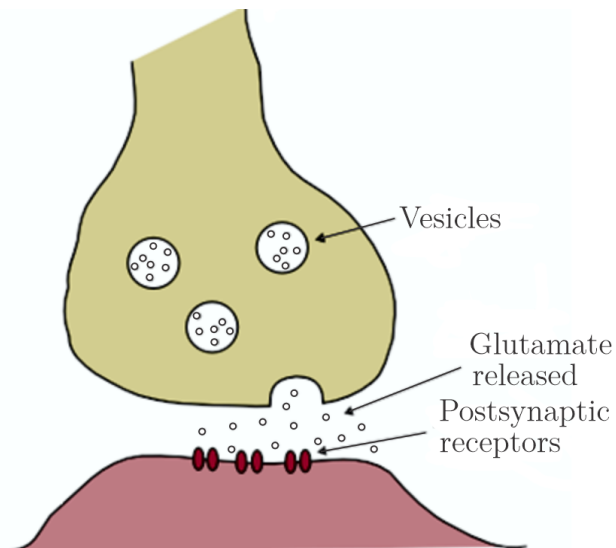


Figure 4.1

Name.....

Code

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).

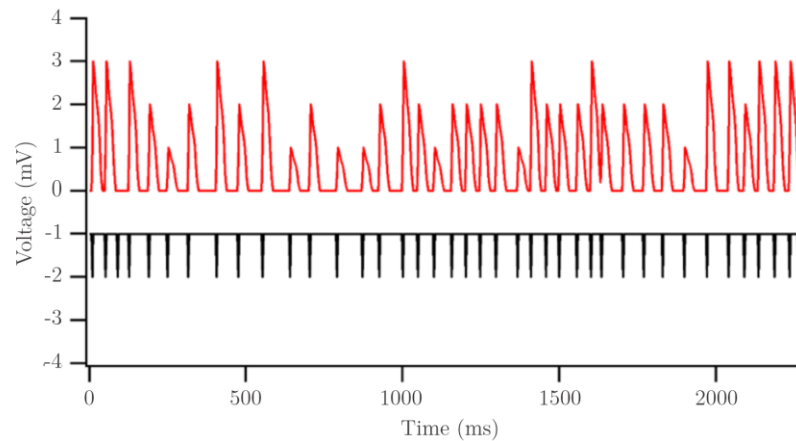


Figure 4.2

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

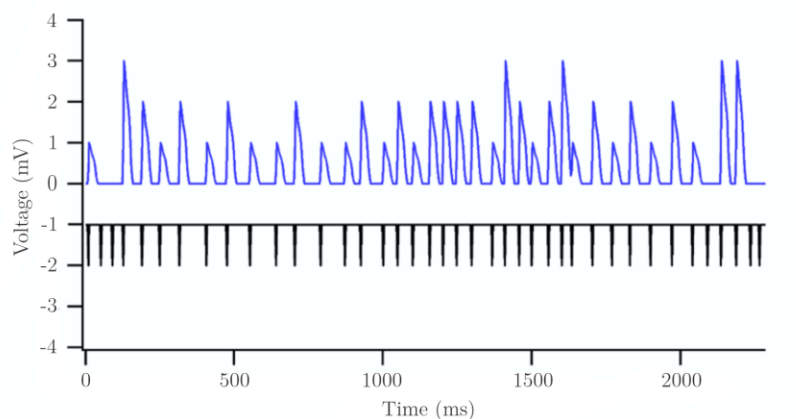


Figure 4.3

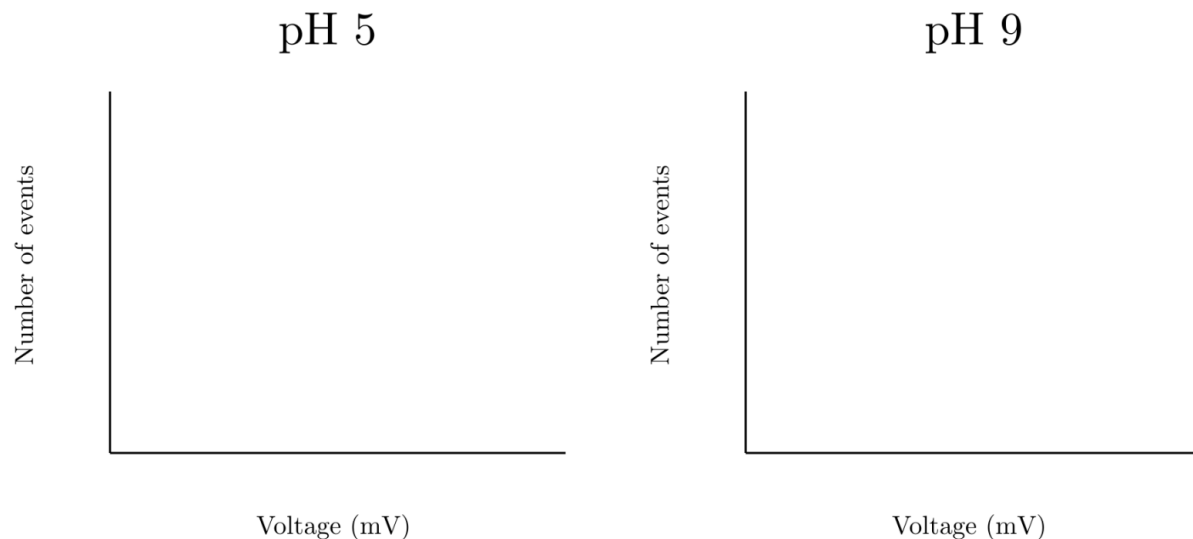
Name.....

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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.



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

Frequency of 1 mV PEPS at pH 9 : _____ and of 1 mV PEPS at pH 5: _____

Frequency of 2 mV PEPS at pH 9: _____ and of 2 mV PEPS at pH 5: _____

Frequency of 3 mV PEPS at pH 9: _____ and of 3 mV PEPS at pH 5: _____

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

Release probability of glutamate PEPS events at pH9 : _____ at pH5 _____

In which condition is this higher? pH: _____

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Code

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 9: _____

Probability of more than two vesicles being released at pH 5: _____

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.
	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

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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 Absciscic acid (AA).

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

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

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

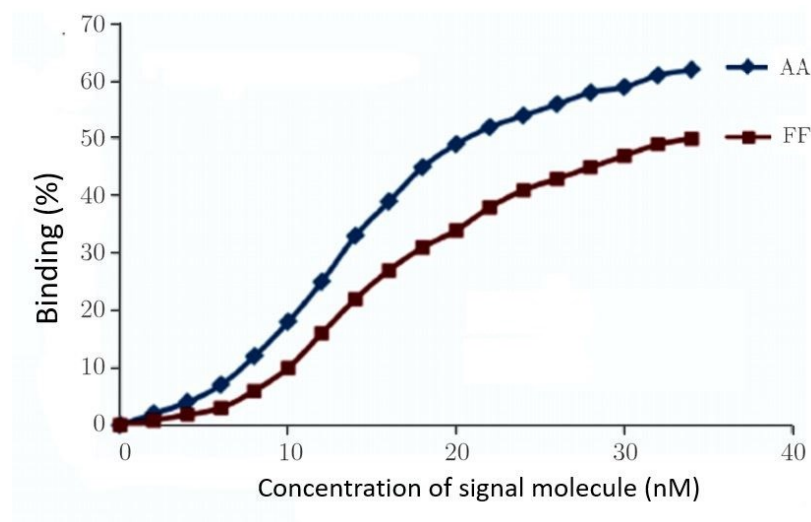


Figure 5.1

Name.....

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

Fungal FragmentFF		Absciscic acid AA	
-------------------	--	-------------------	--

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.

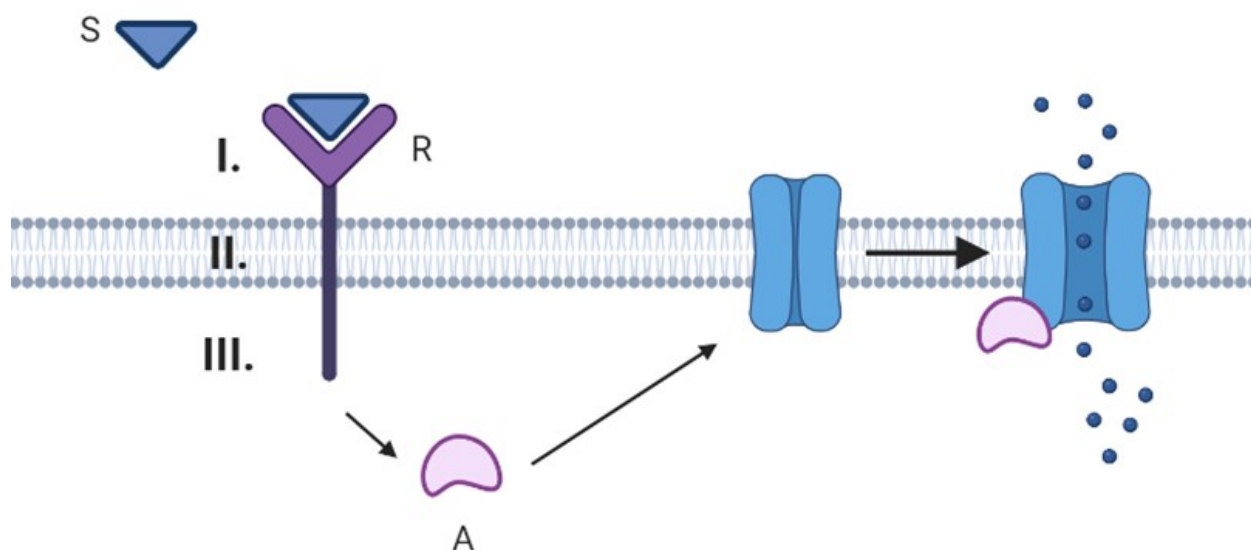


Figure 5.2, S = signal molecule, R = receptor, A = activator

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.		
II.		
III.		

Name.....

Code

-
3. [1.00 marks] Mark with X which of the terms apply to figure 5.2

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

4. [0.50 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?

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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

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 per hectare

Name.....

Code

-
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)

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 K_a of ammonium ions is 5.60×10^{-10} and that ammonium ions are the only source of H^+ ions, neglect any other source of H^+ ions.

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

pH of topsoil _____ 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?

Application mass (kg) per hectare _____.

Name.....

Code

-
6. [0.75 marks] This mixture of phosphate creates a buffer solution in the groundwater. If the K_a of dihydrogen phosphate ion is 6.30×10^{-8} calculate the pH of this buffer formed in the soil based only on the equilibrium between the mono and dihydrogen phosphate ions.

pH of buffer _____ (answer to two decimal places)

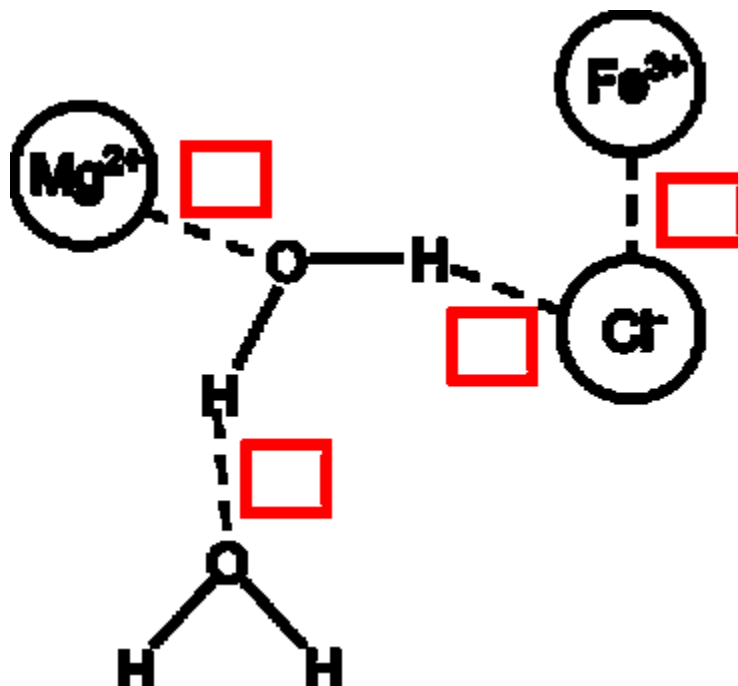
PART 2

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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

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						

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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 2.07×10^{-33} and 9.84×10^{-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)

Soil with higher concentration _____

How many times bigger _____

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 % 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).

Volume of Malathion _____ [0.25 marks]

Volume of wetting agent _____ [0.25 marks]

Volume of water _____ [0.25 marks]

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

Mark with X all the locations that apply:

Selection	Location of corrosion
	On the parts of the aluminium bolt that are wetted
	On the wetted parts of the copper bolt
	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
	On the wetted iron around the copper bolt

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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.

Component	% by Mass
Moisture (H ₂ O)	9.6
Ash (metal and silicon oxides)	1.7
Proteins	10.7
Insoluble Fibres	2.2
Carbohydrate	70.4
Lipids	5.4

(Source: FAO)

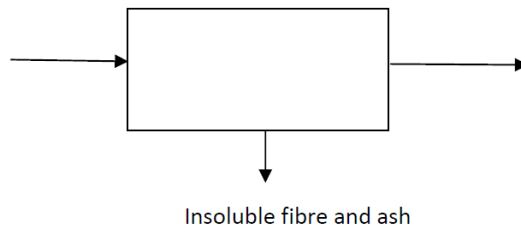
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1. [0.5 marks] One maize-to-ethanol plant processes 5000 tonnes of milled maize per day by adding 2.50 L of water per kg of milled maize. Identify the mass flow rates (kg/s) in and out of the enzyme digestion process and show these on the diagram below

Milled maize + water

Carbohydrates, lipids, water



Input maize and water rate

Output fibre and ash rate

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Output carbohydrates, lipids, water rate

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 respire 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



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.

Flow rate of cooling water 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.

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Volume of 2.50M sulphuric acid required _____ 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. ($R = 8.314 \text{ J/mol.K}$)?

Volume of carbon dioxide emitted 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.

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Energy released from the combustion of 1.00L of blended fuelkJ

QUESTION 3

PART 1

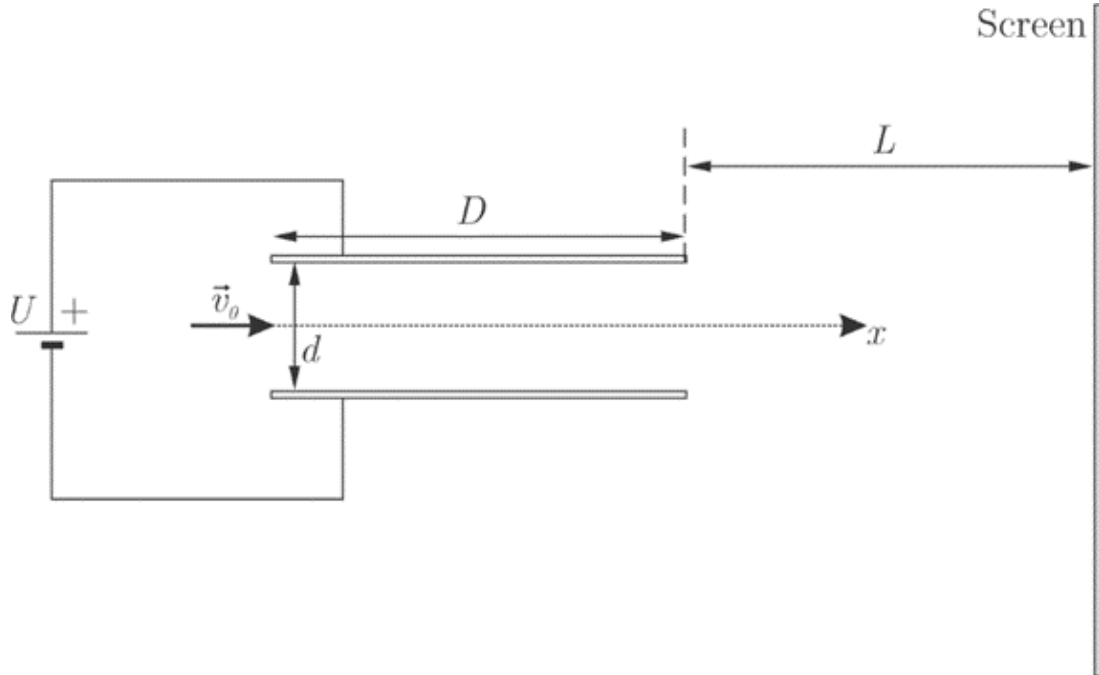
When an electrically charged particle enters the space between two electrically charged plates, it is deflected from the direction in which it was originally moving. For a given configuration of the plates, the deflection depends on the mass and the charge of the ion. This is the principle of a simple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

Name.....

Code



Data:

Elementary charge e :	$1.60 \times 10^{-19} \text{ C}$
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 :	$1.0 \times 10^5 \text{ m/s}$

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.

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.

Name.....

Code

YES	NO

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 .

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.

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 .

Name.....

Code

$h_1/h_2 =$ _____

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.

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.

Name.....

Code

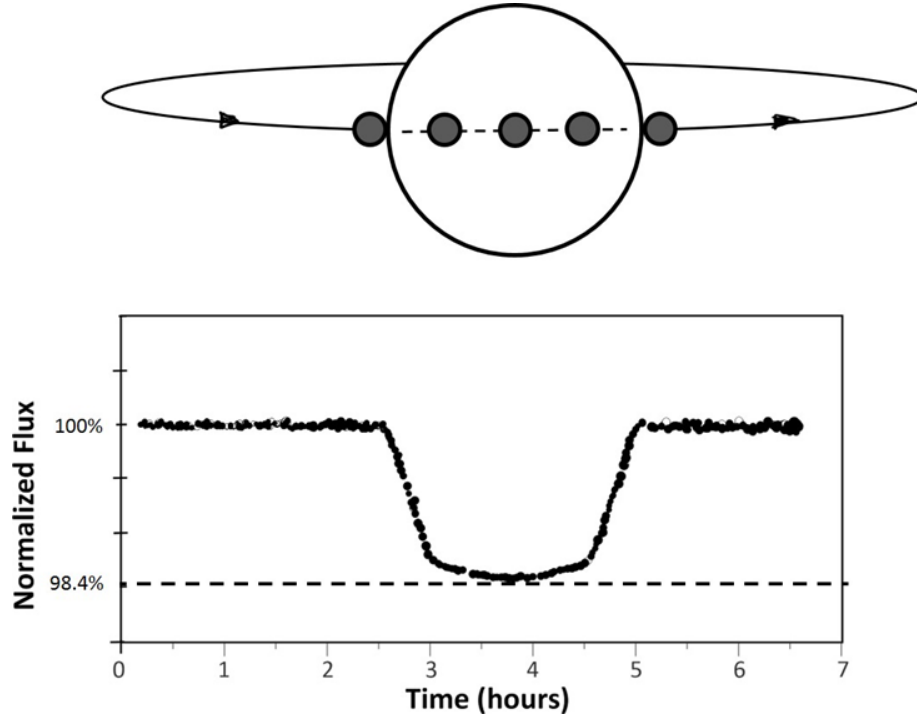
Distance between the marks in mm: _____

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.

Name.....

Code



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: $M_{planet} = 155.5 M_{Earth}$

Name.....

Code

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

Mass of the Earth: $M_{\text{Earth}} = 5.974 \times 10^{24} \text{ kg}$

Mass of the Sun: $M_{\text{Sun}} = 1.989 \times 10^{30} \text{ kg}$

Universal gravitational constant: $G = 6.674 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

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) _____

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.

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.

Name.....

Code

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_____

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

Name.....

Code

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