Formula One 🏎️

IJSO Theory Mock Test

Solutions

Question 1 — Physics behind Formula One (10.00 points)

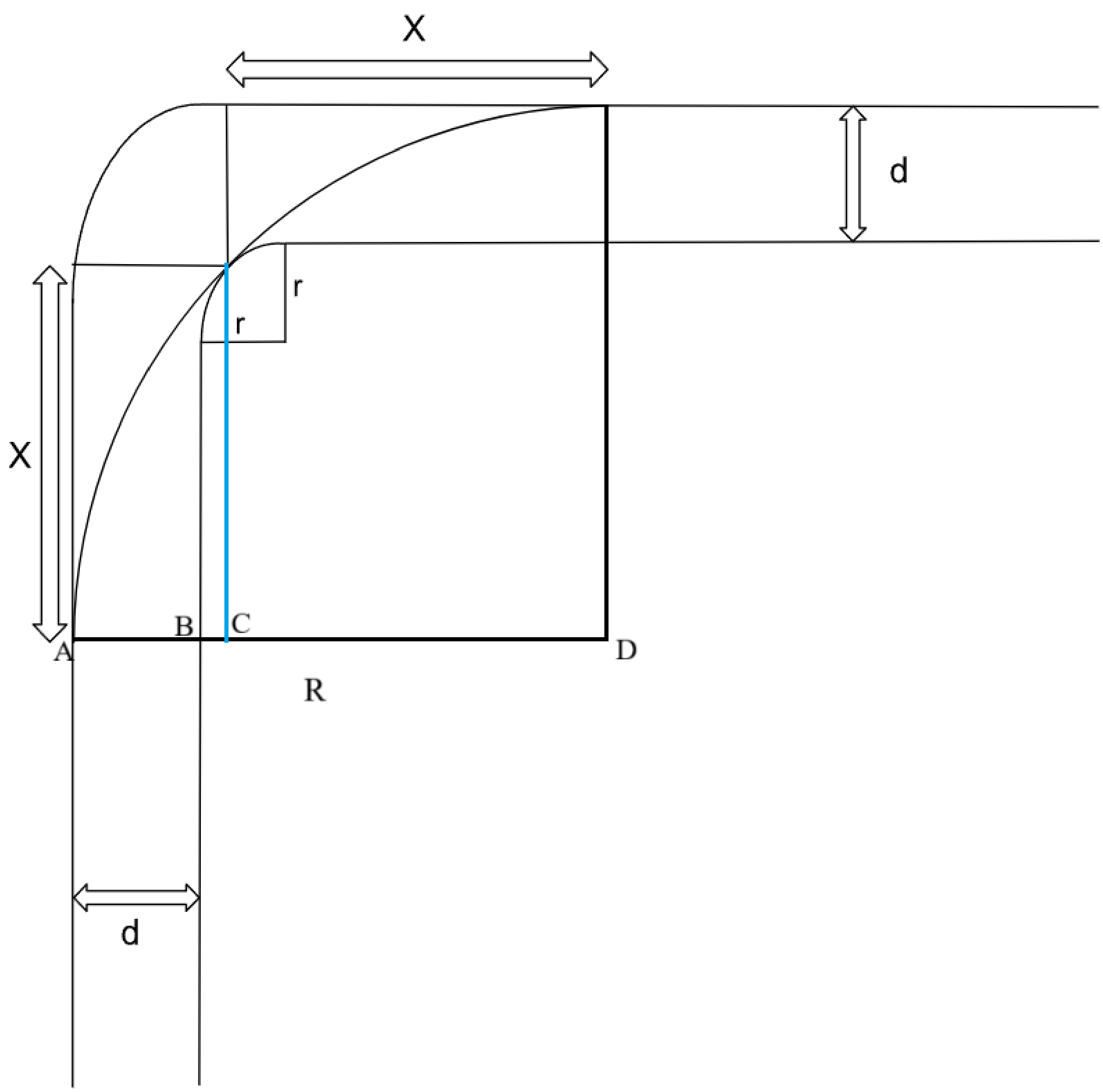
Part A – Corners (2.30 points)

A1. Find the radius of the racing line in terms of X, d, and r.

(1.00 points)

Calculation:

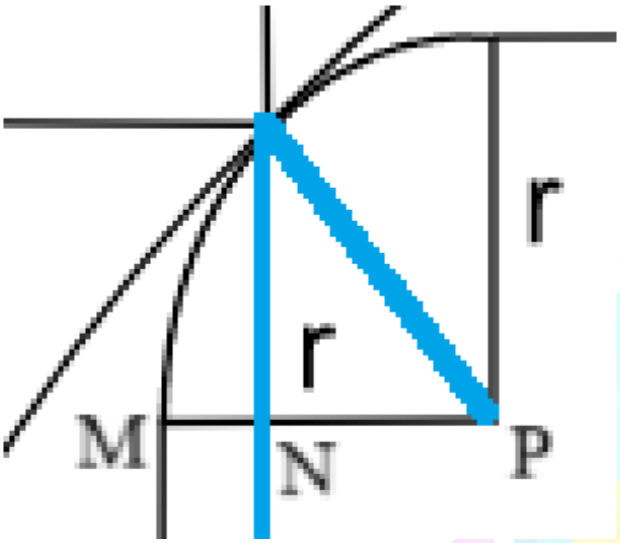
The radius that we want to find is R in the following drawing. The blue line is drawn to help with orientation:



We know that AB = d and CD = X. The problem is just about finding the small segment BC.

(0.40 points)

To find BC, let us zoom in on the circle with radius r:



Since the angle of the right triangle is 45°, we know $NP = r\cos\ 45^\circ\ = r\frac{\sqrt{2}}{2}$

(0.20 points)

MP is a radius of the circle, so MP = r, from which

$$MN = MP - NP = r\left(1 - \frac{\sqrt{2}}{2}\right)$$

(0.20 points)

But $BC = MN = r\left(1 - \frac{\sqrt{2}}{2}\right)$,

so $R = AB + BC + CD = X + D + r\left(1 - \frac{\sqrt{2}}{2}\right)$

(0.20 points)

$$R = X + D + r\left(1 - \frac{\sqrt{2}}{2}\right)$$

A2. Find the maximum velocity the car can have if the radius of the turn is 50m.

(0.50 points)

Calculation:

In the frame of reference attached to the car, a centrifugal force will act on it, radially, "pulling" the car from the circular path. This centrifugal force has to be balanced by the friction force.

(0.20 points)

$F_{cf} = f \leq \mu N = \mu M g$

This is equivalent to $M\frac{v^2}{R} \leq \mu M g \Rightarrow v^2 \leq \mu g R \Rightarrow v \leq \sqrt{\mu g R}$

(0.20 points)

Numerically we get $v \leq 28.87\frac{m}{s}$

(0.10 points)

An approach taking the limit case and using " = " instead of " ≤ " is just as correct and should be awarded full marks.

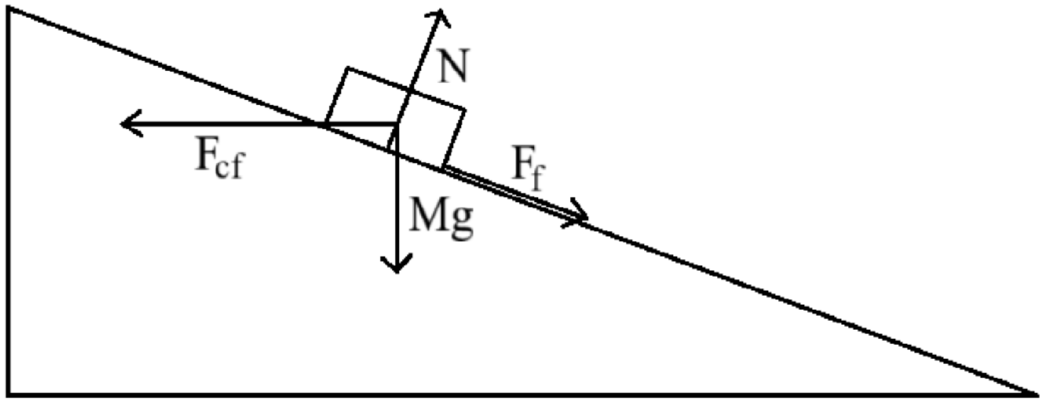
This problem can also be solved in the Earth's frame of reference, where the friction force must generate a centripetal acceleration.

$$v_{max} = 28.87\frac{m}{s}$$

A3. Find the maximum velocity at this corner.

(0.80 points)

Calculation:



The normal force is equal to the sum of the components of the weight and of the centrifugal force, which are perpendicular to the incline:

$$N = Mg\cos\theta + M\frac{v^2}{R}\sin\theta$$

(0.30 points)

That means the friction force is

$$F_f = \mu N = \mu Mg\cos\theta + \mu M\frac{v^2}{R}\sin\theta\,.$$

(0.10 points)

The equilibrium along the direction of the incline is:

$$\mu Mg\cos\theta + \mu M\frac{v^2}{R}\sin\theta + Mg\sin\theta = M\frac{v^2}{R}\cos\theta$$

(0.20 points)

Solving for the speed, we get:

$$v = \sqrt{Rg\frac{\sin \sin \theta \ + \mu \cos \cos \theta}{\cos \cos \theta \ - \mu \sin \sin \theta}} = 47.1\frac{m}{s}$$

(0.20 points)

Note: Deduct 0.20 points if friction force is taken upwards.

$$v_{max} = 47.1\frac{m}{s}$$

Part B – Downforce (1.00 points)

B1. Find the downforce generated in terms of v, α, A_{wing} and ρ_{air}.

(0.50 points)

Calculation:

The wings are thin enough to neglect any change in the term ρgh. We can now write Bernoulli's equation as:

$$P_{top} + \frac{1}{2}\ \rho_{air}\ v_{top}^2 = P_{bottom} + \frac{1}{2}\ \rho_{air}\ v_{bottom}^2$$

(0.25 points)

The pressure difference pushing down on the car is $\Delta P = P_{top} - P_{bottom} = \frac{1}{2}\rho_{air}v^2 \cdot 4\alpha = 2\rho_{air}v^2\alpha$

(0.15 points)

$$F_{down} = \Delta P \cdot A = 2A_{wing}\ \rho_{air}\ v^2\alpha$$

(0.10 points)

B2. Find the new maximum velocity for part A2.

(0.50 points)

Calculation:

Using the same reasoning as in part A2, but with $N = Mg + F_{down}$, we get:

$$M\frac{v^2}{R} \leq \mu Mg + 2\mu\, A_{wing}\, \rho_{air}\, v^2\alpha$$

(0.25 points)

Solving for v, we get:

$$v \leq \sqrt{\frac{\mu Mg}{\frac{M}{R} - 2\mu\, A_{wing}\, \rho_{air}\, \alpha}}$$

(0.15 points)

Numerically, $v \leq 29.21\,\frac{m}{s}$

(0.10 points)

$$v_{max} = 29.21\,\frac{m}{s}$$

Part C – Straights (1.00 points)

C1. Find the total resistive force against an F1 car travelling at a velocity v assuming no wind speed.

(0.40 points)

Calculation:

In part B2, we've shown $F_{down} = 2\, A_{wing}\, \rho_{air} v^2 \alpha$.

The total resistive force is:

$$F_{res} = F_{drag} + F_{friction} = \frac{1}{2}\, \rho_{air}\, C_D A v^2 + \mu\left(Mg + 2A_{wing}\, \rho_{air}\, v^2 \alpha\right) =$$
$$\left(\frac{1}{2} \rho_{air}\, C_D\, A_{frontal} + 2\mu\, A_{wing}\, \rho_{air}\, \alpha\right) v^2 + \mu Mg$$

(0.10 points for summing the two forces, 0.20 points for substituting the expressions, 0.10 points for correct calculations leading to the final form)

Deduct 0.20 points if the downforce is not taken into account.

C2. Write a cubic equation (but do not solve) about the maximum velocity of an F1 car in a straight.

(0.60 points)

Calculation:

At maximum speed, the force of the engine is equal to the total resistive force.

(0.10 points)

We can write $P = F \cdot v = \left(\frac{1}{2}\rho_{air}\, C_D\, A_{frontal} + 2\mu\, A_{wing}\, \rho_{air}\, \alpha\right) v^3 + \mu M g v$

(0.20 points, full marks even if result in C1 is wrong)

We can write the equation as:

$$\left(\frac{1}{2}\rho_{air}\, C_D\, A_{frontal} + 2\mu\, A_{wing}\, \rho_{air}\, \alpha\right) v^3 + \mu M g v - P = 0$$

(0.10 points)

Using the general form $ax^3 + bx^2 + cx + d = 0$, we have:

$a = \frac{1}{2}\rho_{air}\, C_D\, A_{frontal} + 2\mu\, A_{wing}\, \rho_{air}\, \alpha = 1.37\ \mathrm{kg\ m^{-1}}$

$b = 0$

$c = \mu M g = 15009\ \mathrm{N}$

$d = -P = -750000\ \mathrm{W}$

Marking scheme:

- a: 0.05 points for formula + 0.05 points for value
- b: 0.03 points
- c: 0.02 points for formula, 0.02 points for value
- d: 0.01 points for formula + 0.01 points for value + 0.01 points for "-" sign

Full marks are awarded if the result is wrong only due to errors in previous parts.

Note: The (real) solution of this equation is approximately $v \approx 42.8\,\frac{\mathrm{m}}{\mathrm{s}}$

Part D – Halo (1.50 points)

D1. Calculate the average impact force on the driver's head.

(0.40 points)

Calculation:

The kinetic force of the tire is $KE = \frac{1}{2}mv^2 = 9000J$

(0.10 points)

Using the work-energy theorem, the work done by the force to stop the tire is equal to this kinetic energy. This gives $F \cdot d = KE$, so $F = \frac{KE}{d}$

(0.20 points)

Numerically, $F = 9 \cdot 10^4$ N

(0.10 points)

$F = 9 \cdot 10^4$ N

D2. Is this force survivable, knowing that forces above $5 \cdot 10^4$ N are fatal.

√ Yes

☐ No

(0.10 points)

D3. Calculate the component of the spring's momentum along the driver's head direction before and after hitting the Halo.

(0.50 points)

Calculation:

Before hitting the halo, the entire momentum of the spring is towards the driver's head:

$$p_0 = mv = 400\ \mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}}$$

(0.20 points)

After hitting the halo, the momentum towards the driver's head now becomes:

$$p_1 = p_0 \cdot \cos\cos 30^\circ = 346.4\ \mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}}$$

(0.30 points)

$$p_1 = 346.4\ \mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}}$$

D4. Estimate by what percentage the Halo reduced the effective impulse on Massa's head.

(0.20 points)

Calculation:

The effective impulse is reduced by $f = \frac{\Delta p}{p_0} = \frac{p_0 - p_1}{p_0} = 1 - \cos\cos 30^\circ = 13.4\%$

Impulse = 13.4%

D5. Which of the following properties of the triangular shape of the halo help resist bending?

- √ The triangular shape distributes impact forces along multiple load paths.
- √ Triangles are inherently rigid, preventing shape deformation under torque.
- ☐ The shape allows the Halo to absorb energy through large elastic stretching.
- ☐ The triangle minimizes the material needed while maximizing strength.
- ☐ Triangles bend easily under off-center impacts, reducing peak forces on the driver.
- √ The triangular shape converts bending torque into compressive and tensile forces along its members.

(0.30 points)

Part E – Pit Stops (0.70 points)

E1. Find the force F_1 a mechanic needs to apply on the small piston to lift the car.

(0.30 points)

Calculation:

By Pascal's principle, the force F_2 that the larger piston will exert obeys $\frac{F_1}{A_1} = \frac{F_2}{A_2}$.

(0.20 points)

Using $F_2 = Mg$, we get $F_1 = \frac{A_1}{A_2} Mg = 176.58N$

(0.10 points)

F = 176.58 N

E2. Calculate how high the car rises.

(0.40 points)

Calculation:

When the mechanic applied F_1 on a distance d, he effectively pushed a volume $\Delta V = dA_1$ of liquid.

(0.15 points)

Since the fluid is incompressible, we can write $DA_2 = \Delta V = dA_1 \Longrightarrow D = \frac{A_1}{A_2} d$

(0.15 points)

Numerically, $D = 0.01m = 1cm$

(0.10 points)

D = 0.01 m

Part F – Light (1.00 points)

F1. Find the image distance v

(0.30 points)

Calculation:

Using the given equation, we easily see that $v = \frac{uf}{u-f}$

(0.20 points)

Numerically, $v \approx -0.30\text{m}$

(0.10 points)

v = 0.30 m

F2. What image width does the driver see?

(0.30 points)

Calculation:

The linear magnification is $M = \frac{v}{u} = 0.015$

(0.10 points)

$$M = \frac{l_{image}}{l_{object}} \Longrightarrow l_{image} = M \cdot l_{object}$$

(0.10 points)

Numerically, $l_{image} = 0.027\text{m} = 2.7\text{cm}$

(0.10 points)

l = 0.027 m

F3. Find the maximum visible distance x_{max}.

(0.40 points)

Calculation:

To find x_{max}, we set $I(x) = I_{th}$

(0.10 points)

Using the Beer-Lambert law, $\alpha x_{max} = \ln \ln \left(\frac{I_0}{I_{th}}\right)$, from which $x_{max} = \frac{1}{\alpha} \ln \ln \left(\frac{I_0}{I_{th}}\right)$

(0.20 points)

Numerically, $x_{max} = 220m$

(0.10 points)

$x_{max} = 220m$

Part G – Thermodynamics (1.00 points)

G1. Calculate the maximum theoretical efficiency of the engine.

(0.40 points)

Calculation:

We can calculate the efficiency using $\eta = 1 - \frac{T_{cold}}{T_{hot}} = 0.611 = 61.1\%$

$\eta = 61.1\%$

G2. Estimate the total energy emitted in one lap by the tire.

(0.60 points)

Calculation:

Using the Stefan-Boltzmann law, the radiating power of the tires is $P = \sigma\varepsilon A T^4 = 3675.7W$

(0.20 points)

Knowing that the duration of 10 laps is 15 minutes, the duration of a lap is $\Delta t = 1.5\ \text{min} = 90s$

(0.20 points)

The energy radiated in this time is $E = P\Delta t = 330.8kJ$

(0.20 points)

$E = 330.8kJ$

Part H – Sound (1.50 points)

H1. Find the frequency when the car is travelling towards the microphone, moving away from the microphone, and just when passing by the microphone.

(1.10 points)

Calculation:

This problem is just an application of the Doppler effect, when the observer is stationary. The formula is:

$$f' = f \cdot \frac{v_s}{v_s - v} \quad (1)$$

With v considered positive when the car is moving towards the microphone.

(0.30 points)

Converting to the same units, $v = \frac{324}{3.6} = 90\,\frac{m}{s}$

(0.20 points)

Using equation (1), when the car is moving towards the microphone:

$$f' = 600 \cdot \frac{343}{343 - 90} = 813.4\ \text{Hz}$$

(0.15 points)

When the car is moving away from the microphone:

$$f' = 600 \cdot \frac{343}{343 - (-90)} = 600 \cdot \frac{343}{343 + 90} = 475.3\ \text{Hz}$$

(0.15 points)

When the car is just passing by the microphone, it's neither getting away from it, nor getting closer to it – the component of the velocity along the car-microphone axis (the radial component) is zero. This means, $f' = f = 600$ Hz.

(0.30 points)

Deduct 0.30 points if signs are switched for the first two cases. Deduct 0.30 points if the source speed is put in the numerator. Deduct 0.60 points if both mistakes are made.

When the car is moving towards the microphone: $f' = 813.4$ Hz

When the car is moving away from the microphone: $f' = 475.3$ Hz

When the car is just passing by the microphone, $f' = 600.0$ Hz

H2. What is the sound intensity I at a distance of $r = 20\text{m}$ from the car?

(0.40 points)

Calculation:

At the distance r, the sound intensity is:

$$I = \frac{P}{4\pi r^2} = 2.39 \times 10^{-2} \frac{W}{m^2}$$

(0.20 points)

The loudness is $L = 10 \log \log \left(\frac{I}{I_0}\right) = 103.8 \text{ dB}$

(0.20 points)

$L = 103.8 \text{ dB}$

Extra Space for Problem 1:

Question 2 — Chemistry behind Formula One (10.00 points)

Part A – Fuel Combustion (3.50 points)

A1. Write balanced chemical equations for the combustion of all compounds when excess oxygen is present.

(0.50 points)

Calculation:

Compound	Balanced Combustion reaction
Octane	$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$
Cyclohexane	$C_6H_{12} + 9O_2 \rightarrow 6CO_2 + 6H_2O$
Toluene	$C_7H_8 + 9O_2 \rightarrow 7CO_2 + 4H_2O$
1-hexene	$C_6H_{12} + 9O_2 \rightarrow 6CO_2 + 6H_2O$
Ethanol	$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

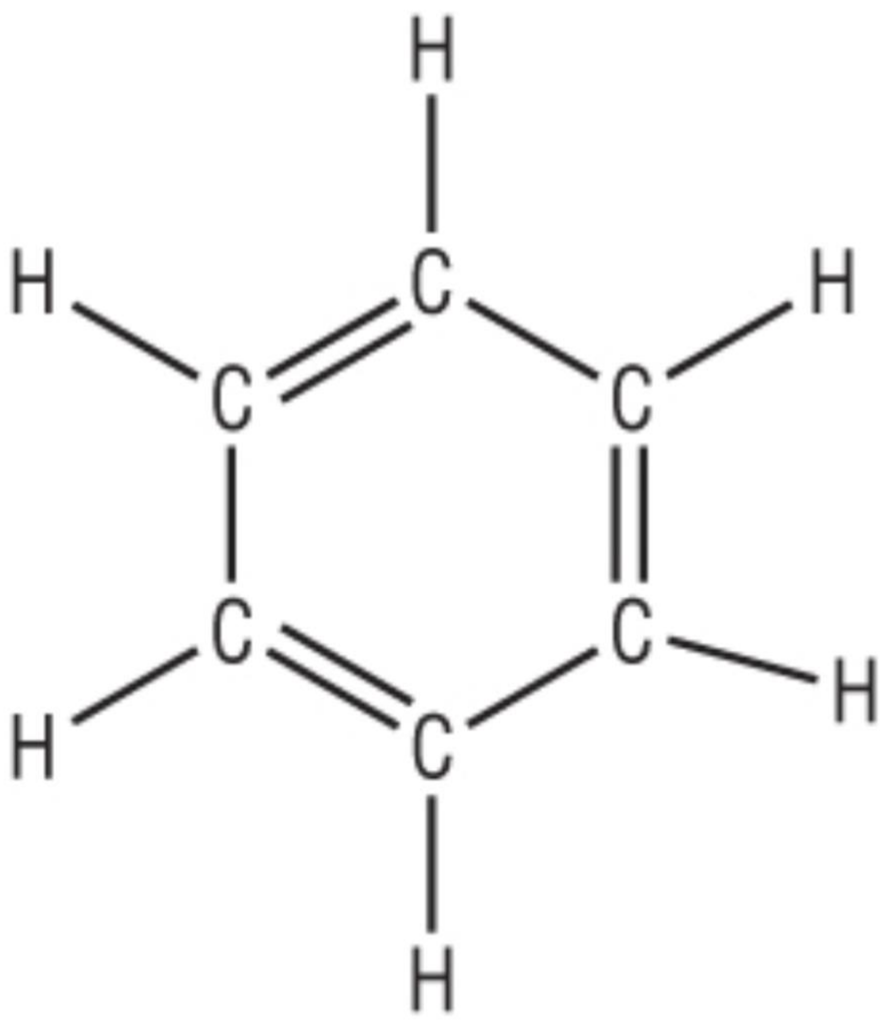
(0.10 x 5 = 0.50 points)

A2. Fill the Kekule structure of benzene with the hydrogen atoms required.

(0.25 points)

Calculation:

Carbon's electron structure is $1s^2\ 2s^2\ 2p^2$. This means it needs 4 electrons in order to become stable (to fill its second layer). Because all 6 carbon atoms already have 3 bonds in total (one double and one single), each carbon atom will have one hydrogen atom bonded to it, so the final structure must look like this:



(0.25 points)

A3. Find the weight of the fuel needed for 1 lap?

(1.50 points)

Calculation:

The efficiency is 55%, so the minimum energy that must be supplied is:

$$E_f = \frac{1.6 \cdot 10^8 \text{ J}}{0.55} = 2.91 \cdot 10^8 \text{ J}$$

The enthalpy combustion for each component per gram:

Octane: $\frac{5471 \text{ kJ/mol}}{114 \text{ g/mol}} = 48 \text{ kJ/g}$

Cyclohexane: $\frac{3920 \text{ kJ/mol}}{84 \text{ g/mol}} = 46.7 \text{ kJ/g}$

Toluene: $\frac{3910.3 \text{ kJ/mol}}{92 \text{ g/mol}} = 42.5 \text{ kJ/g}$

1-hexene: $\frac{4003 \text{ kJ/mol}}{84 \text{ g/mol}} = 47.65 \text{ kJ/g}$

Ethanol: $\frac{1366.8 \text{ kJ/mol}}{46 \text{ g/mol}} = 29.71 \text{ kJ/g}$

The weighed average energy density based on mass percentage:

$$0.45 \times 48 + 0.27 \times 46.67 + 0.135 \times 42.5 + 0.045 \times 47.65 + 0.1 \times 29.71$$

$$= 45.05 \text{ kJ/g} = 4.505 \cdot 10^4 \text{ J/g}$$

The mass of fuel needed:

$$m = \frac{2.91 \cdot 10^8 \text{ J}}{4.505 \cdot 10^4 \text{ J/g}} = 6457.3 \text{ g}$$

A4. Calculate the total amount of CO_2 produced in one lap.

(0.50 points)

Calculation:

From combustion reactions we find that:

1 mol Octane gives - 8 mol CO_2

1 mol Cyclohexane - 6 mol CO_2

1 mol Toluene - 7 mol CO_2

1 mol 1-hexene - 6 mol CO_2

1 mol Ethanol - 2 mol CO_2

So, CO_2 yield per gram of each fluid can be found as:

Octane - $\frac{8 \times 44}{114} = 3.09 \ \frac{g_{CO_2}}{g_{fuel}}$

with same method, cyclohexane - 3.14, toluene - 3.35,

1-hexene - 3.14, ethanol - 1.91 $\frac{g_{CO_2}}{g_{fuel}}$.

Using mass percentages, the total amount of CO_2 $0.45 \times 3.09 + 0.27 \times 3.14 + 0.135 \times 3.35 + 0.045 \times 3.14 + 0.1 \times 1.91$ is 3.023 g_{CO_2} per one gram of fluid.

So, total CO_2 pass for m = 6457.3 g is 19520.4 grams, or **19.52** kg.

m = 19.52 kg

A5. Find the mass percent composition of the exhaust gas mixture.

(0.75 points)

Calculation:

The average molar mass can be calculated from the ideal gas law as

$M = \frac{\rho RT}{P}$ where ρ = 1.3 g/l, P =1 atm, T = 298K and R = 0.082 $\frac{\text{atm} \cdot \text{L}}{\text{K} \cdot \text{mol}}$.

M is found to be 31.8 g/mol. Let the fraction of CO be x.

Then, $28x + 44(1 - x) = 31.8$ g, and x is 0.7625. Mass percentages:

$$\%_{CO} = \frac{7625 \times 28}{31.8} = 0.671 = 67.1\ \%$$

$$\%_{CO_2} = 100\ \% - \%_{CO} = 100\ \% - 67.1\ \% = 32.9\ \%$$

$\%_{CO} = 67.1\ \%$

$\%_{CO_2} = 32.9\ \%$

Part B – Paint (3.50 points)

B1. Indicate the chemical formulas of compounds A, B, C and D.

(0.80 points)

Calculation:

A = H_2SO_4

B = $Cu(OH)_2$

C = CuO

D = $CuCl_2$

(0.20 x 4 = 0.80 points)

B2. Write the balanced equation for the last reaction.

(0.75 points)

Calculation:

Unbalanced reaction:

$CuCl_2 + N_2H_4 + H_2O \rightarrow Cu_2O + HCl + N_2$

Cu goes from +2 oxidation state to +1 while N goes from -2 oxidation state to 0.

Half reactions:

$2\ Cu^{2+} + H_2O + 2e^- \rightarrow Cu_2O + 2H^+$

$N_2H_4 \rightarrow N_2 + 4H^+ + 4e^-$

(0.20 x 2 = 0.40 points)

Balancing those, we get

$4\ Cu^{2+} + 2\ H_2O + N_2H_4 \rightarrow Cu_2O + N_2 + 8\ H^+$

(0.20 points)

Balanced reaction:

$4\ CuCl_2 + 2\ H_2O + N_2H_4 \rightarrow 2\ Cu_2O + N_2 + 8\ HCl$

(0.15 points)

$4\ CuCl_2 + 2\ H_2O + N_2H_4 \rightarrow 2\ Cu_2O + N_2 + 8\ HCl$

B3. What are the smallest integer values for x and y?

(1.75 points)

Calculation:

Number of copper atoms in Azurite = Number of copper atoms in cuprous oxide

(0.30 points)

Hence, moles of Azurite $\times \frac{x+y}{2}$ = moles of cuprous oxide

(0.20 points)

Moles of Azurite $= \frac{m}{M} = \frac{50.00\ g}{x\ (63.55 + 12.01 + 3 \times 16.00) + y\ (63.55 + 2 \times (16.00 + 1.01)}$

$= \frac{50.0}{123.56\ x\ +\ 97.57\ y}$

(0.40 points)

Moles of cuprous oxide $= \frac{m}{M} = \frac{31.14\ g}{2 \times 63.55 + 16.00} = \frac{31.14}{143.1} = 0.2176\ mol$

(0.30 points)

$$0.2176 = \frac{50.0}{123.56\,x\ +\ 97.57\,y}\ \frac{x\ +\ y}{2}$$

$$26.89\,x + 21.23\,y = 25\,x + 25\,y$$

$$1.89\,x = 3.77\,y$$

$$x = 2y$$

(0.40 points)

Smallest possible integer values are x = 2 and y = 1.

(0.15 points)

X = 2

Y = 1

B4. Is the paint described a homogeneous or a heterogenous system?

(0.20 points)

The particles do not dissolve at the molecular level. The components are in different phases (solid azurite and liquid water.) Therefore, the given mixture is heterogeneous.

Part C – Cooling Fluids (1.50 points)

C1. Calculate the molality of the coolant

(0.30 points)

Calculation:

$$\text{Molality} = \frac{\text{Moles of Solute}}{\text{kg of Solvent}}$$

Assuming the total mass is 100g, ethylene mass = 40g, water mass = 60g

(0.15 points)

$$\text{Moles} = \frac{\text{m}}{\text{M}} = \frac{40\text{ g}}{2\times 12.01 + 6\times 1.01 + 2\times 16.00} = \frac{40}{62.08} = 0.644\text{ mol}$$

$$\text{Molality} = \frac{0.644\text{ mol}}{0.060\text{ kg}} = 10.73\text{ mol/kg}$$

(0.15 points)

C2. Using the approximate formula, find the temperature (Celsius) at which the coolant freezes.

(0.30 points)

Calculation:

$$\text{M} = 2\times 1.01 + 16.00 = 18.02\text{ g/mol} = 0.01802\text{ kg/mol}$$

(0.10 points)

$$\Delta T_f = \frac{RT_f^{\,2}Mm}{\Delta H} = \frac{8.314 \times (273)^2 \times 0.01802 \times 10.73}{6.01 \cdot 10^3} = 19.94\text{ K}$$

$$\text{New } T_f = 0\text{ °C} - 19.94\text{ °C} = -19.94\text{ °C}$$

(0.20 points)

C3. Find the exact temperature at which the coolant freezes, using the exact formula.

(0.30 points)

Calculation:

$$\Delta T_f = \frac{RT_f^2}{\Delta H} \ln(1 + Mm) = \frac{8.314 \times (273)^2}{6.01 \cdot 10^3} \ln(1 + 0.01802 \times 10.73)$$

$$= 18.22 \text{ K}$$

(0.20 points)

$$\text{New } T_f = 0\,^\circ\text{C} - 18.22\,^\circ\text{C} = -18.22\,^\circ\text{C}$$

(0.10 points)

C4. Is using the approximate formula justified?

(0.30 points)

√ Yes
○ No

$$\%\ \text{error} = \frac{|\text{Approximated value} - \text{Real value}|}{\text{Real value}} \times 100\% = 9.44\%$$

C5. It is known that the latent heat of fusion of ethylene glycol is L = 160 kJ/kg. Find the enthalpy of fusion for ethylene glycol.

(0.30 points)

Calculation:

$$\text{Molar mass} = 62.08 \text{ g/mol}$$

$$\text{Enthalpy of fusion} = 160 \text{ kJ/mol} \times 0.06208 \text{ kg/mol} = 9.93 \text{ kJ/mol}$$

(0.30 points)

Part D – Tires (1.50 points)

D1. Calculate the number of moles of nitrogen in the tire and the mass of nitrogen

(0.50 points)

Calculation:

Using the ideal gas $PV = nRT$,

$n = \frac{PV}{RT} = 4.065$ mol.

(0.30 points)

The mass of $N_2 = 28n = 114$ g.

(0.20 points)

$n = 4.065$ mol

mass $= 114$ g

D2. Find the new pressure P_2 inside the tyre (in atm).

(0.50 points)

Calculation:

The volume increases by 2%, so $V_2 = V_1 \times 1.02 = 51$ L.

(0.15 points)

T_2 is 360 K. Using the combined gas law for n=const,

$P_1V_1T_2 = P_2V_2T_1$, P_2 is found to be **2.35** atm.

(0.35 points)

$P_2 = 2.35$ atm

D3. Calculate the new pressure P_3. Give the pressure drop $P_2 - P_3$ in atm.

(0.50 points)

Calculation:

At constant V_2 and T_2, pressure is proportional to n:

(0.20 points)

$$P_2 - P_3 = 0.01 \times P_2 = 0.0235 \text{ atm}$$

(0.30 points)

$$P_2 - P_3 = 0.0235 \text{ atm}$$

Extra space for problem 2:

Question 3 — Biology behind Formula One (10.00 points)

Part A – Adrenaline (3.00 points)

A1. Tick the correct answers.

- √ Increases heart rate and blood pressure to enhance oxygen and nutrient delivery to skeletal muscle and the brain.
- o Dilates most arterioles in the skin and digestive tract while constricting those in skeletal muscle.
- √ Causes bronchial smooth muscle relaxation, increasing airflow to the lungs.
- √ Stimulates glycogenolysis and lipolysis, raising blood glucose and fatty acid levels.
- o Constricts pupils to reduce glare under bright track lights.

(0.75 points)

A2. Select the correct option with regards to what leads to this glucose increase:

A. Only gluconeogenesis, the process of creating glucose from precursors like lactate, glycerol, or amino acids leads to the increase in glucose levels.

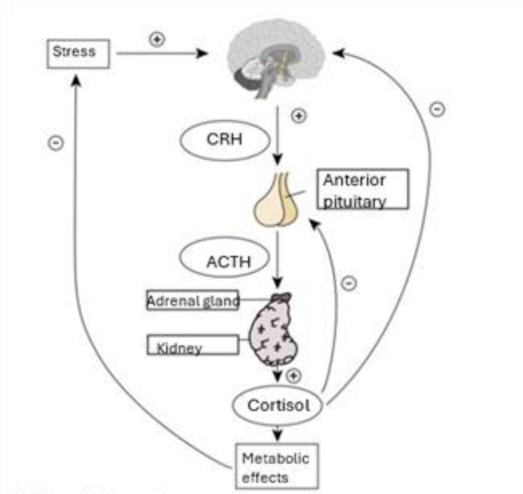
B. Only glycogenolysis, the process of converting glycogen (converting energy) into glucose (usable energy).

C. Gluconeogenesis and glycogenolysis BOTH occur to substantially increase glucose levels in the bloodstream.

D. Only glycogenesis, the process of converting glucose to glycogen and storing it in the liver.

(0.50 points)

A3. Fill in the blanks using the word bank below:



Word Bank:

Stress Hypothalamus Cortisol ACTH

Metabolic Effects Anterior Pituitary

Adrenal Gland CRH Kidney

(0.75 points)

A4. Which of the following options are incorrect with regards to how reflexes are triggered and executed?

A. Simple reflexes do not require direct brain involvement, most of them are mediated at the spinal cord - speeding up response time.

B. Adrenaline causes reflexes by increasing neuronal conduction velocity via production of more oligodendrocytes that produce myelin.

C. Heightened reflexes occur under adrenaline partially because of the simultaneous release of excitatory neurotransmitters increasing neural activity.

D. Reflex arcs involve a sensory receptor, sensory neuron, motor neuron, and possibly interneuron.

(1.00 points)

Part B – Studying the surrounding ecosystem (4.50 points)

B1. Calculate and select the correct approximate Shannon Index for this community:

A. 0.23
B. 0.36
C. 1.34
D. 2.00

(1.00 points)

Calculation:

First we need to find the proportion pn of each species (total = 100 individuals):

- Anas superciliosa: pn = $\frac{35}{100}$ = 0.35
- Gallinula tenebrosa: pn = $\frac{27}{100}$ = 0.27
- Cygnus atratus: pn = $\frac{15}{100}$ = 0.15
- Pteropus poliocephalus: pn = $\frac{23}{100}$ = 0.23

Now we need to calculate:

ln (pn)

- $\ln(0.35) \approx -1.05$
- $\ln(0.27) \approx -1.31$
- $\ln(0.15) \approx -1.90$
- $\ln(0.23) \approx -1.47$

Next, multiply:

$\ln(pn) \times pn$

- $0.35 \times (-1.05) = -0.37$
- $0.27 \times (-1.31) = -0.35$
- $0.15 \times (-1.90) = -0.29$
- $0.23 \times (-1.47) = -0.34$

We use the equation to find H:

$H = -\Sigma(pn \times \ln(pn)) = 1.34$

B2. Calculate the maximum possible diversity in the Albert Park community.

(0.40 points)

Calculation:

$H_{max} = \ln(S) = \ln(4) = 1.39$

$H_{max} = 1.39$

B3. What is the evenness index of this community?

(0.40 points)

Calculation:

Evenness index $= \frac{H}{Hmax} = \frac{1.34}{1.39} = 0.96$

Evenness index = 0.96

B4. a) Recalculate the Shannon index for the remaining three species.

(0.60 points)

Calculation:

We follow the same steps as in B1, just without the number of Cygnus atratus (15):

$$H_1 = -\Sigma(pn \times \ln(pn)) = 1.10$$

*Note: To find pn, don't forget to divide with 85 because the number of total species has also changed with the disappearance of the black swans :)

b) The Shannon index increased/remained the same/<u>decreased</u>

(0.20 points)

c) The maximum possible diversity increased/remained the same/<u>decreased</u>.

(0.20 points)

Calculation:

After the oil spill, the number of species decreases to 3, so

$$H_{max} = \ln(S) = \ln(3) = 1.10$$

B5. Does the diversity index increase, remain the same, or decrease?

(0.50 points)

Calculation:

Simillar to B1, we need to find the proportion pn of each species

- Anas superciliosa: pn = $\frac{35}{123}$ = 0.285
- Gallinula tenebrosa: pn = $\frac{27}{123}$ = 0.220
- Cygnus atratus: pn = $\frac{15}{123}$ = 0.122
- Pteropus poliocephalus: pn = $\frac{46}{123}$ = 0.374

Calulating $\ln(pn) \times pn$

- $0.285 \times \ln(0.285) = -0.358$
- $0.220 \times \ln(0.220) = -0.333$
- $0.122 \times \ln(0.122) = -0.257$
- $0.374 \times \ln(0.374) = -0.368$

$H = -\Sigma(pn \times \ln(pn)) = 1.316$

The diversity index increased, remained the same, or <u>decreased</u>.

B6. Using the original proportions, calculate the Simpson's Index

(0.75 points)

Calculation:

Finding $n_i\,(n_i - 1)$ for each species

- Anas superciliosa: $35 \times 34 = 1190$
- Gallinula tenebrosa: $27 \times 26 = 702$
- Cygnus atratus: $15 \times 14 = 210$
- Pteropus poliocephalus: $23 \times 22 = 506$

$\Sigma\, n_i\,(n_i - 1) = 1190 + 702 + 210 + 506 = 2608$

$$D = \frac{\Sigma\, n_i\,(n_i - 1)}{N\,(N - 1)} = \frac{2608}{100\,(99)} = 0.263$$

D = 0.263

B7.

a. Which index is more sensitive to rare species?

<u>Shannon index</u> / Simpson index

(0.15 points)

b. Which index is more influenced by the most abundant species?

Shannon index / <u>Simpson index</u>

(0.15 points)

c. Which index is less affected by the total number of individuals sampled (N) and therefore more stable when sample size changes?

Shannon index / <u>Simpson index</u>

(0.15 points)

Part C – The ecological effects of racing (2.50 points)

C1. Which hormone is most disrupted?

A. Thyroxine
B. Cortisol
C. Melatonin
D. Dopamine

(0.15 points)

C2. Which biological rhythm is most disturbed?

A. Annual biological rhythm
B. Daily circadian rhythm
C. Lunar tidal rhythm
D. Seasonal photoperiodism

(0.15 points)

C3. Which structure is blocked first, limiting gas exchange?

A. Xylem
B. Stomata
C. Guard cells
D. Root hairs

(0.15 points)

C4. This process of increasing concentration across trophic levels is called:

A. Eutrophication
B. Bioaccumulation
C. Biomagnification
D. Bioremediation

(0.15 points)

C5. State whether they are at risk by circling one of the options:

Yes, at risk / No, not at risk

(0.75 points)

Calculation:

Yes, they are at risk (60% = 0.6 $0.6 \times 9\frac{\mathrm{mg}}{\mathrm{L}} = 5.4\ \mathrm{mg/L}$

$9 - 5.4 = 3.6\ \mathrm{mg/L} < 4.0\ \mathrm{mg/L}$)

C6. Which immediate plant response is most likely?

A. Reduced leaf surface area
B. Increased growth from extra nutrients
C. Reduced root length
D. Chlorophyll breakdown

(0.25 points)

C7. In high doses, zinc interferes with enzyme function by binding to:

A. Active sites of proteins
B. Sulfhydryl groups of amino acids
C. Ribosomal RNA in cytoplasm
D. Phospholipid bilayers of cell membranes

(0.50 points)

C8. Ozone primarily damages plants by:

A. Causing oxidative stress in leaf cell membranes
B. Inhibiting stomatal opening and closing
C. Mutating nuclear DNA of guard cells
D. Blocking phloem transport of sugars

(0.25 points)

C9. What is the first biological response in the aquatic ecosystem?

A. Rapid growth of algae and cyanobacteria
B. Decline in dissolved oxygen
C. Fish mortality
D. Increase in decomposer activity

(0.15 points)

Extra space for problem 3: