Formula One 🏎️

IJSO Theory Mock Test

This is an IJSO mock test, a paper made to mimic the style and difficulty of IJSO questions. Its aim is to help students in preparing for the IJSO and IJSO like competitions.

The questions in this paper were made by the following members of our team (in alphabetical order):

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- Josephine Ankomah (Canada)
- Kotryna Mieldažytė (Lithuania)
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No.	Problem	Author	Marks
1	Physics behind Formula One	Thenura Wickramaratna Mubarak Aouda	10.00
2	Chemistry behind Formula One	Alex Jicu Thenura Wickramaratna	10.00
3	Biology behind Formula One	Kotryna Mieldažytė Josephine Ankomah	10.00

In solving the questions, you might need to use the following constants:

Constant	Notation	Value
Acceleration due to gravity	g	$9.8\ ms^{-2}$
Gravitational constant	G	$6.67 \cdot 10^{-11}\ m^3/\ kg \cdot s^2$
Planck's constant	h	$6.62 \cdot 10^{-34}\ J \cdot s$
Elementary charge	e	$1.6 \cdot 10^{-19}\ C$
Speed of light in vacuum	c	$3 \cdot 10^8\ ms^{-1}$
Density of water	ρ	$1000\ kg\ m^{-3}$
Stefan-Boltzmann constant	σ	$5.67 \cdot 10^{-8}\ \frac{W}{m^2K^4}$
Universal gas constant	R	$8.314\ J\ mol^{-1}\ K^{-1}$ $0.08206\ atm\ L\ mol^{-1}\ K^{-1}$
Avogadro's number	N_A	$6.022 \cdot 10^{23}\ mol^{-1}$
Faraday's constant	F	$96\ 500\ C/mol$
Pi	π	3.14
Electrical permittivity of free space	ε_0	$8.85 \cdot 10^{-12}\ F \cdot m^{-1}$
Magnetic permeability of free space	μ_0	$4\pi \cdot 10^{-7}\ H/m$
Mass of Earth		$5.97 \cdot 10^{24}\ kg$
Mass of Moon		$7.35 \cdot 10^{22}\ kg$
Mass of Sun		$1.99 \cdot 10^{30}\ kg$
Radius of Earth		$6.4 \cdot 10^6\ km$
Radius of Moon		$1.7 \cdot 10^6\ km$
Radius of Sun		$6.96 \cdot 10^8\ km$
Specific heat capacity of water	c_w	$4200\ J/kg \cdot °C$
Average molar mass of air	M	$28.9\ g/mol$

If any other value is provided in the problem, use the value provided, not the one in the table. You can also use the following conversion formulas:

$T\ (K) = t\ (°C) + 273$	$t\ (°F) = \frac{9}{5} t\ (°C) + 32$
$1bar = 1atm = 101\ 000Pa = 760mmHg$	$1u = 1Da = 1.66 \cdot 10^{-27} kg$
$1L = 10^{-3}\ m^3$	$1\ day = 24h$

If needed, you can use the periodic table given below:

(Use atomic masses rounded to two decimal places.)

IUPAC Periodic Table of the Elements

Key: atomic number / Symbol / name / abridged standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen 1.0080 ± 0.0002																	2 He helium 4.0026 ± 0.0001
3 Li lithium 6.94 ± 0.06	4 Be beryllium 9.0122 ± 0.0001											5 B boron 10.81 ± 0.02	6 C carbon 12.011 ± 0.002	7 N nitrogen 14.007 ± 0.001	8 O oxygen 15.999 ± 0.001	9 F fluorine 18.998 ± 0.001	10 Ne neon 20.180 ± 0.001
11 Na sodium 22.990 ± 0.001	12 Mg magnesium 24.305 ± 0.002											13 Al aluminium 26.982 ± 0.001	14 Si silicon 28.085 ± 0.001	15 P phosphorus 30.974 ± 0.001	16 S sulfur 32.06 ± 0.02	17 Cl chlorine 35.45 ± 0.01	18 Ar argon 39.95 ± 0.16
19 K potassium 39.098 ± 0.001	20 Ca calcium 40.078 ± 0.004	21 Sc scandium 44.956 ± 0.001	22 Ti titanium 47.867 ± 0.001	23 V vanadium 50.942 ± 0.001	24 Cr chromium 51.996 ± 0.001	25 Mn manganese 54.938 ± 0.001	26 Fe iron 55.845 ± 0.002	27 Co cobalt 58.933 ± 0.001	28 Ni nickel 58.693 ± 0.001	29 Cu copper 63.546 ± 0.003	30 Zn zinc 65.38 ± 0.02	31 Ga gallium 69.723 ± 0.001	32 Ge germanium 72.630 ± 0.008	33 As arsenic 74.922 ± 0.001	34 Se selenium 78.971 ± 0.008	35 Br bromine 79.904 ± 0.003	36 Kr krypton 83.798 ± 0.002
37 Rb rubidium 85.468 ± 0.001	38 Sr strontium 87.62 ± 0.01	39 Y yttrium 88.906 ± 0.001	40 Zr zirconium 91.224 ± 0.002	41 Nb niobium 92.906 ± 0.001	42 Mo molybdenum 95.95 ± 0.01	43 Tc technetium [97]	44 Ru ruthenium 101.07 ± 0.02	45 Rh rhodium 102.91 ± 0.01	46 Pd palladium 106.42 ± 0.01	47 Ag silver 107.87 ± 0.01	48 Cd cadmium 112.41 ± 0.01	49 In indium 114.82 ± 0.01	50 Sn tin 118.71 ± 0.01	51 Sb antimony 121.76 ± 0.01	52 Te tellurium 127.60 ± 0.03	53 I iodine 126.90 ± 0.01	54 Xe xenon 131.29 ± 0.01
55 Cs caesium 132.91 ± 0.01	56 Ba barium 137.33 ± 0.01	57-71 lanthanoids	72 Hf hafnium 178.49 ± 0.01	73 Ta tantalum 180.95 ± 0.01	74 W tungsten 183.84 ± 0.01	75 Re rhenium 186.21 ± 0.01	76 Os osmium 190.23 ± 0.03	77 Ir iridium 192.22 ± 0.01	78 Pt platinum 195.08 ± 0.02	79 Au gold 196.97 ± 0.01	80 Hg mercury 200.59 ± 0.01	81 Tl thallium 204.38 ± 0.01	82 Pb lead 207.2 ± 1.1	83 Bi bismuth 208.98 ± 0.01	84 Po polonium [209]	85 At astatine [210]	86 Rn radon [222]
87 Fr francium [223]	88 Ra radium [226]	89-103 actinoids	104 Rf rutherfordium [267]	105 Db dubnium [268]	106 Sg seaborgium [269]	107 Bh bohrium [270]	108 Hs hassium [269]	109 Mt meitnerium [277]	110 Ds darmstadtium [281]	111 Rg roentgenium [282]	112 Cn copernicium [285]	113 Nh nihonium [286]	114 Fl flerovium [290]	115 Mc moscovium [290]	116 Lv livermorium [293]	117 Ts tennessine [294]	118 Og oganesson [294]

57 La lanthanum 138.91 ± 0.01	58 Ce cerium 140.12 ± 0.01	59 Pr praseodymium 140.91 ± 0.01	60 Nd neodymium 144.24 ± 0.01	61 Pm promethium [145]	62 Sm samarium 150.36 ± 0.02	63 Eu europium 151.96 ± 0.01	64 Gd gadolinium 157.25 ± 0.03	65 Tb terbium 158.93 ± 0.01	66 Dy dysprosium 162.50 ± 0.01	67 Ho holmium 164.93 ± 0.01	68 Er erbium 167.26 ± 0.01	69 Tm thulium 168.93 ± 0.01	70 Yb ytterbium 173.05 ± 0.02	71 Lu lutetium 174.97 ± 0.01
89 Ac actinium [227]	90 Th thorium 232.04 ± 0.01	91 Pa protactinium 231.04 ± 0.01	92 U uranium 238.03 ± 0.01	93 Np neptunium [237]	94 Pu plutonium [244]	95 Am americium [243]	96 Cm curium [247]	97 Bk berkelium [247]	98 Cf californium [251]	99 Es einsteinium [252]	100 Fm fermium [257]	101 Md mendelevium [258]	102 No nobelium [259]	103 Lr lawrencium [262]

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For notes and updates to this table, see www.iupac.org. This version is dated 4 May 2022.

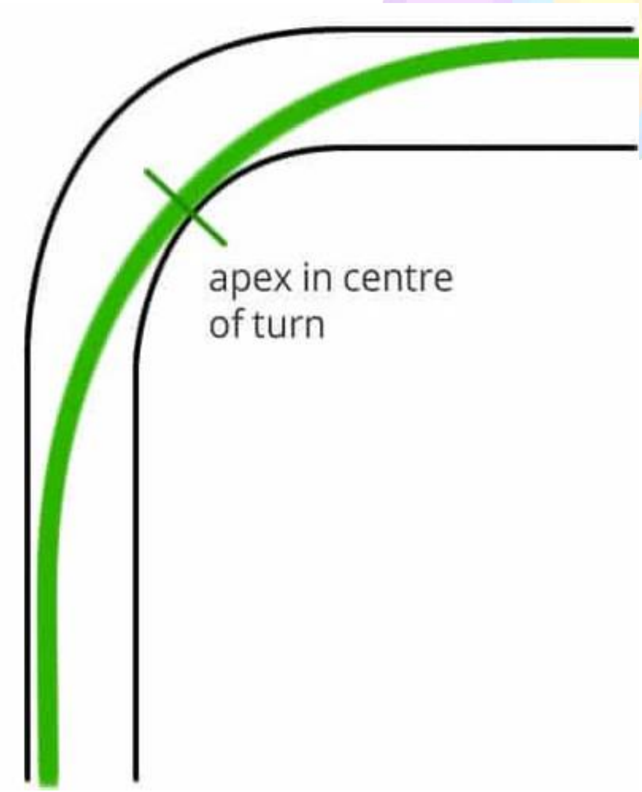
Question 1 — Physics behind Formula One (10.00 points)

Formula one is one of the toughest sports in the world. This problem will explore the physics concepts behind F1.

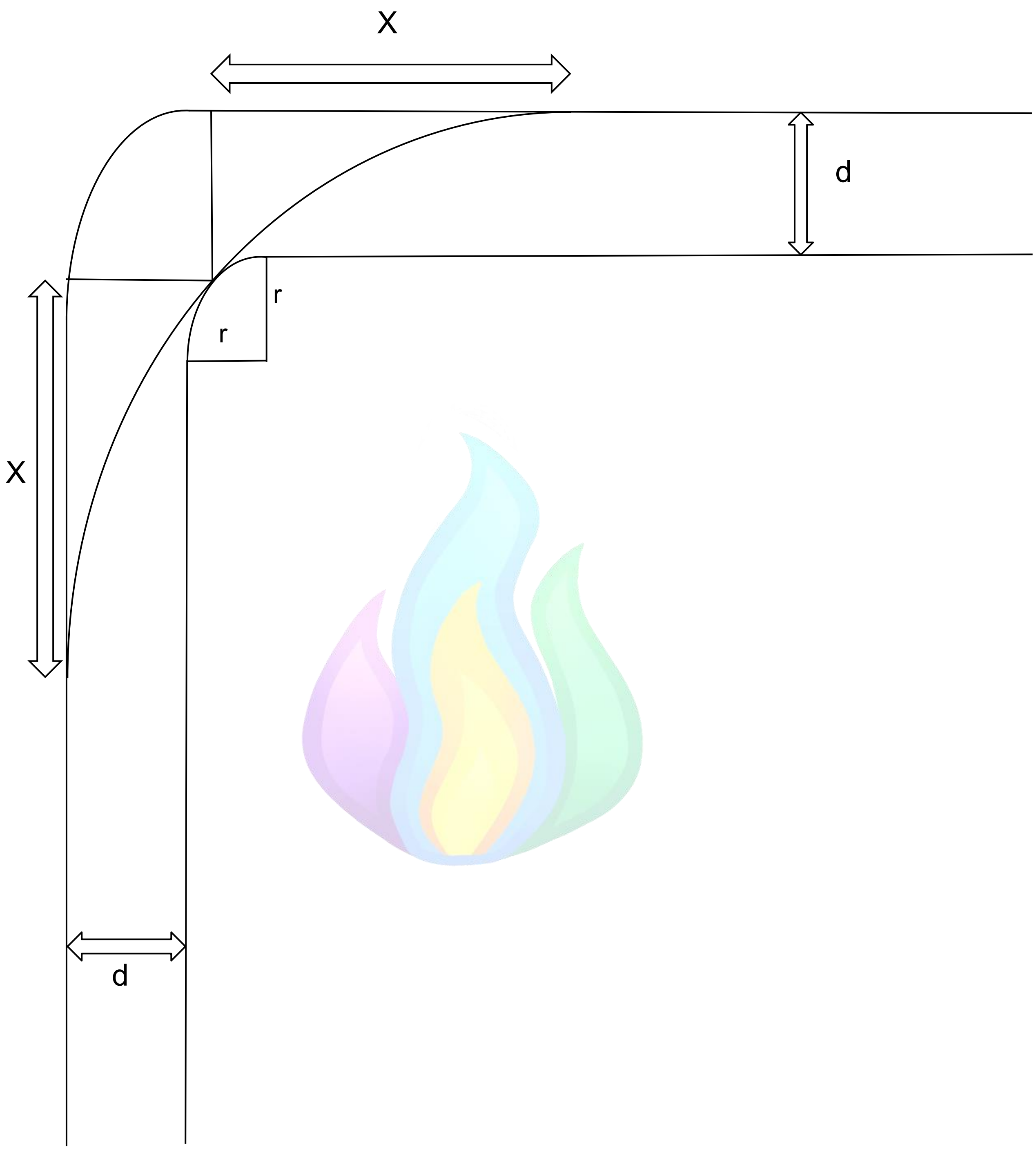
Part A – Corners (2.30 points)

Unlike a Bugatti cruising effortlessly on the autobahn, F1 cars face the challenge of high-speed cornering. This is why the fastest car in a straight line isn't necessarily the fastest over an entire lap. By regulation, an F1 car with the driver and equipment must weigh at least 798 kg. For this problem, we'll assume a base car mass of 800 kg (excluding fuel) plus 100 kg of fuel at the race start. For the remainder of this problem, take the mass of the car to be its base car mass and the mass of the fuel.

The apex of a turn means the midpoint of the turn of the inner road (look at the figure below)



A 90 degree turn in a circuit can be drawn as follows.



In the above diagram, X is the perpendicular distance from the apex to the turning point which is equal to the perpendicular distance from the apex to the end of the turn. d is the width of the road before and after the turn and r is the radius of the inner turn.

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

(1.00 point)

Assume the centripetal force is purely due to the frictional force and that the frictional coefficient is 1.7 between the tires and the ground.

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

(0.50 points)

A3. The famous turn 14, Arie Luyendykbocht, at Zandvoort circuit has a bank angle of 18°. A bank angle is the horizontal inclination of a track, especially in a corner, to help with turning. If the turn in A1 had a similar bank angle, find the maximum velocity at this corner.

(0.80 points)

Part B – Downforce (1.00 points)

In modern F1 cars, a front wing is mounted at the front of the car.

It functions like an inverted airplane wing. The velocity of wind above the wing, v_{top}, is higher than the velocity of the wind below the wing, v_{bottom}. This creates a pressure difference due to Bernoulli's equation. This generates downforce, improving the car's grip and cornering performance.

Bernoulli's equation states that incompressible fluids (air can be considered incompressible throughout this problem) obey the equation:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

where P is the fluid's pressure, ρ is its density, v is its flow velocity, h is the altitude relative to a reference point and g is the acceleration due to gravity.

For parts B and C, let's assume a simplified model where $v_{top} = v(1 + \alpha)$ and $v_{bottom} = v(1 - \alpha)$ where v = velocity of the car.

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

(0.50 points)

B2. Use $\rho_{air} = 1.2\ \text{kg/m}^3$, $A_{wing} = 1.0\ \text{m}^2$ and $\alpha = 0.10$. Find the new maximum velocity for part A2.

(0.50 points)

Part C – Straights (1.00 points)

When a car is in a straight, it still has to overcome the frictional forces and air resistance. Use the same data given in part B2.

The air drag force of the F1 cars can be written using the following equation

$$F = -\frac{1}{2}\rho C_D A_{frontal} v^2$$

where:

- ρ = air density (= 1.2 kg/m^3 at sea level)
- v = car's velocity relative to air
- C_d = drag coefficient (= 0.8 for this problem)
- $A_{frontal}$ = frontal area of the car (= 2.0 m^2 for this problem)

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

(0.40 points)

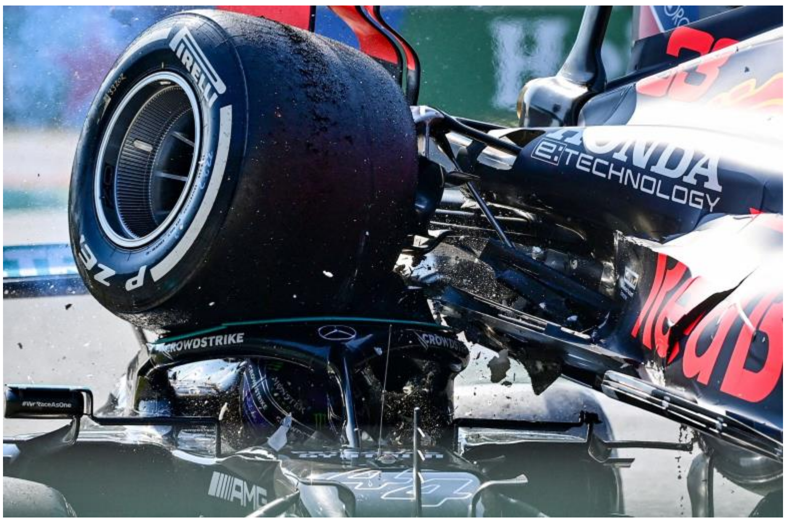
C2. The power of an F1 car is 750 kW. Write a cubic equation (but do not solve) about the maximum velocity of an F1 car in a straight. The cubic equation should be of the format $av^3 + bv^2 + cv + d = 0$, where a, b, c, and d are constants.

(0.60 points)

Part D – Halo (1.50 points)

The Halo is a titanium safety device mounted above the driver's cockpit in F1 cars. Its primary purpose is to protect the driver's head from flying debris, collisions, and other high-speed impacts. The Halo is designed to withstand large forces and torques, deflect objects away from the helmet, and absorb impact energy, greatly reducing the risk of serious injury. Its triangular geometry provides rigidity and resists bending.

One noticeable incident where the halo saved F1 drivers' lives is the 2021 Italian grand prix where the championship contender, Max Verstappen (now, a four-time world champion) ran over the car of Lewis Hamilton (reigning world champion back then and a 7-time world champion).



Suppose a tire of mass $\mathrm{m} = 20$ kg strikes a driver's helmet directly at a speed of $\mathrm{v} = 30\ \mathrm{m/s}$. Assume the helmet stops the tire over a very short distance of $\mathrm{d} = 1.0$ cm.

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

(0.40 points)

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

- ☐ Yes
- ☐ No

(0.10 points)

In the 2009 Hungarian Grand Prix, a suspension spring from the car ahead, weighing $\mathrm{m} = 4$ kg, detached and struck Felipe Massa's helmet at high speed ($\mathrm{v} = 100\ \mathrm{m/s}$). It is said that the spring's initial trajectory was perpendicular to the helmet. Assume the Halo was in place and deflected the spring at an angle of $30°$ from the original trajectory.

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

(0.50 points)

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

(0.20 points)

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)

F1 cars make pit stops where the pit crew quickly changes the tires. During a pit stop, a hydraulic jack is used to lift the car efficiently. Assume the jack has a small piston of area $A_1 = 0.01\ m^2$ connected via hydraulic fluid to a larger piston under the car of area $A_2 = 0.5\ m^2$.

E1. Using Pascal's principle, find the force F_1 a mechanic needs to apply on the small piston to lift the car. Neglect the weight of the jack itself.

(0.30 points)

E2. If the mechanic applies the force F_1 through a distance of 0.5 m, calculate how high the car rises. Assume the hydraulic fluid is incompressible and the pistons move vertically.

(0.40 points)

Part F – Light (1.00 points)

Just like normal cars, F1 cars also have rear view mirrors. A driver's right-side mirror is a spherical convex mirror with focal length $f = -0.30\ \mathrm{m}$. The following car is on the mirror's principal axis at distance $u = -20.0\ \mathrm{m}$ (real object in front; use standard sign convention). The mirror is $12\ \mathrm{cm}$ wide (horizontal aperture), and the driver's eye is $0.60\ \mathrm{m}$ from the mirror along the axis.

F1. Using $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, find the image distance v

(0.30 points)

F2. Find the linear magnification $M = \frac{v}{u}$. If the rear car is $1.8\ \mathrm{m}$ wide, what image width does the driver see?

(0.30 points)

In heavy spray, drivers often struggle with extremely limited visibility, making accidents far more likely. A dramatic example was the 1998 Belgian Grand Prix, where the opening lap saw one of the biggest pileups in Formula 1 history, involving over a dozen cars in a chain-reaction crash caused by the near-zero visibility.

During heavy spray, light's irradiance is attenuated according to the Beer–Lambert law.

$$I(x) = I_0 e^{-\alpha x}$$

where $I(x)$ is the irradiance (W/m^2) at the follower's eye when the axial separation is x (m), I_0 is the irradiance at a reference close distance, and α is the attenuation coefficient of the spray.

Take a reasonable heavy-spray attenuation coefficient $\alpha = 0.040\ m^{-1}$. Suppose the light produces $I_0 = 10.0\ W/m^2$ near the source, and the minimum irradiance required for the driver to reliably see the light is $I_{th} = 1.5 \times 10^{-3}\ W/m^2$.

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

(0.40 points)

Part G – Thermodynamics (1.00 points)

An F1 engine operates between a maximum cylinder temperature of 900 K and a cooling system temperature of 350 K. Assume the engine behaves as an ideal Carnot engine.

The efficiency of a Carnot engine is given by $\eta = 1 - \frac{T_{cold}}{T_{hot}}$

G1. Calculate the maximum theoretical efficiency of the engine.

(0.40 points)

After 10 laps (= 15 minutes), an F1 car's tire has a surface temperature of 700 K and a total radiating area of $0.3\ m^2$. Assume the tire behaves like a blackbody with emissivity $\epsilon = 0.9$.

The power radiated per unit area is given by the Stefan-Boltzmann law:

$$P = \sigma\epsilon A T^4$$

where σ is the Stefan-Boltzmann constant, ϵ is the emissivity of the tire surface, A is the area, and T is the absolute temperature.

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

(0.60 points)

Part H – Sound (1.50 points)

An F1 car produces a sound of frequency $f_s = 600$ Hz when stationary. The car is moving at $324\ km/h$ towards a trackside microphone. The speed of sound in air is $v_s = 343\ m/s$.

Consider a car moving in a straight line toward the microphone and eventually passing by the microphone very closely.

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)

At full throttle, an F1 car produces a sound power of about $P = 120\,W$. The sound spreads roughly spherically, so the intensity at a distance r is given by $I = \frac{P}{4\pi r^2}$

where I is the intensity (in W/m^2).

The loudness of sound is often measured in decibels (dB), using the formula

$$L = 10 \log_{10} \left(\frac{I}{I_0}\right)$$

where $I_0 = 10^{-12}\,W/m^2$ is the reference intensity (threshold of human hearing).

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

(0.40 points)

Question 2 — Chemistry behind Formula One (10.00 points)

Formula One cars are not only feats of engineering, but also of chemistry. Fuel composition, cooling fluids, tire materials, and even brake fluids rely on chemical principles. This problem explores the chemistry concepts behind F1.

Part A – Fuel Combustion (3.50 points)

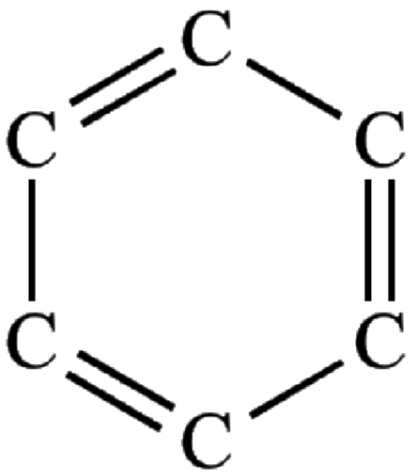
Since the 2022 season, F1 has adopted E10 fuel, a blend of 90% fossil-derived fuel and 10% ethanol. This transition aims to reduce carbon emissions and promote sustainability in motorsport. For the sake of this problem, let us assume that the composition of fuel is as given below.

Compound	Formula	Percentage (w/w)
Octane	C_8H_{18}	45.0 %
Cyclohexane	C_6H_{12}	27.0 %
Toluene	C_7H_8	13.5 %
1-hexene	C_6H_{12}	4.5 %
Ethanol	C_2H_5OH	10 %

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

(0.50 points)

One important component of the fuel is toluene, which is generally obtained from another organic hydrocarbon called benzene. Benzene has a complex structure, which was completely deciphered many years after its discovery. The first proposed structure of benzene (known as the Kekule structure) belongs to August Kekule. It was the first time a compound was thought to have a cyclic structure (and benzene does indeed have a cyclic structure). It is said that Kekule came up with it after dreaming about six monkeys in a circle, holding each other's tails. Below, only the carbon atoms and their bonding from the Kekule structure of benzene are given:



A2. Knowing that benzene only contains carbon and hydrogen and all carbon atoms are shown, fill the Kekule structure of benzene with the hydrogen atoms required.

(0.25 points)

The following table gives the enthalpy change of combustion for 1 mole of each of the compounds.

Compound	Enthalpy (kJ/mol)
Octane	-5471.0
Cyclohexane	-3920.0
Toluene	-3910.3
1-hexene	-4003.0
Ethanol	-1366.8

A3. To go one lap, a car needs 1.60×10^8 J of energy. If the efficiency of a F1 engine is 55%, find the weight of the fuel needed for 1 lap?

(1.50 points)

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

(0.50 points)

Until now, we've studied an ideal case in which enough oxygen is present such that combustion can take place completely. However, in reality, due to the high combustion rates and small available spaces, the combustion doesn't always take place in the presence of enough oxygen. Because of that, exhaust gases are mixtures, which contain mainly CO and CO_2. Let's assume the exhaust gas of a particular car has a density of 0.13g/L at atmospheric pressure and T = 298K.

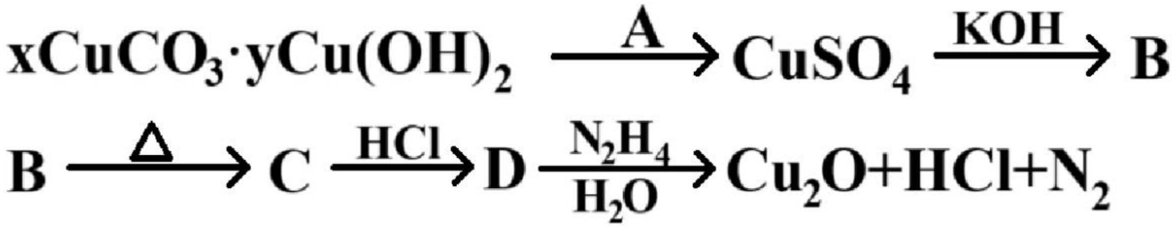
A5. Find the mass percent composition of the exhaust gas mixture.

(0.75 points)

Part B – Paint (3.50 points)

An F1 fan, specifically a fan of the Red Bull Racing team, wants to build a scaled down model of one of Red Bull's cars. To obtain the team's characteristic blue color, he decides to use an azurite-based paint.

Azurite is a copper mineral, frequently used as a blue pigment. It's a basic copper carbonate with the general formula $x\,CuCO_3 \cdot y\,Cu(OH)_2$. Azurite can participate in the following reaction sequence:



Not all products are shown, only the copper containing ones (except for the last reaction where all products have been given), and the substances indicated on the arrows are reactants. Δ refers to heating the substance. It is known that an aqueous solution of substance A has a pH of around 1.

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

(0.80 points)

B2. Write the balanced equation for the last reaction. Use a method of your choice to balance it.

(0.75 points)

B3. If 50.00g of azurite are used in the given reaction scheme, 31.14g of cuprous oxide Cu_2O are produced. Knowing that all reactions have a 100% yield, what are the smallest integer values for x and y?

(1.75 points)

Azurite is highly insoluble in water. To be able to use it as a paint, it can be suspended in water (very small particles of azurite "float" in the entire mass of the water and are evenly distributed). After the paint is applied, the water evaporates, and the blue azurite remains on the surface.

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

(0.20 points)

Part C – Cooling Fluids (1.50 points)

F1 cars use water + ethylene glycol mixtures in their cooling systems. Ethylene glycol ($C_2H_6O_2$) lowers the freezing point of water. We define the molality of a solution as the number of moles of solute per mass of solvent (usually measured in mol/kg). A typical coolant contains 40% (w/w) ethylene glycol and 60% water.

C1. Calculate the molality of the coolant

(0.30 points)

The presence of the solute (ethylene glycol), lowers the freezing point by a quantity which can be calculated using the following formula:

$$\Delta T_f = \frac{R T_f^{\,2}}{\Delta H} \ln(1 + Mm)$$

Where R is the ideal gas constant, T_f is the freezing point of pure water, M is the molar mass of water (SI unit), $\Delta H = 6.01 \times 10^3$ J/mol is the enthalpy of fusion for water and m is the molality of the solution.

For dilute solutions we can make the approximation Mm << 1, and using $\ln(1 + x) \approx x$, we get to the formula:

$$\Delta T_f = \frac{RT_f^2 M}{\Delta H} m$$

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

(0.30 points)

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

(0.30 points)

C4. Is using the approximate formula justified? We consider an approximation good enough if the error is less than 10%.

(0.30 points)

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)

Part D – Tires (1.50 points)

F1 tires are often inflated with nitrogen. A tire is filled to an initial pressure $P_1 = 2.00$ atm at temperature $T_1 = 300$ K. The tyre initial internal volume is $V_1 = 50.0$ L. Treat the gas as ideal.

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

(0.50 points)

During a race the tire heats up to $T_2 = 360$ K and, because of tyre expansion, the internal volume increases by 2.0 %.

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

(0.50 points)

D3. If 1.0% of the nitrogen leaks out during the race (all leakage occurs after heating, so temperature and volume remain T_2 and V_2), calculate the new pressure P_3. Give the pressure drop $P_2 - P_3$ in atm.

(0.50 points)

Question 3 — Biology behind Formula One (10.00 points)

When an F1 driver hits the gas pedal, braces for acceleration, makes risky but calculated decisions, and drives in pursuit of the win, several physiological processes make this possible. Adrenaline, also known as epinephrine, is a hormone released during a fight-or-flight response. An F1 driver may process this as excitement and energy, but the body sees it to be a very stressful situation. The acute focus required to control a car moving at such high speeds, coupled with the extreme G-forces, are more than enough to cause such stress. The G-forces experienced by F1 drivers can feel like more than 30 kg pushing on their neck. G-forces increase in curves and when decelerating. Upper body strength is especially important for F1 drivers.

Part A – Adrenaline (3.00 points)

During a Grand Prix, F1 racers experience a surge in adrenaline levels. The following questions will test your knowledge of the effects of adrenaline on the body and the processes it is involved in:

A1. Tick the correct answers.

- ☐ Increases heart rate and blood pressure to enhance oxygen and nutrient delivery to skeletal muscle and the brain.
- ☐ 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.
- ☐ Constricts pupils to reduce glare under bright track lights.

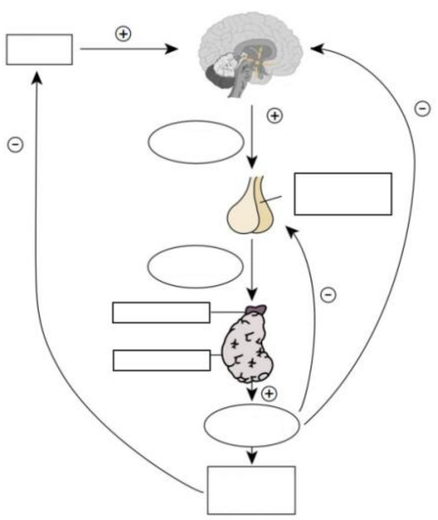
(0.75 points)

A2. During an adrenaline release, glucose levels also increase. 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. Adrenaline is synthesized and produced in various organs, 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. Another influence adrenaline has on the body is heightened reflexes. Reflexes are quick, involuntary responses to stimuli. 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)

A Grand Prix of Formula One is a world-class spectacle, which attracts thousands of spectators and requires extensive preparation. However, when races are organized in iconic locations, such as Albert Park in Melbourne, they can have a substantial effect on the surrounding species.

B1. The Shannon diversity index is a quantitative measure of the diversity of an ecosystem, taking into account species richness and distribution. This index, H′, is calculated as:

$$H = -\Sigma(p_n \times \ln(p_n))$$

p_n – the proportion a certain species in an ecosystem

Species counts near a track (100 individuals total):

- Anas superciliosa: 35
- Gallinula tenebrosa: 27
- Cygnus atratus: 15
- Pteropus poliocephalus: 23

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)

B2. The maximum possible diversity is calculated by the formula $H_{max} = \ln(S)$ where S is the number of species in the community. Calculate the maximum possible diversity in the Albert Park community.

(0.40 points)

B3. Evenness index is calculated by dividing the Shannon index by the maximum possible diversity. What is the evenness index of this community?

(0.40 points)

B4. Suppose an oil spill during preparation for the GP weekend wipes out Cygnus atratus (black swan).

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

b) Compare it to the original index. Underline the correct option below in the answer sheet

The Shannon index increased/remained the same/decreased.

c) How is the maximum possible diversity affected? Underline the correct option in the answer sheet

The maximum possible diversity increased/remained the same/decreased.

(1.00 points)

B5. During the weekend, extra artificial lighting attracts more Pteropus poliocephalus (fruit bats), doubling their number to 46 (total N = 123). Does the diversity index increase, remain the same, or decrease?

(0.50 points)

B6. Using the **original** proportions, calculate the Simpson's Index, also used to measure the diversity of a community (please note, that the formula given is used to calculate the diversity of a finite set of specimens):

$$D = \frac{\Sigma n_i(n_i - 1)}{N\,(N - 1)}$$

N – The number of individuals in a community

n_i – The number of individuals of species i in the community

(0.75 points)

B7. You have calculated both the Shannon index (B1) and the Simpson index (B6) for the Albert Park community.

a. Which index is more sensitive to rare species?

Shannon index / Simpson index

(0.15 points)

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

Shannon index / Simpson index

(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 / Simpson index

(0.15 points)

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

The bright lights, loud sounds, pollution, oil-run-off, and more are all accompanying the F1 experience. While exciting for spectators and drivers, nearby ecological communities are struggling to cope with the disturbances. The following questions will test your knowledge of the various ecological effects of racing on specific species.

C1. Artificial lighting at night races, such as at the Singapore Grand Prix, alters bat activity. Which hormone is most disrupted?

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

(0.15 points)

C2. Light pollution at night races can also disorient migratory birds. 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. Oil run-off coats aquatic plants. Which structure is blocked first, limiting gas exchange?

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

(0.15 points)

C4. Brake dust metals enter aquatic food chains. This process of increasing concentration across trophic levels is called:

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

(0.15 points)

C5. Before the race, a nearby lake holds 9.0 mg/L dissolved oxygen. An oil spill reduces oxygen by 60%. If fish require $\geq$ 4.0 mg/L, state whether they are at risk by circling one of the options:

Yes, at risk / No, not at risk

(0.75 points)

C6. Exhaust gases increase nitrate deposition around the track. 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. Brake dust raises zinc concentration in water. 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. Exhaust fumes raise ozone levels near the circuit. 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. Runoff from the circuit increases phosphate levels in Albert Park Lake. 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)

—End of the Paper—