

A Journey to Europa 🚀

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 past IJSO participants (in alphabetical order):

- Alex Jicu (Romania)
- Filip Kilibarda (Serbia)
- Jailson Godeiro (Brazil)
- Jathurshan Myuran (Sri Lanka)
- Mateo Sancho Dive (Costa Rica)
- Parthipan Kasiban (Sri Lanka)
- Thenura Dilruk (Sri Lanka) - Mock Test no. 2 Coordinator

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

Number	Constant	Notation	Value
1	Acceleration due to gravity (in Earth)	g	9.8
2	Gravitational constant	G	$6.67 \cdot 10^{-11}$
3	Planck's constant	h	$6.62 \cdot 10^{-34}$
4	Elementary charge	e	$1.60 \cdot 10^{-19}$
5	Speed of light in vacuum	c	$3.00 \cdot 10^8$
6	Density of water	ρ	1000
7	Stefan-Boltzmann constant	σ	$5.67 \cdot 10^{-8}$
8	Universal gas constant	R	8.314
9	Avogadro's number	N_A	$6.022 \cdot 10^{23}$
10	Faraday's constant	F	96500

All constants are provided in their respective SI units. If any other value is provided in a problem, use the value provided, not the one in the table.

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

(Use atomic masses rounded to two decimal places.)

IUPAC Periodic Table of the Elements

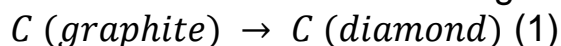
1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18									
1 H hydrogen 1.00794 ± 0.00002		3 Li lithium 6.94 ± 0.006		11 Na sodium 22.990 ± 0.002		19 K potassium 39.098 ± 0.001		27 Rb rubidium 85.468 ± 0.001		35 Sr strontium 87.62 ± 0.01		55 Cs caesium 132.91 ± 0.01		87 Fr francium [223]		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 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002	
4 Be beryllium 9.0122 ± 0.0001		12 Mg magnesium 24.305 ± 0.002		20 Ca calcium 40.078 ± 0.004		38 Y yttrium 88.906 ± 0.001		56 Ba barium 137.33 ± 0.01		88 Ra radium [226]		104 Rf rutherfordium [261]		105 Db dubnium [268]		23 Sc scandium 44.956 ± 0.001		24 Ti titanium 47.867 ± 0.001		25 Cr chromium 51.996 ± 0.001		26 Mn manganese 54.938 ± 0.001		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 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002	
5 B boron 10.81 ± 0.02		13 Al aluminum 26.982 ± 0.001		21 Sc scandium 44.956 ± 0.001		39 Zr zirconium 91.224 ± 0.002		57-71 Lanthanoids		89-103 Actinoids		106 Sg seaborgium [266]		107 Bh bohrium [270]		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 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002									
6 C carbon 12.011 ± 0.002		14 Si silicon 28.085 ± 0.001		22 Ti titanium 47.867 ± 0.001		40 Nb niobium 92.906 ± 0.001		72 Hf hafnium 178.49 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		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 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002											
7 N nitrogen 14.007 ± 0.001		15 P phosphorus 30.974 ± 0.001		23 V vanadium 50.942 ± 0.001		41 Mo molybdenum 95.94 ± 0.01		73 Ta tantalum 180.95 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		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 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002													
8 O oxygen 15.999 ± 0.001		16 S sulfur 32.06 ± 0.02		24 Cr chromium 51.996 ± 0.001		42 Ru ruthenium 101.07 ± 0.02		74 W tungsten 183.84 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		30 Zn zinc 65.38 ± 0.02		31 Ga gallium 69.723 ± 0.001		32 Ge germanium 72.630 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002															
9 F fluorine 18.998 ± 0.001		17 Cl chlorine 35.45 ± 0.01		25 Mn manganese 54.938 ± 0.001		43 Tc technetium [97]		75 Re rhenium 186.21 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		31 Ga gallium 69.723 ± 0.001		32 Ge germanium 72.630 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002																	
10 Ne neon 20.180 ± 0.001		18 Ar argon 39.95 ± 0.16		26 Fe iron 55.845 ± 0.002		44 Rh rhodium 102.91 ± 0.01		76 Os osmium 190.23 ± 0.03		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		32 Ge germanium 72.630 ± 0.006		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002																			
11 Na sodium 22.990 ± 0.002		19 K potassium 39.098 ± 0.001		27 Rb rubidium 85.468 ± 0.001		45 Pd palladium 106.42 ± 0.01		77 Ir iridium 192.22 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		33 As arsenic 74.922 ± 0.001		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002																					
12 Mg magnesium 24.305 ± 0.002		20 Ca calcium 40.078 ± 0.004		28 Ni nickel 58.693 ± 0.001		46 Pt platinum 195.08 ± 0.02		78 Pt platinum 195.08 ± 0.02		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		34 Se selenium 78.971 ± 0.006		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002																							
13 B boron 10.81 ± 0.02		21 Sc scandium 44.956 ± 0.001		29 Cu copper 63.546 ± 0.003		47 Ag silver 107.87 ± 0.01		79 Au gold 196.97 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		35 Br bromine 79.904 ± 0.003		36 Kr krypton 83.798 ± 0.002																									
14 C carbon 12.011 ± 0.002		32 Ge germanium 72.630 ± 0.006		40 Zr zirconium 91.224 ± 0.002		50 Sn tin 118.71 ± 0.01		80 Hg mercury 200.59 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		36 Kr krypton 83.798 ± 0.002		37 Tl thallium 204.38 ± 0.01		38 Pb lead 207.2 ± 1.1		39 Bi bismuth 208.98 ± 0.01		40 Po polonium [209]		41 At astatine [210]		42 Rn radon [222]		43 Fr francium [223]													
15 N nitrogen 14.007 ± 0.001		33 As arsenic 74.922 ± 0.001		41 Nb niobium 92.906 ± 0.001		51 Sb antimony 121.76 ± 0.01		81 Tl thallium 204.38 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		37 Tl thallium 204.38 ± 0.01		38 Pb lead 207.2 ± 1.1		39 Bi bismuth 208.98 ± 0.01		40 Po polonium [209]		41 At astatine [210]		42 Rn radon [222]		43 Fr francium [223]															
16 O oxygen 15.999 ± 0.001		34 Se selenium 78.971 ± 0.006		42 Mo molybdenum 95.94 ± 0.01		52 Te tellurium 127.6 ± 0.03		82 Pb lead 207.2 ± 0.5		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		38 Pb lead 207.2 ± 1.1		39 Bi bismuth 208.98 ± 0.01		40 Po polonium [209]		41 At astatine [210]		42 Rn radon [222]		43 Fr francium [223]																	
17 F fluorine 18.998 ± 0.001		35 Br bromine 79.904 ± 0.003		43 Tc technetium [97]		53 I iodine 126.90 ± 0.01		83 Bi bismuth 208.98 ± 0.01		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		39 Bi bismuth 208.98 ± 0.01		40 Po polonium [209]		41 At astatine [210]		42 Rn radon [222]		43 Fr francium [223]																			
18 Ar argon 39.95 ± 0.16		36 Kr krypton 83.798 ± 0.002		44 Ru ruthenium 101.07 ± 0.02		54 Xe xenon 131.29 ± 0.01		84 Po polonium [209]		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		40 Po polonium [209]		41 At astatine [210]		42 Rn radon [222]		43 Fr francium [223]																					
19 K potassium 39.098 ± 0.001		37 Rb rubidium 85.468 ± 0.001		45 Pd palladium 106.42 ± 0.01		55 Cs caesium 132.91 ± 0.01		85 At astatine [210]		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		41 At astatine [210]		42 Rn radon [222]		43 Fr francium [223]																							
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22 Ti titanium 47.867 ± 0.001		40 Nb niobium 92.906 ± 0.001		48 Cd cadmium 112.41 ± 0.01		58 Ce cerium 140.12 ± 0.01		87 Fr francium [223]		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		44 Ac actinium [227]		45 Th thorium 232.04 ± 0.04																									
23 V vanadium 50.942 ± 0.001		41 Mo molybdenum 95.94 ± 0.01		49 In indium 114.82 ± 0.01		59 Pr praseodymium 140.91 ± 0.01		88 Ra radium [226]		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		45 Th thorium 232.04 ± 0.04		46 Pa protactinium 231.04 ± 0.04																									
24 Cr chromium 51.996 ± 0.001		42 Ru ruthenium 101.07 ± 0.02		50 Sn tin 118.71 ± 0.01		60 Nd neodymium 144.24 ± 0.01		89-103 Actinoids		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		46 Pa protactinium 231.04 ± 0.04		47 U uranium 238.03 ± 0.04																									
25 Mn manganese 54.938 ± 0.001		43 Tc technetium [97]		51 Sb antimony 121.76 ± 0.01		61 Pm promethium [145]		90 Th thorium 232.04 ± 0.04		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		47 U uranium 238.03 ± 0.04		48 Ac actinium [227]																									
26 Fe iron 55.845 ± 0.002		44 Rh rhodium 102.91 ± 0.01		52 Te tellurium 127.6 ± 0.03		62 Sm samarium 150.36 ± 0.02		91 Pa protactinium 231.04 ± 0.04		106 Sg seaborgium [266]		107 Bh bohrium [270]		108 Hs hassium [277]		48 Ac actinium [227]																											

Problem 1 - Gaseous Planets (5.25 points)

As experienced astronomers, the crew discusses various planets in the Solar System during their voyage to Europa. One crew member recalls that on distant planets like Uranus and Neptune, diamonds can form naturally from methane under extreme pressure.

Part A : Diamond formation

The crew begins to discuss the chemistry behind such transformations. To understand how graphite can turn into diamond, they start crunching the numbers. The reaction is given below:



The enthalpies of formation are:

$$H_f(\text{graphite}) = 0 \text{ kJ/mol},$$

$$H_f(\text{diamond}) = 1.9 \text{ kJ/mol}$$

A1. Find the enthalpy change of reaction

(0.25 points)

A2. The ratio between the rate constants of reaction (1) at temperatures $T_1 = 3000\text{K}$ and $T_2 = 2500\text{K}$ is $r = 75$.

Using the Arrhenius equation:

$$k = Ae^{-\frac{E_a}{RT}}$$

Find the activation energy E_{a_1} of reaction (1)

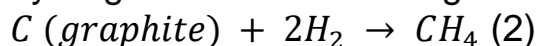
(1.00 points)

A3. Find the activation energy E_{a_2} of the inverse reaction

(0.25 points)

Part B : Decomposition of methane

Still fascinated by planetary chemistry, the crew begins discussing how methane — abundant in the atmospheres of gas giants — could form under extreme heat or pressure. They decide to analyze the thermodynamics of this transformation, starting from graphite and hydrogen. The reaction is given below:



The enthalpy of formation of methane $H_f(CH_4) = -74.2 \text{ kJ/mol}$.

B1. Calculate the enthalpy change of reaction (2)

(0.25 points)

B2. Which of the following will increase the rate of the forward reaction?

Tick the appropriate boxes

- ☐ Increase the temperature
- ☐ Decrease the temperature
- ☐ Increasing the pressure
- ☐ Decreasing the pressure
- ☐ Adding more methane
- ☐ Adding a catalyst

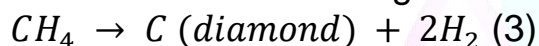
(0.50 points)

B3. If the equilibrium constant K for the reaction is 0.25 at 1000 K. At equilibrium, the concentration of methane is measured to be 0.10 mol/L. Find the equilibrium concentration of hydrogen gas $[H_2]$ in mol/L.

(0.75 points)

Part C : Reaction in the planets

To understand the reaction better, the scientists created a simplified model and carried out the reaction inside it. The diamonds are formed from methane according to the reaction given below.



C1. Calculate the enthalpy change of reaction (3)

(0.25 points)

D1. Using the Gibbs free energy formula that accounts for pressure:

$$\Delta G = \Delta H + P\Delta V$$

Calculate the Gibbs free energy change (ΔG) for this reaction at a pressure of 100 GPa.

(1.00 points)

D2. Based on your result in D1, state whether diamond formation is thermodynamically favorable under these conditions.

(0.25 points)

D3. Calculate the minimum temperature (in K) at which the reaction might become spontaneous if pressure is kept very high to cancel out the volume term,

(0.25 points)

D4. If the crew has a 250 g methane tank, calculate the total energy input (in kJ) required to completely convert all the methane into diamond under high-pressure conditions.

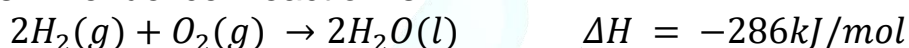
(0.50 points)

Problem 2 - Before the Journey in Europa (3.85 points)

Before embarking on a multi-day expedition across Europa's harsh icy terrain, Jicu and his international science team are preparing the HydroRover — their hydrogen-oxygen fuel-cell powered vehicle. They're also calibrating analytical equipment, checking thermal shielding, and finalizing energy budgets. At the mission base, Europa's surface temperature hovers around -160°C , and the atmosphere is nearly nonexistent, making pressure regulation, gas compression, and thermal management critical.

Part A: Preparing the Fuel Supply

The fuel cell operates using compressed hydrogen and oxygen stored in gas tanks. The fuel cell reaction is:



A1. If the rover is expected to consume $1 \cdot 10^6$ kJ of energy over the entire journey, how many grams of hydrogen gas do we need?

(0.60 points)

A2. If the hydrogen is stored at 300K and 200 atm, what is the minimum tank volume (in liters) needed to store all the hydrogen?

(0.65 points)

A3. Each crew member uses approximately 12000 kJ/day, and their bodies generate energy primarily through aerobic respiration of glucose. Assuming 100% of energy comes from glucose oxidation, calculate the extra tank volume (in litres) needed to store the oxygen needed for the entire trip if the trip lasts for 2 weeks.

(0.60 points)

Part B: Thermal Shielding & Material Selection

Europa's surface is extremely cold, and the rover electronics are insulated using a thin aluminum layer. The inner walls must maintain a temperature of 25°C.

B1. If the thermal conductivity of aluminum is 205 W/m·K, and the wall is 1.0 cm thick, what is the heat flux (W/m²) through the aluminum if one side is at 25°C and the other at -160°C?

(0.50 points)

B2. To reduce heat loss, Jicu's team wants to add a 2 cm thick Polyurethane foam layer (thermal conductivity = 0.030 W/m·K) inside the aluminum panel.

Assuming the same temperature difference, calculate the new total heat flux through the combined system (aluminum + foam), treating the layers as resistors in series.

(1.00 points)

B3. Although Europa receives little sunlight, the rover's solar panel casing absorbs some thermal radiation during surface daylight. Assume daylight lasts for 5 days throughout the trip.

Europa is located $7.80 \cdot 10^8$ km from the sun. The sun emits $3.8 \cdot 10^{26}$ W. The solar panel has an area of 0.5 m², and an absorptivity of 0.85.

Calculate the total power absorbed (in watts) by the solar panel due to sunlight throughout the whole trip.

(0.50 points)

Problem 3 - Discovery during the Journey (4.25 points)

Halfway through the rover expedition, Jicu's team stops near a cracked ridge on Europa's surface.

Part A: Chemical Analysis of the Reddish Sample

Their instruments detect strange reddish streaks across the ice — possibly organic salts or oxidized metal compounds from Europa's subsurface ocean erupting and freezing instantly.

The sample is suspected to contain a mixture of Fe^{2+} (from $FeSO_4$) and Mg^{2+} (from $MgCl_2$).

To analyze Fe^{2+} content, the sample is dissolved in water and treated with excess $NaOH$, forming a green precipitate of $Fe(OH)_2$.

A1. If 1.80 g of $Fe(OH)_2$ precipitate is formed, calculate the mass of $FeSO_4$ originally present.
(0.50 points)

A2. If 0.84 g of $MgCO_3$ is obtained, calculate the mass of $MgCl_2$ in the original sample.
(0.50 points)

A3. Based on your answers to A1 and A2, calculate the mass percent composition of $FeSO_4$ and $MgCl_2$ in the original 10.0 g sample.
(0.25 points)

Part B: The depth of the crater

During the exploration, they also discover a crater, their main goal is to discover its depth, their method will consist of dropping an object and measuring the time it takes for the sound produced to be detected. The most important parameters for the experiment will be the gravity of Europa and the speed of the sound.

B1. An experiment was done to determine the gravitational acceleration, it consisted of dropping an object from a known height (20m) and measuring the time it took to hit the ground (5.50s). What is the gravitational acceleration on Europa?

(0.50 points)

B2. The speed of sound through the air is given by the equation

$v = \sqrt{\frac{\gamma RT}{M}}$. Assume that $\gamma = 1.4$ Where M is the molar mass of the air, note that it is not the same speed of sound for the earth because Europa's atmosphere is different from earth's. Considering that the air is fully oxygen and it has a temperature of 120K, what is the speed of sound?

(0.75 points)

B3. An instrument was placed near the crater to detect the sound wave produced by the collision of the object with the bottom, it also has a chronometer, timing starts from the moment the object is dropped and ends when it detects a sound wave, it measured a time of 15.21 seconds, what is depth of the crater?

(1.50 points)

B4. The instrument detected a frequency of 5.84 kHz, what is the wavelength of that sound wave?

(0.25 points)

Problem 4 - Life in Europa (9.40 points)

While analyzing reddish streaks on Europa's surface, Jicu's rover detects a thermally active crevice releasing volatile compounds. Filament-like structures—thin and spiraling—emerge from the plume, responding to light and heat. Spectroscopy reveals organic molecules, iron, and sulfur, hinting at possible chemosynthetic life. A sampling probe is deployed for closer analysis.

Part A: Interpreting Signs of Life

The initial atmospheric data and the subsequent discovery of potential microbial structures raise fundamental questions about how scientists identify and characterize life, especially in extraterrestrial environments. The presence of certain gases and the very definition of life become critical.

A1. The atmospheric analysis of Europa revealed oxygen, water vapor, methane, and carbon dioxide. Identify two of these gases whose simultaneous presence in significant quantities in Europa's atmosphere (which lacks widespread surface photosynthesis) provides the strongest indication of potential ongoing biological or complex disequilibrium processes.

(0.50 points)

A2. Which of the following classes of macromolecules is LEAST exclusively formed by biological processes and can sometimes have abiotic origins in simpler forms, making it a slightly weaker primary indicator of current life on its own compared to others? *Tick the appropriate box.*

- ☐ Proteins with specific chirality (e.g., L-amino acids)
- ☐ Nucleic acids (like DNA or RNA)
- ☐ Polysaccharides (e.g., storage or structural polymers)
- ☐ Hydrocarbons or amino acids

(0.30 points)

A3. The simultaneous persistence of significant amounts of atmospheric oxygen (O_2) and methane (CH_4) on a moon like Europa is particularly interesting because these gases tend to react with each other, leading to their mutual destruction over geological timescales.

For both gases to remain present in noticeable quantities, their combined net production rate must be at least what in relation to their combined net destruction rate? *Tick the appropriate box.*

- ☐ Greater than
- ☐ Equal to
- ☐ Less than
- ☐ Has no effect

(0.30 points)

Part B: Life in the European Ocean Depths

The mission confirmed a subsurface ocean with hydrothermal vents—environments known to support life on Earth. In a 0.010 mL fluid sample, microscopic analysis showed an average of 250 rod-shaped structures per field of view, with 40 total fields. Each structure averaged 2.0 μm in length and 0.5 μm in diameter, approximated as cylinders for volume calculations.

B1. Based on the information provided:

a) Calculate the concentration of these structures in terms of structures per mL.

(0.40 points)

b) Calculate the approximate volume of a single average rod-shaped structure in cubic micrometers (μm^3).

(0.50 points)

c) If $1\mu\text{m}^3$ is equal to 10^{-15} Liters (L), what is the volume of a single structure in Liters?

(0.30 points)

B2. Life thriving near European hydrothermal vents would be extremophilic. Select all likely adaptations these microbes might possess, given their environment. *Tick the appropriate boxes*

- ☐ Cell membranes with specialized lipids to maintain fluidity under high pressure and low ambient temperatures (away from direct vent heat).
- ☐ Enzymes that function optimally at near-freezing temperatures (psychrophilic) for life further from vent openings.
- ☐ Efficient mechanisms to repair DNA damage, considering Jupiter's radiation environment and potential residual radiation.
- ☐ Strict dependence on sunlight for energy production.
- ☐ Ability to utilize inorganic chemical compounds as an energy source.
- ☐ Thick cell walls primarily composed of cellulose for structural support.

(0.60 points)

B3 (Fill-in-the-blank)

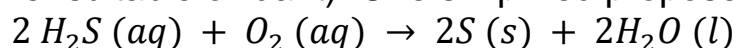
To maintain cell membrane fluidity in the generally cold deep-ocean of Europa (away from the immediate vent plume), the fatty acid chains in their phospholipid bilayer membrane would likely need a _____ (higher / lower) proportion of chemical bonds that introduce kinks into the fatty acid chains, such as _____ (double / triple / single) bonds.

(0.40 points)

Section C: Metabolism and the Chemistry of Alien Life

Understanding the energy pathways and fundamental chemical makeup of any potential European life is a primary goal. The presence of sulfur compounds near vents and the atmospheric gases provide clues.

The primary energy source for these European organisms is believed to be chemosynthesis. A key reaction hypothesized involves hydrogen sulfide (H_2S) from the vents and dissolved oxygen (O_2) from the European ocean water (or another suitable oxidant). One simplified proposed reaction is:



This reaction releases approximately 210 kJ of energy per mole of O_2 consumed.

C1. When considering the above case,

a) What is the general metabolic term for organisms that obtain energy by oxidizing inorganic substances, like the European microbes utilizing H_2S ?

(0.30 points)

b) In the given reaction, is H_2S acting as an oxidizing agent or a reducing agent?

(0.20 points)

C2. If the S production rate was identified to be 0.64 g for every 12 hours. How much energy (in kJ) does this colony generate per hour from this reaction?

(0.40 points)

C3. Scientists sometimes speculate about life forms based on silicon (Si) rather than carbon (C).

a) For each of the following statements, evaluate its accuracy and relevance to the potential of group 14 elements to form macromolecules:

- **✓ (Tick):** If the statement is scientifically correct AND directly relevant to the context.
- **0 (Zero):** If the statement is scientifically correct BUT its direct relevance to the context is minor, indirect, or it pertains to a different aspect not central to the discussion.
- **✗ (Cross):** If the statement is scientifically incorrect.

Statements	Evaluation
A. The tendency of Group 14 elements to form extended chains by bonding with themselves (catenation) is a key factor in their ability to create the framework of macromolecules.	
B. Due to possessing four valence electrons, elements in Group 14 typically engage in forming up to four covalent bonds with other atoms.	
C. Certain microorganisms, like diatoms, incorporate silicon into their cell walls in the form of silica, creating intricate protective structures.	
D. When forming the structural basis of large molecules, Group 14 elements achieve stability primarily through the formation of ionic bonds.	
E. The energy and stability of the bonds formed between identical atoms of a Group 14 element (e.g., C-C vs. Si-Si) are virtually the same, making them equally suitable for chain formation under all conditions.	

(0.50 points)

b) If a silicon-based organism existed on Europa and metabolized silicon-containing compounds, and assuming it required a liquid solvent, Which of the following hypothetical solvents might be considered, given that Silicon compounds often have different solubilities and reactivities than carbon compounds in water? *Tick the appropriate box.*

- ☐ Liquid methane (a non-polar solvent abundant in the outer solar system)
- ☐ Highly purified water (as it is a universal solvent)
- ☐ Molten sulfur (found in volcanic regions, could dissolve some silicon compounds)
- ☐ Gaseous hydrogen (as a lightweight atmospheric component)

(0.40 points)

c) Fill in the blanks

Biological catalysts and many cellular structures on Earth are primarily made of macromolecules called proteins. These are polymers of _____. For any molecule to effectively serve as the primary hereditary material (e.g., DNA on Earth), it must primarily be capable of accurate self-_____ and the stable _____ of genetic information. A major challenge for a hypothetical silicon-based life (compared to carbon-based life that produces gaseous CO_2 as a waste product) is that the primary oxide of silicon (silicon dioxide, SiO_2) is typically a _____ (physical state) at common planetary surface temperatures, making its metabolic cycling and disposal difficult.

(0.60 points)

Part D: Dynamics of European Microbial Life

Following the initial discoveries, the Thalassian Odyssey team focused on a specific, well-monitored hydrothermal vent, designated 'Vent Prime,' to study the population dynamics and genetic makeup of the dominant rod-shaped chemoautotrophs. Continuous monitoring and sample analysis provided insights into their growth patterns and genetic variation.

D1. A patch of microbes near Vent Prime was found to contain an initial population (N_0) of approximately 2.0×10^4 viable cells. These organisms reproduce by binary fission. Under the prevailing stable conditions with ample nutrients and energy from the vent, the population's mean generation time (the time it takes for the population to double) was determined to be 10 Earth hours.

a) Assuming continuous exponential growth, calculate the number of microbial cells expected after 40 Earth hours.
(0.70 points)

b) How many generations would have occurred during these 40 Earth hours?
(0.30 points)

D2. Further genetic analysis of 200 microbial individuals sampled from the Vent Prime population focused on a gene designated 'ThermoStab,' which influences cell membrane stability during temperature fluctuations which are common near the vent. Two alleles were identified: T_S (associated with superior membrane stability at higher temperatures) and T_F (associated with greater membrane flexibility at typical vent temperatures but less stability during heat bursts). The observed genotype counts from the sample were:

- $T_S T_S$: 60 individuals
- $T_S T_F$: 80 individuals
- $T_F T_F$: 60 individuals

a) Calculate the frequency of the T_S allele in this sampled population.
(0.60 points)

b) Calculate the frequency of the T_F allele in this sampled population.

(0.60 points)

c) If the Vent Prime microbial population were in Hardy-Weinberg equilibrium for the ThermoStab gene, what would be the expected frequency of the $T_F T_S$ (heterozygous) genotype? Show your calculation.

(0.60 points)

d) The observed frequency of the $T_S T_F$ genotype is different from the calculated frequency. Select all the plausible evolutionary factors, potentially related to the specific environmental conditions at Vent Prime (e.g., occasional bursts of very hot water, or the general nature of the vent environment) or the population's structure, that could explain the mismatch of heterozygote frequency when compared to Hardy-Weinberg expectations. *Tick the appropriate boxes.*

- ☐ Heterozygous genotype being more suited since they have both characters
- ☐ Lacking distinct specializations reduces an organism's fitness in environments that specifically favor any one of those specializations.
- ☐ The TS and TF alleles are codominant, and codominance inherently causes a disruption in the expected Hardy-Weinberg equilibrium for heterozygotes.
- ☐ The population at Vent Prime is small and relatively isolated, leading to a higher incidence of inbreeding
- ☐ Vent Prime may consist of distinct micro-habitats with differing selective pressures

(0.60 points)

e) If, intense and frequent heat bursts led to the T_S allele becoming the *only* allele for this gene present in the population at Vent Prime, what term describes the status of this allele in the population?

(0.30 points)

Problem 5 - Life sustaining Chemicals (2.25 points)

As the search for life continues on Europa, astrochemists along with astrobiologists look for life sustaining chemicals. As you know (hopefully), organic compounds are the base of life and carbon is the base of organic compounds. So it's not a surprise that the discovery of carbon dioxide on Europa was a huge discovery. As the NASA website says:

"Astronomers using data from NASA's James Webb Space Telescope have identified carbon dioxide in a specific region on the icy surface of Europa. Analysis indicates that this carbon likely originated in the subsurface ocean and was not delivered by meteorites or other external sources."

Two almost identical compounds in which the only difference is the isotope in which one (or more) atom(s) is (are) found are called isotopologues. For example, H_2O and D_2O are isotopologues.

A mass spectrometer is a machine that can separate particles with different mass (for example isotopologues of a molecule). It records the number of particles with each mass and calculates their respective frequencies (abundances). The result is a mass spectrum which shows a number of peaks corresponding to each molecular mass, each peak having a relative intensity assigned. The peak with the highest abundance is assigned a relative intensity of 100% and the others are assigned their relative intensities proportionally.

As soon as the crew gets on Europa, the crew's astrochemist collects a CO_2 sample from the site indicated by NASA and puts it in a mass spectrometer. The spectrum has three peaks, corresponding to molecular masses 44u, 46u, 48u.

A. If in the sample carbon is only found as one isotope and oxygen as two isotopes, find the mass numbers of the isotopes

(0.50 points)

B. Find the number of neutrons in each isotope

(0.25 points)

C. If the 44u peak has a 100% relative intensity, the 46u peak has a 22.22% relative intensity and the 48u peak has a 1.23% relative intensity:

Find the relative abundances of the three isotopologues

(0.25 points)

D. Consider the abundance of the lower mass O isotope is a_1 and that of the higher mass O isotope is a_2 , it can be shown that the abundances of the three isotopologues are equal to a_1^2 , a_2^2 , $2 \cdot a_1 \cdot a_2$

1. Attribute each abundance to its isotopologue

(0.50 points)

2. Calculate the abundances of the two isotopes in the sample from Europa.

(0.75 points)

Problem 6 - Jicu and His Rover (5.00 points)**Part A : Uncontrolled Descent**

Two days after the end of the trip, Jicu takes a small trip in his four wheeled rover and he finds a heat signature. Eager to investigate, he overrides the rover's cautious autopilot and initiates a manual descent down a 15° icy slope. Filip, back on the orbiter, watches nervously as the rover begins to accelerate faster than expected.

Jicu casually radios, "Relax, bro. I've got this. The rover has top-tier braking systems."

Filip responds, "Top-tier brakes mean nothing on ice, Jicu. This isn't a Go-Kart. There is negligible friction on this surface."

As the rover slides, the crew needs to do the math — can the braking motors save the descent, or is Europa claiming another hero? *(For this problem, use the value you found in part B1 in problem 3 for gravity.)*

A1. Assume that a Jicu weighs 70 kg and that the rover weighs 500kg. Find how much force is pulling the rover downhill with Jicu onboard.
(0.25 points)

A2. Assuming no brakes and no slipping, calculate the acceleration of the rover.
(0.25 points)

A3. Filip tells the AI to apply torque to hold speed steady. How much braking torque per wheel is needed to maintain constant speed (i.e., zero acceleration)? Assume the radius of a wheel to be 0.30m.
(0.50 points)

A4. If the rover slips and reaches a rough patch with μ_k of 0.15. Calculate the thermal energy generated by friction over 4m (along the slope) of uncontrolled slide in the rough patch.

(0.50 points)

Despite Filip's warnings, Jicu refuses to engage the brakes in time. The rover's wheels begin to slide, losing grip on the icy slope. The system logs a surge in frictional heating — but it's too late. With a dramatic spin, the rover skids sideways and flips into a European snowbank, landing at an awkward tilt.

Filip sighs and mutters into the comms: "Well... at least now you've got a better view of the ice crystals."

After the dramatic tumble, sensors indicate the rover impacted the icy surface at a horizontal velocity of 3.2 m/s before flipping. The collision time with the snowbank is estimated to be 0.8 seconds. Assume the impact was perfectly inelastic and the rover came to a stop.

A5. Estimate the energy dissipated during the impact (in kJ)

(0.50 points)

A6. If the center of mass of the rover was 1.2 m above the ground at the moment of flip, calculate the rotational kinetic energy lost assuming it pivoted onto its side during the crash. (Assume all mass is concentrated at the center.)

(0.50 points)

Part B: Aftermath of the Crash

After the rover finally comes to a stop, Jicu and Filip begin assessing the situation. The rover's systems are offline, but there's still hope to salvage the mission. They need to determine whether the rover's structural integrity has been compromised enough to require a full evacuation, or if they can repair the damage and continue their exploration of Europa's surface.

B1. The rover has a metal frame that's designed to withstand impacts, but the crash was severe. The frame has a compressive yield strength of $2.5 \times 10^8 \text{ N/m}^2$, and it's made of a lightweight alloy. If the impact force from the crash is distributed evenly across the contact area of the rover's bottom (0.5 m^2), calculate whether the frame would have deformed plastically or remained intact.

(1.00 points)

B2. Post-impact, the rover starts emitting low-frequency vibrations due to its sudden stop. Filip uses the rover's onboard sensors to monitor these vibrations. Assume the oscillation frequency is found to be 4 Hz and that the effective mass of the rover's top section is 200 kg. Calculate the spring constant of the rover's suspension system based on the observed vibrations.

(0.50 points)

B3. Now that the rover is stabilized, Jicu decides to perform a check on the navigation system. The slope at the crash site is roughly 12° . Assume the rover is now at rest and that the frictional force between the tires and the icy surface in the new position is 0.15 times the normal force. How much force is required to overcome this static friction if Jicu attempts to move the rover uphill at a constant speed?

(0.75 points)

B4. With the rover's power reserves running low, Jicu and Filip must decide whether to use the last bit of energy to communicate the situation back to the base or use it for a self-repair operation. The rover's battery stores a total of 1200 J of energy, and its power consumption is rated at 50 W for communication and 80 W for self-repair. If they need to send a distress signal, how much time (in minutes) will they have before the battery runs out?

(0.25 points)

— End of the Paper —