Ocean exploration and studies of water

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) – Mock Test no. 1 Coordinator
- Filip Kilibarda (Serbia)
- Fillios Memtsoudis (Cyprus)
- Jathurshan Myuran (Sri Lanka)
- Parthipan Kasiban (Sri Lanka)
- Thenura Wickramaratna (Sri Lanka)

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

Number	Constant	Notation	Value
1	Acceleration due to gravity	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	$1.6 \cdot 10^{-19}$
5	Speed of light in vacuum	c	$3 \cdot 10^{8}$
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	96 500
11	Pi	π	3.14
12	Electrical permittivity of free space	ε_0	$8.85 \cdot 10^{-12}$
13	Magnetic permeability of free space	μ_0	$4\pi \cdot 10^{-7}$
14	Mass of Earth		$5.97 \cdot 10^{24}$
15	Mass of Moon		$7.35 \cdot 10^{22}$
16	Mass of Sun		$1.99 \cdot 10^{30}$
17	Radius of Earth		$6.4 \cdot 10^{6}$
18	Radius of Moon		$1.7 \cdot 10^{6}$
19	Radius of Sun		$6.96 \cdot 10^{8}$
20	Specific heat capacity of water	c_w	4200
21	Average molar mass of air	M	28.9

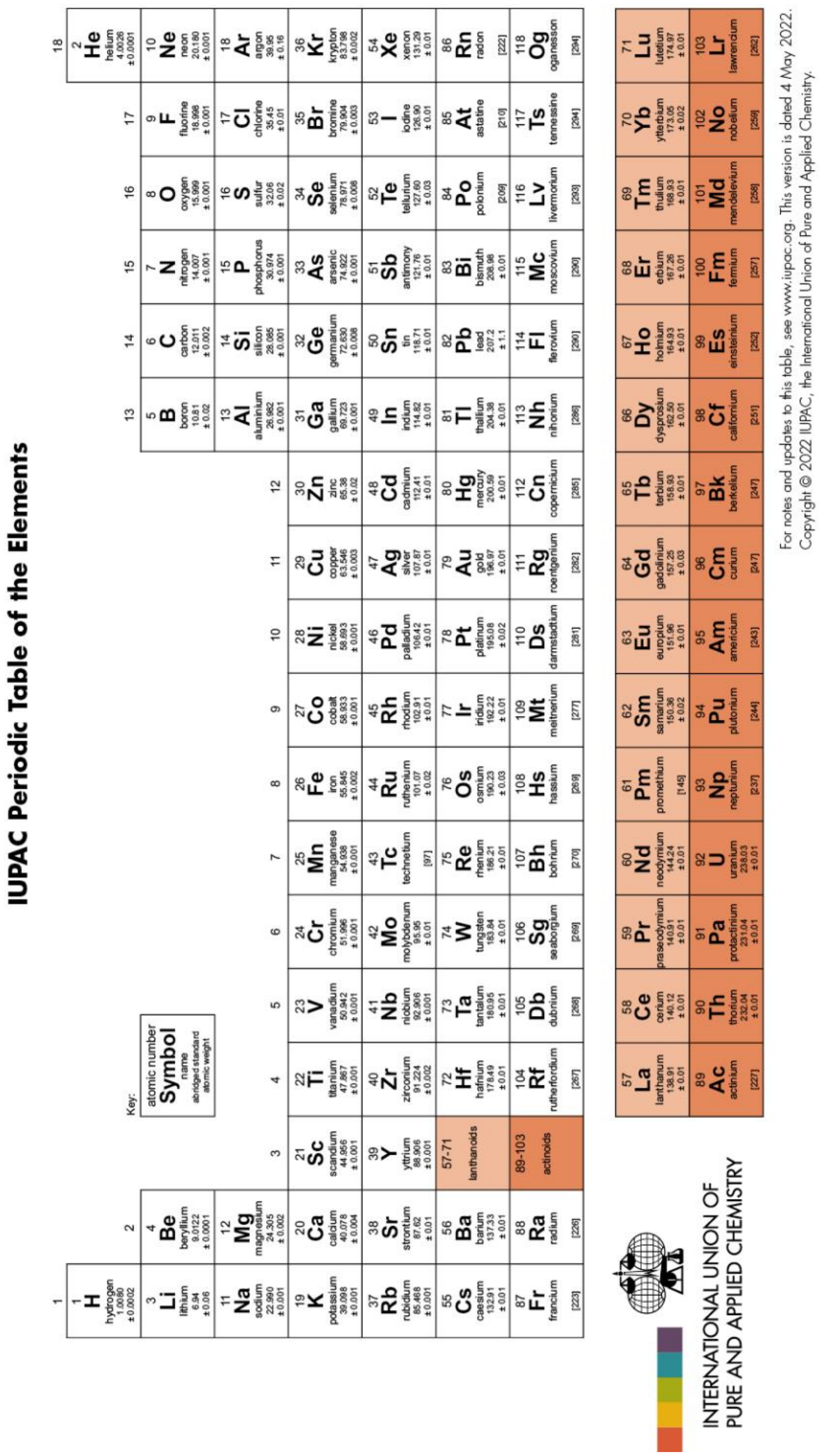
All constants are given in their respective SI units. If any other value is provided in the problem, use the value provided, not the one in the table.

You can also use the following conversion formulas:

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

You should give all numerical answers to three significant figures.

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



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.

Use atomic masses rounded to two decimal places.

Problem 1 – Little Timmy again (3.50 points)

Remember little Timmy from the MCQ test? He was the boy stranded on an island.

Specifically, little Timmy was stranded on a desert island, surrounded by the endless ocean. He knew that to survive he needed fresh water supply. Luckily Timmy was a smart kid and knew electrochemistry and electrolysis. He found a lithium-ion car battery with a voltage of 12V and an internal resistance of 0.5Ω. He designed a desalination unit that uses an electrochemical cell that extracts sodium and chloride ions from seawater by applying an electric current. The cell has a variable resistance R_{cell} that depending on its design and dimensions Timmy can use to optimize power delivery.

Part A. Optimizing the cell (1.50 points)

A.a. What should the value of R_{cell} be such that the power delivered to the electrochemical cell is maximum?

(1.10 points)

A.b. In the conditions found above, what is the maximum power delivered?

(0.40 points)

After he set the cell up, little Timmy started desalinating water using it.

Part B. Desalination rate (2.00 points)

B.a. At a power of 50W, what is the maximum possible amount of charge delivered to the cell per hour?

(1.20 points)

B.b. At a maximum power, what mass of NaCl can be removed per hour using this setup?

(0.60 points)

B.c. If the system operates at an efficiency of 70%, what mass of NaCl is actually removed per hour using this setup?

(0.20 points)

Problem 2 – The research team (4.00 points)

Near deep-sea hydrothermal vents, the temperature can exceed 400K, while the surrounding ocean temperature is around 275K. A research team led by Jicu deploys a thermoelectric generator (TEG) to harvest this temperature difference and power a deep-sea probe. The generator consists of 30 thermocouples in series, each generating voltage according to the Seebeck effect.

The Seebeck effect is the phenomenon consisting in the appearance of an electric current due to temperature differences between endpoints of a conductor. The current appears because of differences in the Brownian movement of electrons.

The voltage generated by the Seebeck effect is described qualitatively by:

$$V = \alpha(T_{hot} - T_{cold})$$

where $\alpha = 2.5 \cdot 10^{-4}\ \mathrm{V\,K^{-1}}$

The internal resistance of a thermocouple is 0.8Ω and they are connected to a resistor simulating the probe's input.

Part A. Thermoelectric voltage (0.75 points)

A.a. Calculate the voltage generated by one thermocouple if $T_{hot} = 390\mathrm{K}$ and $T_{cold} = 275\mathrm{K}$.

(0.25 points)

A.b. Calculate the voltage generated by the 30 thermocouples in series.

(0.25 points)

A.c. Calculate the total internal resistance of the thermocouple array.

(0.25 points)

Part B. Magnetic field interaction with thermoelectric circuit (1.00 point)

The research team considers that the long wires connecting the TEG to the deep sea-probe could experience external magnetic fields due to oceanic crust magnetism or nearby research equipment. These fields could induce additional forces or EMF's in the circuit.

B.a. A small compass is placed near the wire to study the magnetic induced magnetic field. Using the right hand rule, sketch a picture which clearly shows the direction of the magnetic field lines.

(0.50 points)

B.b. Assuming the wire carrying current from the thermocouple array is 1.5 meters long and placed perpendicular to the magnetic field in $B = 0.02T$. Calculate the magnetic force acting on the wire if the current is $I = 70mA$.

(0.50 points)

Part C. Communicating using ultrasonic waves (2.25 points)

To maintain communication with the surface, the deepsea probe emits ultrasonic waves (f = 500kHz). The speed of sound in seawater is approximately 1500m/s

C.a. Calculate the wavelength of the ultrasonic signal used by the probe.

(0.50 points)

C.b. If the probe is located 2000m below the surface of the water, calculate the time delay in receiving the signal at the ship on the surface of the water.

(0.30 points)

C.c. The ship releases a submersible towards the probe. The submersible travels down towards the probe at the speed of 5m/s. Calculate the frequency detected by the submersible?

(1.45 points)

Problem 3 – The other research team (5.00 points)

The Indian Ocean has a maximum depth of around 8000m. A Sri Lankan research team lead by the former IJSO participant Thenura is sending a probe in the waters of the Indian Ocean to conduct some research about the chemical composition of the waters.

They find that the density of the water right at the surface is $\rho_0 = 1000\ \text{kg} \cdot \text{m}^{-3}$.

Using previous research papers they learn that the density of the water at the bottom of the Indian Ocean is $\rho = 1080\ \text{kg} \cdot \text{m}^{-3}$.

You can work under the assumption that density decreases linearly with depth, the dependence being given by the law $\rho(y) = \rho_0(1 + \alpha y)$.

Part A. Determining characteristics of the water (0.25 points)

Find the value of constant α.

Part B. Sending the probe (0.50 points)

The probe sent by Thenura's team is spherical, of radius $R = 10.0\text{cm}$ and of mass $M = 4.30\text{kg}$. It floats in equilibrium at a depth y_0.

Find the value of the depth y_0

Part C. Moving the probe (1.75 points)

A curious shark notices the probe and moves it downwards by a distance $\Delta y = 50\text{m}$. After that, it gets bored and lets the probe move freely with no initial velocity.

C.a. Find the resultant force acting on the probe at depth $y_0 + \Delta y$

(0.60 points)

C.b. Find the speed of the probe after it gets back in the equilibrium position

(1.15 points)

For parts B and C you may consider the density of the water in the vicinity of the sphere approximately constant and equal to that of the water at the level of the center of the sphere.

Part D. The results (2.50 points)

After recovering the probe, Thenura's team sends the water for analysis to their chemist friends. They ran tests to find the concentrations of different ions in the water. The results are found below:

Ion	Sodium	Potassium	Chloride	Calcium
Concentration (g/L)	13.75	0.40	23.50	-------------------

While running the tests, just before finding the calcium concentration, the machine broke!

D.a. Convert the known concentrations to molar concentrations

(0.30 points)

D.b. Find the concentration (g/L) of calcium ions

(0.80 points)

D.c. Find the salinity (sodium chloride w/w% concentration) of the sea water considering the density to be $\rho_0 = 1\text{kg/L}$

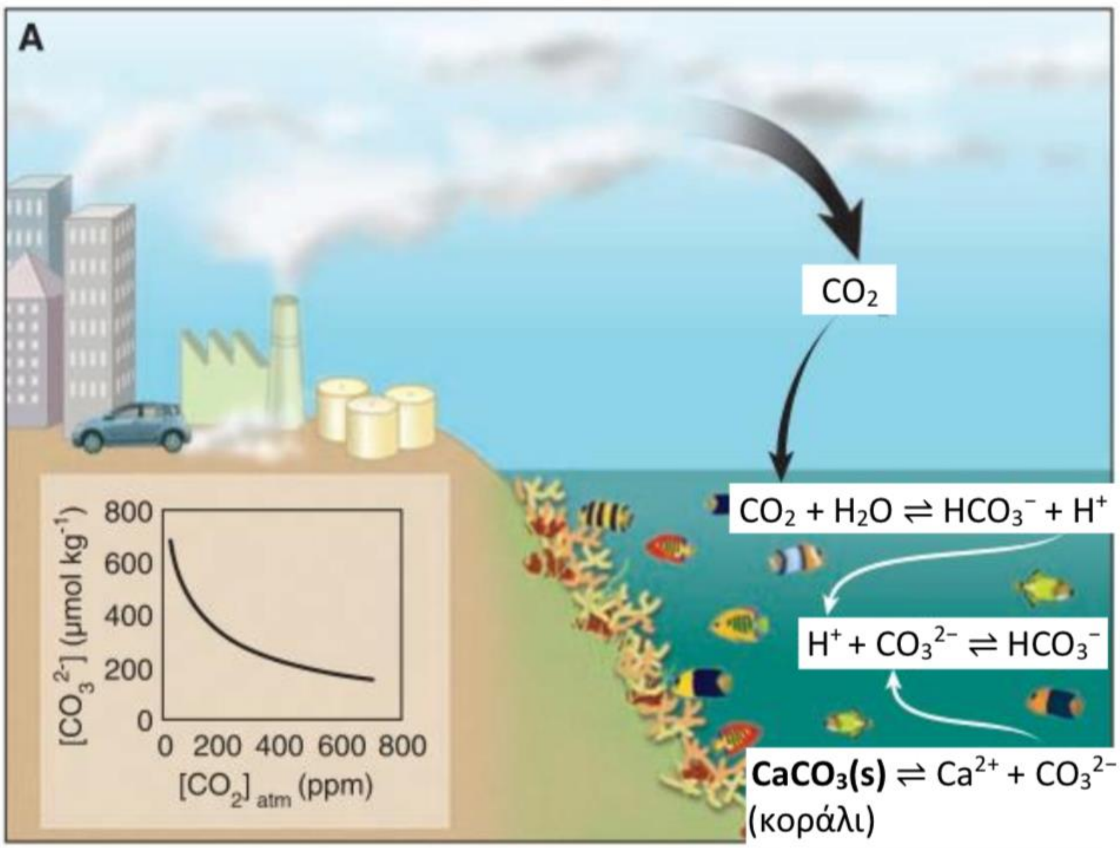
(0.50 points)

D.d. Chlorine is found in nature as two isotopes with mass numbers A and $A + 2$. If the isotope of mass A is more abundant, find the value of A and the abundances of the two isotopes

(0.90 points)

Problem 4 – Carbon dioxide in oceanic ecosystems (6.50 points)

In the scientific journal Science, Volume 318 (2007), a study was published on the impact of so-called climate change on coral reefs, which are primarily composed of $CaCO_3$(s). According to this study, 25% of the atmospheric CO_2(g) emitted from anthropogenic activities during 2000–2006 dissolved in the oceans forming H_2CO_3(aq), and this process was linked to the dissolution of coral $CaCO_3$. The figure below, taken from the study, illustrates this phenomenon.



Part A. $CaCO_3$ dissolution (1.00 points)

Based on the chemical equilibria shown in the figure above and the diagram of oceanic $[CO_3^{2-}]$ as a function of atmospheric $[CO_2]$, explain the phenomenon of $CaCO_3$ dissolution in corals due to increased CO_2 concentration in the atmosphere, by choosing the correct effects of the increase in atmospheric CO_2 concentration.

Part B. Carbon dioxide absorber (2.00 points)

Anthropogenic carbon dioxide can increase the greenhouse effect. Because of this, a very large number of researchers are looking for ways to minimize carbon dioxide emissions.

The emitted $CO_2(g)$ can be absorbed by a $Ca(OH)_2$ solution, according to the reaction:

$$CO_{2(g)} + Ca(OH)_{2(aq)} \longrightarrow CaCO_{3(s)} + H_2O_{(\ell)}$$

A 500 mL $Ca(OH)_2$ solution has an initial concentration of $5 \cdot 10^{-3}$ M and final pH = 11.

B.a. Characterize CO_2 as an acidic or basic oxide.

(0.50 points)

B.b. Calculate the volume (in mL at STP - $p = 1atm, T = 273K$) of $CO_{2(g)}$ that was absorbed by the solution, as well as the amount (mol) of the formed precipitate. Assume the volume and temperature remain constant at 25°C, and that $K_W = 10^{-14}$.

(1.50 points)

Part C. Photosynthesis (2.5 points)

The atmospheric concentration of $CO_2(g)$ decreases with photosynthesis, a complex process where plants, using sunlight and chlorophyll, convert water and CO_2 into glucose, $C_6H_{12}O_6$. Photosynthesis is summarized by the chemical equation:

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

Given thermochemical equations:

(1) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$, $\Delta H^\circ_1 = -80$ kJ

(2) $C_2H_5OH + 3O_2 \rightarrow 3H_2O + 2CO_2$, $\Delta H^\circ_2 = -1370$ kJ

C.a. Calculate the enthalpy change (ΔH°) of the photosynthesis reaction.

(0.80 points)

C.b. Equation (2) corresponds to alcoholic fermentation catalyzed by enzymes. As temperature increases, the rate of this reaction increases up to a point, beyond which it decreases. Mark with an X the option correctly explaining this.

1. High temperatures increase the solubility of CO_2, which increase the concentration of CO_2, which shifts equilibrium to the left.	
2. High temperatures favour the inverse reaction combining carbon dioxide and ethanol to yield glucose in a photosynthesis-like reaction.	
3. High temperatures denature the enzymes catalyzing the reaction.	
4. By the Le Chatelier principle, high temperatures shift the equilibrium of this exothermic reaction to the reactants side.	

(0.50 points)

A plant absorbs $4.8 \cdot 10^{-3}$ mol of $CO_2(g)$ per hour through photosynthesis.

C.c. If we assume that all of this CO_2 is converted directly into glucose, how long will it take to produce 1.8 g of glucose?

(1.20 points)

Part D. Starch (1.00 points)

A lot of plants store the glucose produced in photosynthesis in the form of starch. Starch is a sugar which can be used in iodometric titrations because in the presence of iodine it turns into a colored complex. In titrations with an appropriate reducing agent, the molecular iodine is reduced and the colored complex disappears.

D.a. What is the color of the starch iodine complex?

(0.25 points)

D.b. What is the reaction between iodine and sodium thiosulfate?

(0.50 points)

D.c. Iodine has a very low solubility in water. However, it easily dissolves in aqueous solutions of compound X. What is the chemical formula of compound X?

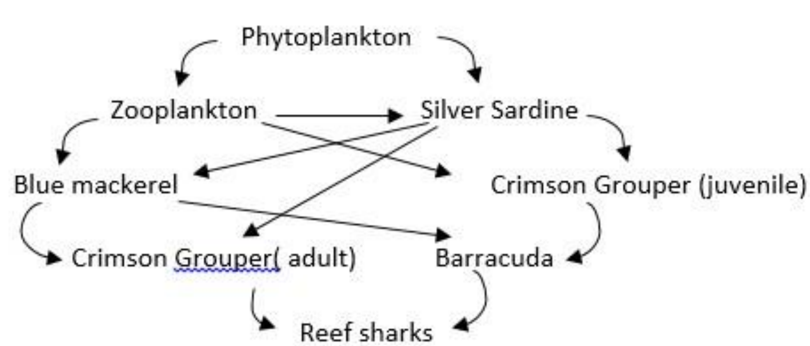
(0.25 points)

Problem 5 – Species in the Palawan archipelago (2.80 points)

The Palawan archipelago, Philippines, a UNESCO Biosphere Reserve, is celebrated globally for its extraordinary marine biodiversity, often referred to as the country's "last ecological frontier." Its intricate network of coral reefs, extensive seagrass meadows, and significant mangrove forests support a complex web of life. This includes ecologically vital and commercially important fish species such as the Crimson Grouper (*Cephalopholis sonnerati*), large schools of Silver Sardine (*Sardinella spp.*), predatory Barracuda (*Sphyraena spp.*), and apex predators like Reef Sharks (*Carcharhinus spp.*).

However, these sensitive environments face mounting pressures from both direct human activities and broader environmental changes. The ecosystem experienced a severe disruption when an underwater submarine implosion released pollutants, causing a significant die-off event that heavily impacted the Silver Sardine population even though its effects on other species are minimal. Concurrently, gradual shifts in regional sea surface temperatures, driven by climate change, are observed to be influencing the distribution and habitat use of species like the Barracuda, potentially leading to long-term evolutionary consequences.

Below is a simplified representation of common trophic interactions within a typical Palawan reef system involving some of these key species:



Part A. Food web (1.30 points)

A.a. Based strictly on the food web provided, identify all the organisms that function as tertiary consumers and quaternary consumers (List the species names).

(0.80 points)

A.b. Given that the introduced pollutant is very persistent (stable, long lifespan), scientists want to investigate its potential long-term physiological effects within the ecosystem's food web. Which single species from the food web provided would likely be the most informative for studying the cumulative physiological effects resulting from the persistence of this pollutant over time?

(0.50 points)

Part B. Ecological disruptions (1.50 points)

A pollutant which was released when a submarine imploded due to some design flaws washed up to the shores of Palawan archipelago. This severely reduced the Silver Sardine population. By random chance, the survivors predominantly exhibited two specific color patterns (regulated by a set of alleles A and a), even though these patterns offered no survival advantage against the pollutant or in the altered environment.

B.a. What evolutionary mechanism most suitably describes the random survival of selected traits after the pollution event? Mark the right mechanism with an X.

1. The bottleneck effect	
2. Genetic drift	
3. Stabilizing selection	
4. Speciation	

(0.30 points)

B.b. In the surviving silver sardine population the percentage of individuals expressing pattern 2 (caused by the expression of recessive allele a) was found to be 2.25% find the frequency of individuals which are heterozygous for the above gene.

(0.80 points)

Observations suggest that due to long-term shifts in water temperature driven by climate change, a particular subspecies of Barracuda has fragmented. One group consistently migrates towards newly available, cooler, deeper waters, while the other remains adapted to the now warmer, shallower traditional habitats. Over many generations, significant reproductive isolation occurs between these two groups due to differences in habitat preference, preventing gene flow. Eventually, they are recognized as distinct species.

B.c. The fragmented species encounters fluctuating environmental conditions and heavy competition from locally existing fish species in their new habitat. State whether a strong regulatory system which controls all changes in DNA effectively or a not so developed system which is prone to make mistakes is better in this condition for the population.

(0.40 points)

Problem 6 – Adaptations to temperature (4.70 points)

The Indian Ocean waters surrounding Sri Lanka are home to a diverse array of marine life, each adapted to its specific ecological niche and the varying environmental conditions. Understanding the physiological capabilities of these organisms is crucial for predicting their responses to environmental changes and for effective conservation. This question explores aspects of metabolic adaptation to temperature in an important fish species and the diving physiology of a common marine mammal found in the region.

Part A. Metabolism in Yellowfin Tuna (*Thunnus albacares*) (1.90 points)

Yellowfin Tuna are large, active predators known for their extensive migrations through waters of varying temperatures. Their metabolic rate is crucial for sustaining their high activity levels. Scientists measured the rate of oxygen consumption (as an indicator of metabolic rate) for Yellowfin Tuna acclimated to different temperatures.

Temperature (℃)	**Mean oxygen consumption ($mL\ O_2/kg/h$)**
20	150
30	330

The Q_{10} temperature coefficient is the factor by which the rate of a reaction or physiological process increases for every $10°C$ rise in temperature. It is given by the formula:

$$Q_{10} = \left(\frac{r_1}{r_2}\right)^{\frac{10}{T_1 - T_2}}$$

where $r_{1,2}$ are the rates at temperatures $T_{1,2}$

A.a. Calculate the Q_{10} value for tuna respiration

(0.30 points)

A.b. Using the Q_{10} value calculated at point A1, predict the mean oxygen consumption rate (in $mL\ O_2/kg/h$) for Yellowfin Tuna if they were acclimated to a temperature $T_3 = 15°C$. Assume the same Q_{10} applies between 15 °C and 20 °C as well.

(0.50 points)

A.c. Based on your calculated Q_{10} value, would you describe the metabolic rate of Yellowfin Tuna as highly sensitive or relatively insensitive to temperature changes within this range?

(0.30 points)

A.d. Imagine this Yellowfin Tuna population begins to differentiate. One group (A) consistently utilizes warmer, near-surface waters (relatively stable temperature), while another group (B) adapts to exploit cooler, deeper waters and warmer shallow waters, frequently migrating vertically between depths with significant temperature differences. Explain whether a high Q_{10} value would likely be physiologically beneficial or detrimental for *each* of these two specialized groups.

(0.80 points)

Part B. Diving of the spinner dolphin (*Stenella longirostis*) (2.80 points)

Spinner Dolphins are commonly observed in Sri Lankan waters and are known for performing dives to forage for food. As mammals, they must carry sufficient oxygen stores to sustain their metabolism while underwater, but they also possess adaptations to tolerate anaerobic metabolism to some extent.

Physiological Data for an Adult Spinner Dolphin:

- Total usable oxygen stores (Blood + Muscle): 100 mL O_2 / kg body mass
- Resting Metabolic Rate (RMR) at the surface: 8.0 mL O_2 / kg / minute
- Average Diving Metabolic Rate (DMR): 4.5 times the Resting Metabolic Rate (RMR)
- Anaerobic Tolerance: Can sustain activity using anaerobic pathways, tolerating lactic acid build-up for an additional 1.5 minutes after depleting usable oxygen stores.
- Average Dive Speed (descent & ascent): 1.5 m/s

B.a. Calculate the average Diving Metabolic Rate (DMR) for the Spinner Dolphin in mL O_2 / kg / minute.

(0.20 points)

B.b. The Aerobic Dive Limit (ADL) is the maximum duration a dive can last using only stored oxygen. Calculate the theoretical ADL for the Spinner Dolphin in minutes.

(0.40 points)

B.c. If a Spinner Dolphin performs a foraging dive that lasts for 75% of its calculated ADL (from part B.b), what volume of its usable oxygen stores (in mL O_2 / kg body mass) would have been consumed during this dive?

(0.30 points)

B.d. Taking into account the dolphin's tolerance for anaerobic metabolism, what is the absolute maximum possible dive duration (aerobic + anaerobic) for this Spinner Dolphin in minutes?

(0.20 points)

B.e. Assuming the dolphin dives vertically down and returns vertically up at the average speed given, spending negligible time actively foraging at the maximum depth, calculate the maximum depth (in meters) it could potentially reach during a dive of the maximum possible duration calculated in part B.d.

(0.40 points)

B.f. A certain dolphin was tracked using GPS and it was resting for 8 minutes on the surface when a squid zoomed past it in a speed of 2.5 ms^{-1} and when the dolphin started chasing it the squid had already travelled 15m .If the squid had low endurance and it gradually slowed with a deceleration of 0.025 ms^{-2} Assuming the chase was linear with the average horizontal top speed of dolphin is 1.75 ms^{-1} and it takes the dolphin 6s to accelerate to that value. Find whether the dolphin will catch the squid before completely exhausting its natural oxygen reserve

(1.30 points)

Problem 7 – Species in the Mariana Trench (3.00 points)

The Mariana Trench, located in the western Pacific Ocean, is the deepest known region of the Earth's ocean, reaching a maximum depth of nearly 11,000 meters. This extreme environment is characterized by very high hydrostatic pressure, low temperatures, absence of light, and low nutrient availability. Despite these harsh conditions, a variety of organisms inhabit the trench, having evolved specialized anatomical and physiological traits that enable survival under extreme pressure and limited energy sources.

In a recent deep-sea research mission, a biological survey team led by Alex Jicu deployed an autonomous underwater vehicle (NEPTUNE) to collect biological specimens and analyze their structural and evolutionary characteristics. The objective was to classify the collected organisms, understand their phylogenetic relationships, and investigate traits potentially adapted to deep-sea environments. Morphological and molecular data were collected and compiled for further analysis.

Part A. Constructing a cladogram (1.00 points)

Consider the following table about species A, B, C, D collected from the Mariana Trench.

Trait	**A**	**B**	**C**	**D**
Segmentation	X			X
Exoskeleton	X			X
Tentacles		X	X	
Radula		X		
Compound Eyes				X
Hydrostatic Skeleton		X	X	

Construct the most likely cladogram (phylogenetic tree) showing the evolution of species A, B, C, D from their common ancestors. On the cladogram, show the points where the different characteristics evolved.

Part B. Structural observations (1.30 points)

Detailed anatomical analysis of three deep-sea animal specimens (Specimens A, B, and C) revealed notable adaptations in muscle structure, skeletal density, and sensory organs. The team noted the following:

Specimen	**Skeletal Density (g/cm^3)**	**Muscle Fiber Density ($fibers/mm^2$)**	**Eye Complexity (1–5 scale)**
A	0.95	2400	5
B	0.67	1500	2
C	0.45	3200	1

B.a. Rank the three specimens by likely depth of habitat.

(0.30 points)

B.b. Mark the right option explaining how reduced skeletal density is an energy-efficient adaptation at high pressure with an X:

1. Reduced skeletal density minimizes the energy required for muscle contraction, allowing organisms to move more easily in high-pressure environments	
2. Lower skeletal density decreases the energy needed for bone formation, which allows more energy to be allocated for other vital processes in deep-sea organisms.	
3. A lighter skeleton requires less energy to support the organism's structure under high-pressure conditions, thus conserving metabolic resources.	
4. Reduced bone density enhances the efficiency of respiration by allowing the organism to have a greater volume of gas exchange surface area in the skeletal structure.	

(0.50 points)

B.c. Species C has minimal visual organs but enhanced lateral line structures. Choose the right explanation for this observation:

1. The specimen lives in high-altitude aquatic environments where visual input is reduced by rapid water flow, so it relies on lateral lines to detect chemical gradients.	
2. The specimen inhabits low-light or turbid environments where vision is less effective, so it relies on lateral line mechanoreceptors to detect water movement and vibrations.	
3. The specimen uses lateral line structures primarily for detecting prey in clear, shallow water, where visual signals are overwhelmed by surface reflections.	
4. The specimen evolved in arid subterranean regions and uses lateral lines to compensate for its inability to detect electromagnetic signals underwater	

(0.50 points)

Part C. Sensory adaptations (1.20 points)

The team exposed neural tissues from a deep-sea fish to various stimuli in a pressure-controlled lab. Response latencies (in ms) were measured across tissues A, B, and C.

Temperature (°C)	**Tissue A**	**Tissue B**	**Tissue C**
2	2.1	3.5	12.4
10	2.2	3.6	11.8
20	4.5	3.7	6.0

C.a. Which of the tissues is likely part of an electroreceptive organ?

(0.70 points)

C.b. Which part of the neuron most likely served as the receptor for the stimuli? Choose the right option from: axon terminals, myelin sheath, Schwann cells, cell body, dendrites.

(0.50 points)