Bullet and Cannon (5 points)

Please read the general instructions in the separate envelope before you start this problem.

Part A. The Modern day bullet (2.5 points)

Nitroglycerin is one of the important ingredients in modern day bullets. The self-combustion of this material is written as

$$2C_3H_5N_3O_9 \longrightarrow 6\,CO_2 \;+3\,N_2 \;+5\,H_2O \;+\tfrac{1}{2}\,O_2 \;+Heat$$

The amount of heat released is 666 kJ for 2 mole of nitroglycerine

11.35 g of this material is used in a cartridge of single bullet. The mass of the actual bullet is 100.0 g

A.1	Find the molar mass of nitroglycerine.	(0.5pt)

A.2	Find the number of moles of nitro-glycerine in one bullet cartridge.	(0.5pt)

A.3	Find the amount of energy released (numerical value in SI unit) during combustion of one bullet.	(0.5pt)

A.4	Assuming that the entire energy evolved during combustion is used to give kinetic energy to the bullet. Calculate the maximum possible muzzle speed (numerical value in SI unit) of this bullet.	(1.0pt)

Answer:
Maximum kinetic Energy is possible only when the entire energy evolved during combustion is used to give kinetic energy to the bullet.

(a) Molar mass of nitro-glycerine = 227 **(0.5 Mark)**

So 11.35g will correspond to 0.05 Mole **(0.5 Mark)**

Releasing 16650 J of energy **(0.5 Mark)**

$\frac{1}{2}mv^2 = 16650;$ `

$v = \sqrt{2 \times \frac{16650}{0.1}} = \mathbf{5.77 \times 10^2 m/s}$ **(1 Mark)**

(Deduct 0.5 if unit is not written along with numerical answer)

……………………………………………………………………………………………

(b) The gases expand through the barrel.

Apply formula $P_1V_1/T_1 = P_2V_2\,/T_2$ **(0.5 Mark)**

Let V be the volume of the barrel:

$V = l\frac{\pi D^2}{4}$ (not necessary to use)

P_1 = 1000 atm, $V_1 = 0.2 \times V$, $V_2 = V$, $T_2 = \frac{1}{3}\,T_1$ **(1.0 Mark)**

(Any one part wrong would lead to deduction of 0.25 Mark)

Calculate: $P_2 = \frac{P_1V_1}{V_2} . \frac{T_2}{T_1} = \frac{P_1}{15} = \frac{\mathbf{1000 \times 1 \times 10^5}}{\mathbf{15}} = 6.67 \times 10^6\ N/m^2.$ **(0.5 Mark)**

(No Unit – Deduct 0.25 Mark)

Force is P X A = $P_2 \times \frac{\pi D^2}{4}$ = $\mathbf{6.67 \times 10^6} \times \frac{\boldsymbol{\pi} \mathbf{\times 0.15 \times 0.15}}{\mathbf{4}}$ **=**1.178 x10^5 N

F= 1.18 X 10^5 N **(0.5 Marks)**

(Double penalty to be avoided) (No Unit – Deduct 0.25 marks)

Part B. Traditional Cannon (2.5 points)

A traditional Cannon barrel of inner diameter 15.0 cm and length 5.0 m was filled with gunpowder (nitrocellulose) to 20% of its length and topped with a cannon ball of same diameter as the barrel.

(Inner walls of the canon barrel are frictionless)

When it is fired, all of the nitrocellulose burns instantly and produces gas with pressure of 1000 standard atmosphere. When the ball exits the barrel the gas temperature drops to one third of the temperature (in K) at the time of ignition.(Assume ideal gas situation)

(Neglect opposing atmospheric pressure)

B.1	Write the formula to find the pressure (final pressure P_2 in terms of initial pressure P_1 , initial volume V_1 , initial temperature T_1 , final volume V_2 and final temperature T_2) when the cannon ball exits the barrel.	(0.5pt)

B.2	Calculate the pressure (numerical value in SI unit) on the ball when it exits the barrel. (Express your answers in three significant figures i.e. two digits after decimal)	(1.5pt)

B.3	Calculate the force (numerical value in SI unit) on the ball when it exits the barrel. (Express your answers in three significant figures i.e. two digits after decimal)	(0.5pt)

(b) The gases expand through the barrel.

Apply formula $P_1V_1/T_1 = P_2V_2\,/T_2$ **(0.5 Mark)**

Let V be the volume of the barrel:

$V = l\frac{\pi D^2}{4}$ (not necessary to use)

P_1 = 1000 atm, $V_1 \ = \ 0.2 \times V,\ \ V_2 \ = \ V\ , T_2 \ = \frac{1}{3}\ T_1$ **(1.0 Mark)**

(Any one part wrong would lead to deduction of 0.25 Mark)

Calculate: $P_2 \ = \frac{P_1V_1}{V_2}.\frac{T_2}{T_1} = \frac{P_1}{15} = \frac{\mathbf{1000\times1\times10^5}}{\mathbf{15}} = 6.67\times10^6\ N/m^2.$ **(0.5 Mark)**

(No Unit – Deduct 0.25 Mark)

Force is P X A = $P_2 \times \frac{\pi D^2}{4}$ = $\mathbf{6.67\times10^6} \times \frac{\mathbf{\pi\times0.15\times0.15}}{\mathbf{4}}$ **=**1.178 x10^5 N

F= 1.18 X 10^5 N **(0.5 Marks)**

(Double penalty to be avoided) <u>(No Unit – Deduct 0.25 marks)</u>

The Sand buggy and Abra (5 points)

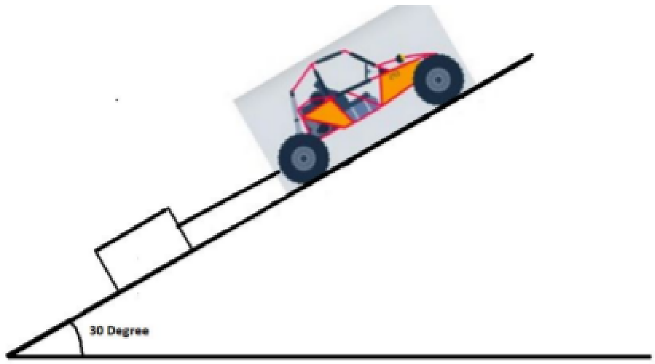
Please read the general instructions in the separate envelope before you start this problem.

Part A. The sand buggy (3.0 points)

A sand buggy (shown in Figure 1) is a vehicle that is used for transportation in deserts. Consider a sand buggy travelling with a constant speed of 72.0 km/h climbing a sand dune which is shown as an inclined plane with an angle of inclination of 30^0. The sand buggy is dragging a box of mass 200 kg upwards. The opposition to motion of the box offered by the sand is 0.15 of the normal force exerted on the box by the sand.

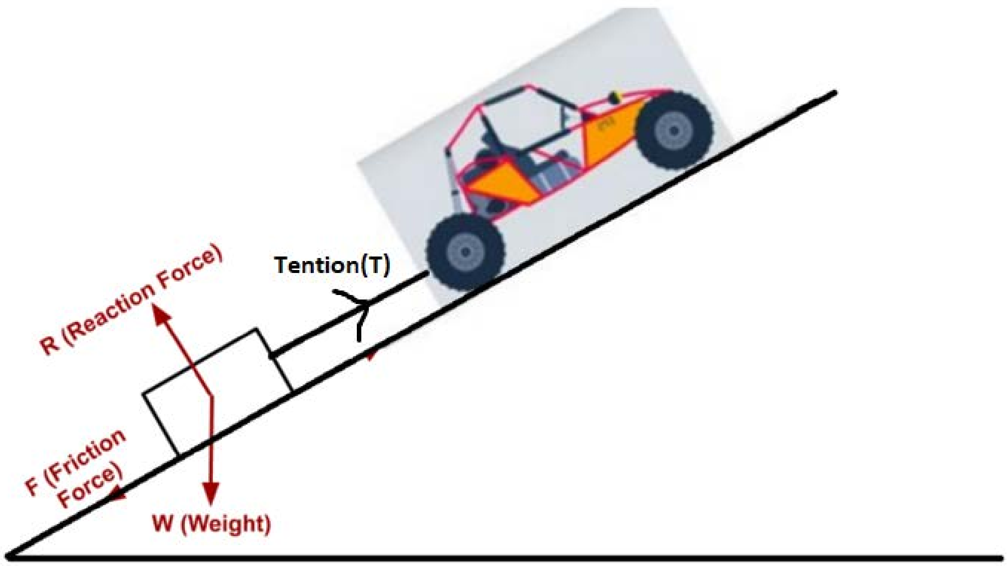
Figure 1 : Representative figure for sand buggy on a slope.

A.1	Draw a VECTOR diagram showing all forces acting on the box in the figure below.	(1.0pt)



A.2	Calculate the total force (numerical value with proper unit) that opposes the motion of the box up the incline.	(0.5pt)
A.3	Calculate the minimum power (numerical value in SI unit) exerted by the sand buggy on the box to sustain the upward motion.	(0.5pt)
A.4	If the box is suddenly detached in the course of upward motion, calculate the retardation acting on the box.(Numerical value in SI unit)	(0.5pt)
A.5	How far will will the box travel (numerical value in SI unit) before coming to rest after it detached from the sand buggy?	(0.5pt)

Answer: **the diagram on the question paper is to be printed on the answer space in the answer sheet,**



0.25 marks for each correct direction shown 4 × 0.25 **(1.0 Mark)**

Part (ii) to (iv) 0.25 Marks to be deducted if the units are missing/wrong

(ii) $F_f + mgsin(30) = mg[0.15\cos(30) + \sin(30)] = 1235\,N$

F = 1.24 x 10³ N **(0.5 Mark)**

(iii) $P_{min} = F_{engine}v = [F_f + mgsin(30)]v = 24692\,W$

P = 2.47 x 10⁴ W **(0.5 Mark)**

(iv) $$a = \frac{F_f + mgsin(30)}{m} = 6.17\,m/s^2$$ **(0.5 Mark)**

$$s = \frac{v^2}{2a}$$ $$s = \frac{20^2}{2\times6.17} = 32.4\,m$$ **(0.5 Mark)**

(0.25 mark to be deducted for not writing correct unit)

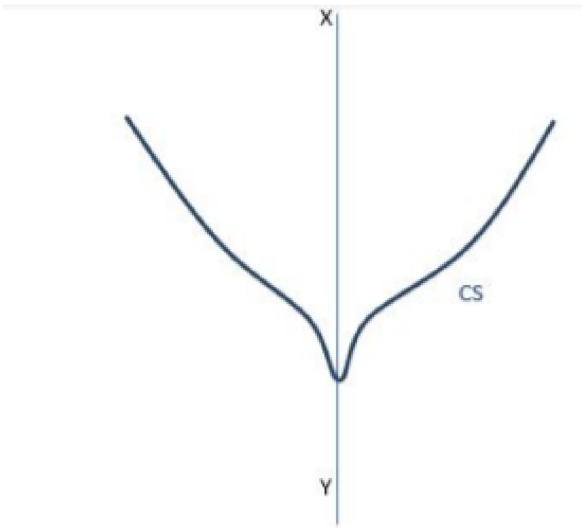
Part B. Abra boat ride (2.0 points)

Dubai city's traditional mode of transport to cross the creek is Abra boat ride (see Figure 2). Abra ride is one of the most economical modes of transport which connects the Old Dubai to New Dubai.

The boats are about 6 m in length and seating arrangement is made of two parallel lines of benches on either side of the vertical plane dividing the boat lengthwise. The center of mass of the boat lies on the vertical line passing exactly through the center of the benches. Passengers can seat on either side on the benches facing the creek.

When the passengers are seated, their centers of mass as a group can be considered to be at a height of 0.4 m above the deck. In case of a maximum payload the water level is 0.5 m below the deck, the buoyant force acts at a point 0.1 m below the water level and the center of mass of the boat lies 1.4 m below the deck. The mass of the unloaded boat is 1000 kg while the average mass of each passenger is 65 kg.

Assume that the point of action buoyant force does not change considerably.

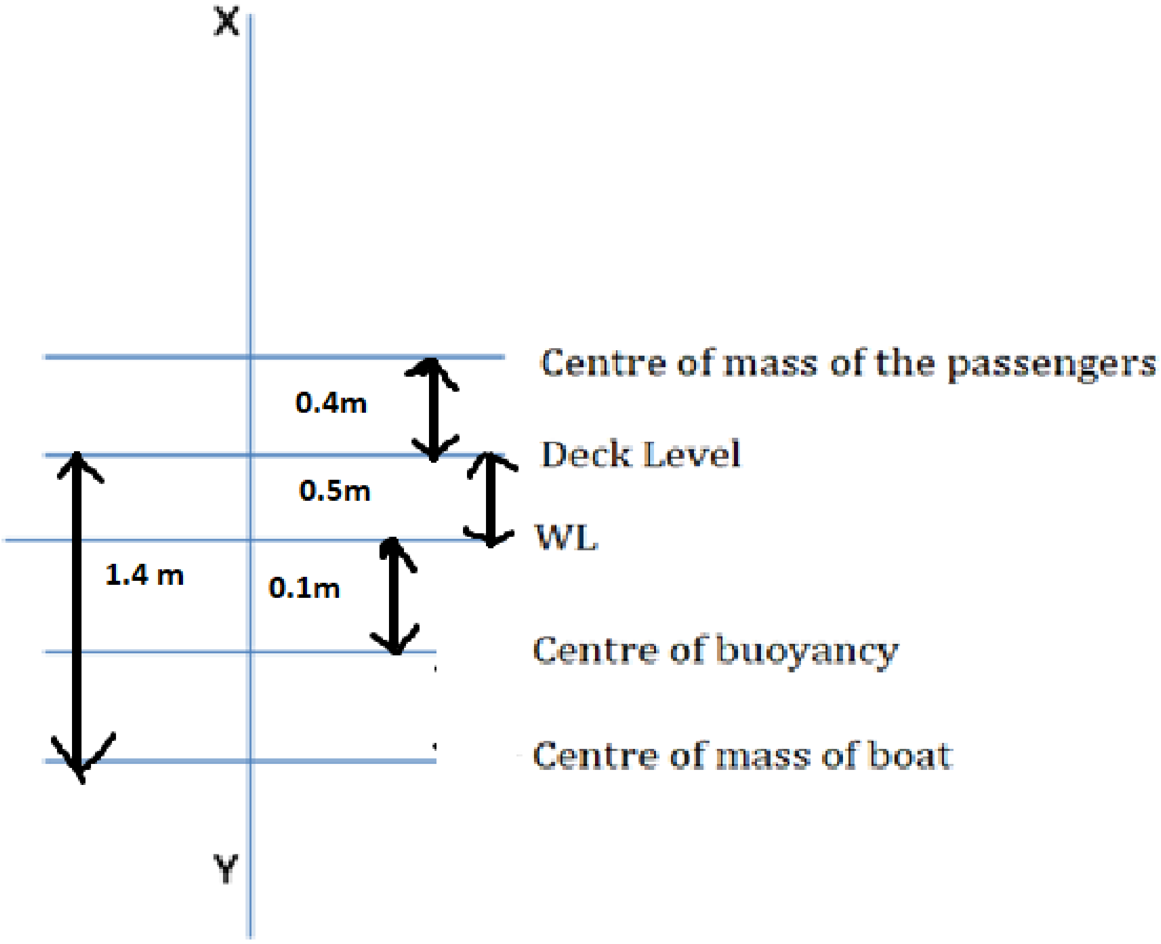
B.1	Draw a schematic sketch along the line XY, of the positions of center of mass of the boat, center of buoyancy of the boat, center of mass of the passengers, and the deck level with respect to the water line and label the distances (need not be on scale). CS – Represents the vertical cross section of the boat in the figure given below.  	(0.5pt)

B.2	Calculate the maximum number of passengers can be seated such that the boat is prevented from capsizing.	(1.5pt)

Answers:

1.

(0.5 Mark)



(The picture of cross section is to be printed in the answer sheet and labeling is to be done in the answer key. The deck level should be included)

Every mistake deduct 0.1 Mark

2. Consider the number of passengers to be ‘n’.

   With respect to the point where the buoyant force acts- is now:

   $65n \times 1.0 < 1000 \times 0.8$ (equality is also acceptable) **(1 Mark)**

   The answer is 12.33=12 **(0.5 Mark)**

IJSO 2021 Chemistry Theory Solutions

Solution: Q.1.1 **2M**

Since the reaction is of first order with respect to sucrose,

Rate constant k=(2.303 /t)* log a/a-x

$$k_{303K} = \frac{2.303}{600} \log \frac{\{12.5 - (-15.5)\}}{\{(-3.0) - (-15.5)\}}$$

$$= \frac{2.303}{600} \log \frac{28.0}{12.5} = \mathbf{1.344 \times 10^{-3}\ s^{-1}}$$ **(0.5 M)**

$$k_{311K} = \frac{2.303}{600} \log \frac{\{12.5 - (-15.5)\}}{\{(-8.0) - (-15.5)\}}$$

$$= \frac{2.303}{600} \log \frac{28.0}{7.5} = \mathbf{2.187 \times 10^{-3} s^{-1}}$$ **(0.5 M)**

Arrhenius eqn: $$\log \frac{k_{311}}{k_{303}} = \frac{E}{2.303\,R} \frac{\{T_2 - T_1\}}{\{T_1 T_2\}}$$

$$\log \frac{2.187 \times 10^{-3}}{1.344 \times 10^{-3}} = \frac{E}{2.303 \times 8.314} \frac{\{311 - 303\}}{\{311 \times 303\}}$$

$$\log 1.627 = \frac{E \{8\}}{2.303 \times 8.314\{311 \times 303\}}$$

E = 47.66 kJ mol^{-1} **(1.0M)**

Deduct 0.25 Marks, if correct units are not written.

Solution:1.2 **1M**

Arrhenius equation log k = log A – E/2.303 RT

T = 27 +273 = 300K

R = 8.314 x 10^{-3} kJ $K^{-1}mol^{-1}$

When E = 60 kJ mol $^{-1}$, log k_2 = log A – 60/2.303 (8.314 x 10^{-3}) 300

When E =66 kJ mol^{-1}, log k_1 = log A -66/2.303(8.314 x 10^{-3}) 300

Subtracting we get,

log k_2 - logk_1 = [-60 –(-66)]/2.303(8.314 x10^{-3}) 300

$= 6/2.303\ (8.314 \times 10^{-3})\ 300$

$= 1.0445$

log k_2/k_1 = 1.0445 **(0.75M)**

Therefore $k_2/k_1 = 11.1$ **(0.25M)**

Solution:

1.3 **2Marks**

(A) : $CuCO_3$ (B) :CuS (C) : $Cu(NO_3)_2$ D: $Cu(OH)_2$ **(0.25 marks for each correct identification)**

Reactions:

$\underset{A}{CuCO_3} + 2HCl \rightarrow CuCl_2 + H_2O + CO_2$

$CuCl_2 + H_2S \rightarrow \underset{B}{CuS} + 2\ HCl$

$3\ CuS + 8\ HNO_3 \rightarrow 3\ \underset{C}{Cu(NO_3)_2} + 2\ NO + 3\ S + 4\ H_2O$

$Cu(NO_3)_2 + 2\ NaOH \rightarrow \underset{D}{Cu(OH)_2} + 2\ NaNO_3$

(0.25 marks for each correctly balanced reaction)

Soluion Q.2

2.1) 1 lit/min for 15 mins 4 times = 60 lit

21% of oxygen = 100 % air

60 lit of oxygen = (60/21) X 100 = **286 lit** **(0.5M)**

(Deduct 0.25 marks if correct unit is not written)

2.2) For getting 60 lit of oxygen

$2H_2O \rightarrow 2H_2 + O_2$

22.4 lit of oxygen = 1 mol O_2 = 2 mol water = 36 g= 36 mL of water

60 lit of oxygen = (60 x 36)/22.4 = **96.43 mL of water** **(0.5M)**

(Deduct 0.25 marks if correct unit is not written)

2.3) $P_1V_1 = P_2V_2$

Available oxygen: 340 L, 13700 kPa

Required at 101.3 kPa

V_2 = (340 x 13700) / 101.3 = **45982 L** **(0.25 M)**

Required rate: 5 L /min

Hence 45982 L available for 9196 min

= 9196/60 = 153 hrs = 6.38 days

Fresh supply needed after 6 days **(0.25 M)**

2.4) **1.5M**

P V = nRT or n = PV/RT = 1 x 2840 / (0.0821 x 303)

n = 114 mol **(0.25M)**

n = 114 mole CO_2= 114 x 44 g CO_2

$CaCO_3 \rightarrow CaO + CO_2$
100g 44g

Required 114 x 44 = **5016g CO_2** **(0.5M)**
(Deduct 0.25 marks if correct unit is not written)
100 x 5016 /44 g $CaCO_3$

But limestone contains 80% $CaCO_3$

100 g limestone = 80 g $CaCO_3$

Hence limestone reqd= (100 x 100 x 5016) / (44 x 80)

= 14250g = **14.25 kg** **(0.25M)**

KE = (3/2) n R T = (3/2) x 114 x 8.314 x 303 joules

= 4.31×10^5 joules = **431kJ** **(0.5M)**

(Deduct 0.25 marks if correct unit is not written)

2.5) **1M**

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

6 moles O_2reqd per mole of glucose

6 X 22.4 lit of oxygen at STP is required for 1 mole of glucose = 134.4 lit of oxygen at STP **(0.25M)**

$P_1V_1 / T_1 = P_2V_2 / T_2$

V_2 = (1 x 134.4 x 303) / 273 = **149.17 L** at 30°C **(0.5M)**

6 moles of oxygen = **192 g** **(0.25 M)**

2.6) **1M**

Let the volume of the gases be a.

rate of diffusion of oxygen = a/3600

$\frac{\text{time taken for } CO_2}{3600} = \sqrt{(44/32)} = \sqrt{1.375} = 1.173$

Time taken for CO_2 = 3600 x 1.173 =**4223 s** **(0.5)**

(Deduct 0.25 marks if correct unit is not written)

Similarly, time taken for Cl_2 = 3600 √ (71/32) = 3600 x 1.489 = **5360.4 s** **(0.5M)**

IJSO 2021

BIOLOGY THEORY

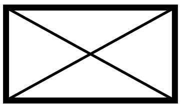
10 points

Solutions & Marking Scheme

General Instruction :

1. Only the answers marked or written in the answer sheet will be evaluated.

2. Instruction to mark a column with a cross (X) as an answer is to be marked as follows:



1. Theory I – Date palm (6.75 points)

1.1 (0.5 points)

Label	**Tissues**					
	1	2	3	4	5	6
A			X			
B				X		
C		X				
D	X					
E						X

0.1 point for each correct label

1.2 (0.25 point).

Tissue	**Yes**	**No**
1	X	
2	X	
3	X	
4	X	
5		X
6		X

0.25 point for all correct answer (no partial marking)
You loose 0.25 points if a wrong box is ticked

Ans: 1, 2, 3, 4 [since they are derived from ovary (2, 3, 4) and ovule (1), with no participation of the male parent]

1.3 (1.0 points)

Statement	Yes	No
1	X	
2		X
3	X	

1 point for all correct answers
0.5 point for 2 correct answers
0 point for 1 correct answer

Statement 1 – At stage 2 there is breakdown of starch and thus enzyme B is active.
Statement 2 – There is only basal level of sugar in stage 1, which is contributed entirely by sucrose, thus enzyme A is not active.
Statement 3- As there is basal level of sugar in stage 1, and higher levels at stage 2 and 3 with depleting levels of sucrose and starch, thus both enzymes are active.

1.4.1 (0.5 point)

Space for calculation The sucrose stock is of 400 mM i.e. 400 millimoles in 1000 ml or 400,000 µmoles in 1000 ml or 400 µmoles in 1ml As the volume of substrate added to reaction mixture is 0.2 ml, the amount of sucrose in the reaction mixture is 80 µmoles
Answer **Amount of sucrose =** **80 µmoles**

No partial marking.

1.4.2 (0.25 point) Concentration (mg/ml) of Glucose = **0.1**

0.1 OD corresponds to 0.1 mg/ml of glucose.

No partial mark

1.4.3 (0.75 point)

Space for calculation Mass of glucose is 180. 180 g in 1 liter corresponds to 1M solution. 180 mg in 1 ml corresponds to 1M solution. 0.1 mg in 1 ml corresponds to 0.1/180 = 0.000555555M = 555.555 µM 555.555 µM = 555.555 µ moles/liter Since the reaction volume was 1 ml, the amount of glucose formed is 0.556 µ moles.
Answer **Amount of Glucose = 0.556 µmoles**

Deduct 0.1 mark if not written to 3 decimal points.

No double penalty, marks to be given if calculation is correct based on the answer to 1.4.2

If the value of.0.4 mg/ml is used for this calculation, the answer will be 2.222 µ mols

1.4.4 (1.5 point)

Space for calculation **(write your final calculation in the answer sheet)** Given that: 1µ moles of glucose formed in 1 min corresponds to 1 U invertase. The present reaction was carried out for 30 minutes and 0.2 ml of the stock enzyme was taken for the reaction. 0.555 µ moles of glucose was formed after a reaction time of 30 min (No double penalty, value at 1.43 will be taken for further calculation) Thus in 1 minute 0.556/30 = 0.0185 µ moles of glucose was formed which is equal to 0.0185U invertase enzyme actvity 0.0185U invertase enzyme actvity was present in 0.2 ml of stock enzyme used in the reaction Therefore 1 ml of the stock enzyme would have (0.0185*1)/0.2 = 0.0927 = 0.093 U
Answer **Invertase activity = 0.093 U/ml**

Deduct 0.25 if not rounded off correctly to 3 decimal points.
If 0.973 µ mole is used for calculation the answer will be 0.162

1.5.1 (1 point)

Table 1.2 :

Step Number	**Purification step**	**Invertase activity (U)**	**Total protein (mg)**	**Specific activity of invertase**	**% recovery of invertase**
1	Crude extract	13,773	13,746	**1.002**	
2	Ammonium sulphate precipitation	12,469	8,234	**1.514**	**90.532**
3	Affinity chromatography	11,487	836	**13.740**	**83.402**
4	Anion exchange chromatography	11,156	567	**19.675**	**80.999**

0.1 point for each correct answer of specific activity
0.2 marks for each correct answer of % recovery

1.5.2 (0.5 point)

Steps	2	3	4
		X	

After affinity chromatography (step 3) there is 10 fold reduction in total protein with a minimal loss in enzyme activity.

1.5.3 (0.5 point)

Steps	2	3	4
	X		

The difference between the enzyme activity between a step and a preceding step. After step 2 the difference is (13773-12469 = 1304).

After step 3 the difference is (12469-11487 = 982).

2. Theory 2 – Bird populations (3.25 points)

2.1. (0.25 point)

S.No.	Relationship	Yes	No
1.	Co-dominance		X
2.	Incomplete dominance	X	
3.	Over dominance		X
4.	Dominant-recessive		X

No partial marking

2.2. (0.5 point)

Space for calculation

Total number of B^R alleles is 6400 + 1600 = 8000

8000 out of 10000 alleles = 0.8

Total number of B^W alleles is 400 + 1600 = 2000

2000 out of 10000 alleles = 0.2

Answers

2.2.1 Frequency of B^R = **0.8**

2.2.2 Frequency of B^W = **0.2**

Marking scheme: 0.5 point (for both correct answers no partial marking)

2.3. (0.50 points)

Statement	Yes	No
1	X	
2	X	
3	X	

Marking scheme: 0.50 points for all three correct answers
0.25 point for 2 correct answers
0 point for 1 correct answer

2.4. (1.5 point)

Space for calculation **(write your final calculation in the answer sheet)**
The reproductive population is 840. B^R= 336 + 252 = 588/840= 0.7 B^w= 252/840 = 0.3 Therefore red beak genotype $B^R\ B^R$ = 0.7 * 0.7 = 0.49 = 49 out of 100 and pink beak genotype $B^R\ B^W$ = 0.3 * 0.7 *2 = 0.42 = 42 out of 100
Answers **2.4.1.** Red beak = **49** **2.4.2.** Pink beak = **42**

Marking scheme: 1.5 points for both correct answers
0.5 point for one correct answer

2.5. (0.5 point)

S.No.	Condition	Yes	No
1.	Occurrence of mutations		X
2.	No gene flow	X	
3.	Random mating	X	
4.	Natural selection		X
5.	Small population size		X

Marking scheme: 0.1 point for each correct answer.