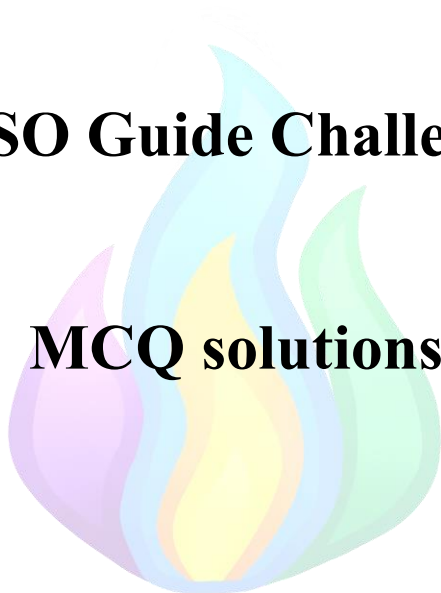


# **IJSO Guide Challenge**

## **MCQ solutions**



## Overview of correct answers

| Question Number | Option       |              |              |              |
|-----------------|--------------|--------------|--------------|--------------|
| 1               | <del>A</del> | B            | C            | D            |
| 2               | A            | <del>B</del> | C            | D            |
| 3               | <del>A</del> | B            | C            | D            |
| 4               | <del>A</del> | B            | C            | D            |
| 5               | A            | <del>B</del> | C            | D            |
| 6               | A            | B            | C            | <del>B</del> |
| 7               | <del>A</del> | B            | C            | D            |
| 8               | A            | B            | C            | <del>B</del> |
| 9               | A            | <del>B</del> | C            | D            |
| 10              | A            | B            | <del>C</del> | D            |
| 11              | <del>A</del> | B            | C            | D            |
| 12              | A            | B            | C            | <del>B</del> |
| 13              | A            | B            | <del>C</del> | D            |
| 14              | <del>A</del> | B            | C            | D            |
| 15              | A            | B            | <del>C</del> | D            |

### (P) Question 1 – Green energy

The mechanical energy is  $E_{\text{mech}} = P_{\text{mech}} \cdot \Delta t = \tau \omega \Delta t$

Since the wheels roll without slipping,  $\omega = \frac{v}{R}$

Substituting,  $E_{\text{mech}} = \tau \frac{v}{R} \Delta t = \tau \frac{v \Delta t}{R} = \tau \frac{D}{R}$

The electrochemical energy is just  $E_{\text{electrochem}} = \eta E_{\text{mech}} = \eta \tau \frac{D}{R}$

The maximum energy stored in the battery is  $E_{\text{max}} = QU$

The percentage at which the battery is charged is  $f = \frac{E_{\text{electrochem}}}{E_{\text{max}}} = \frac{\eta \tau D}{RQU} = 0.167 = 16.7\%$

The correct answer option is **A**.



## (B) Question 2 – Fish fossils

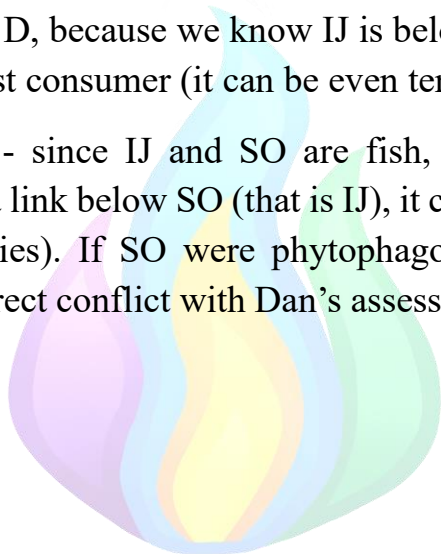
Firstly, we can eliminate answer option A, without even reading the question - proteins are not directly excreted through urine. The first step in urine formation is the filtration in the Bowmann capsule, which removes all proteins and cells from the blood. Since the primary urine (glomerular filtrate) contains no proteins, the final urine doesn't contain proteins either, so they are not excreted through urine.

Using the concept of bioamplification, we know that SO is above IJ in the food chain.

We can remove C, because SO doesn't have to come right after IJ, we only know it comes sometime after (for what we know, IJ could be a primary consumer and SO could be a quaternary consumer).

Similarly, we can remove D, because we know IJ is below SO, but we have no way to be sure it was the lowest consumer (it can be even tertiary, if SO is quaternary).

The correct option is **B** - since IJ and SO are fish, not plants, they cannot be producers. Since there is a link below SO (that is IJ), it can't be the lowest consumer (so a phytophagous species). If SO were phytophagous, IJ would have to be a producer - and that is a direct conflict with Dan's assessment that the fossils are fish fossils.

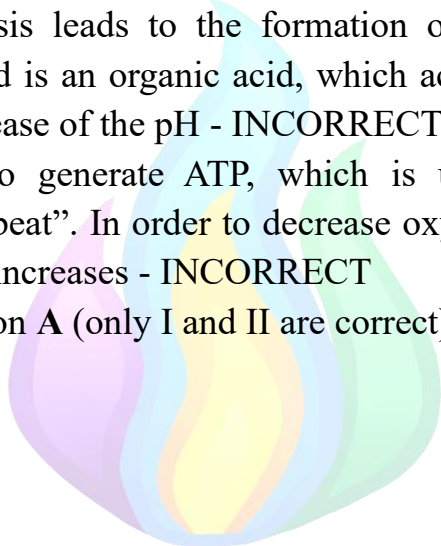


### **(B) Question 3 – More fish**

Let's analyze each statement:

- I. When deep diving, the pressure drastically increases, increasing the solubility of gases, especially nitrogen. A rapid ascent leads to a rapid depressurization, which decreases the solubility of gases. They then go back into the gas phase, forming bubbles, which can block blood vessels (in a way similar to clots). This is called decompression sickness and has the mentioned symptoms - **CORRECT**
- II. The inner ear pressure remains approximately constant. However, the outer pressure decreases due to the high hydrostatic pressure. The higher pressure acting from the outside of the ear drum curves it inwards - **CORRECT**
- III. Anaerobic glycolysis leads to the formation of lactic acid. As its name suggests, lactic acid is an organic acid, which acidifies the muscle tissues - this leads to a decrease of the pH - **INCORRECT**
- IV. Oxygen is used to generate ATP, which is used by the heart muscle (myocardium) to “beat”. In order to decrease oxygen consumption the heart rate decreases, not increases - **INCORRECT**

The correct option is option **A** (only I and II are correct).



### (C) Question 4 – A new mineral!

From the first experiment we can determine the percentage of  $\text{CO}_3^{2-}$  in the chemical. Part of the sulfuric acid is neutralized by the carbonate of the rock. The rest is titrated:



$$\text{Initially } n(\text{H}_2\text{SO}_4) = 0.05(0.5) = 0.025\text{mol}$$

$$\text{Used } n(\text{NaOH}) = 0.5(0.044) = 0.022\text{mol}$$

$$\text{In the reaction, the amount of sulfuric acid consumed is } x = \frac{n(\text{NaOH})}{2} = 0.011\text{ mol}$$

So, the amount of sulfuric acid neutralized by the carbonate is:

$$0.025 - 0.011 = 0.014\text{ mol H}_2\text{SO}_4$$

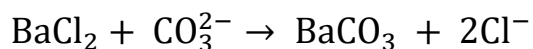
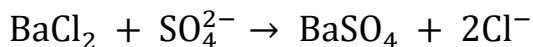
Since  $\text{CO}_3^{2-} + \text{H}_2\text{SO}_4 \rightarrow \text{SO}_4^{2-} + \text{H}_2\text{O} + \text{CO}_2$ , we have 0.014mol of carbonate

$$M(\text{CO}_3^{2-}) = 12 + 3(16) = 60 \frac{\text{g}}{\text{mol}}$$

$$\text{The mass of carbonate is } 60 \cdot 0.014 = 0.84\text{g}$$

$$\text{Percentage-wise: } \frac{0.84}{10} \cdot 100\% = 8.4\% \text{ of } \text{CO}_3^{2-}$$

For the second experiment we can determine the  $\text{SO}_4^{2-}$  ions. The precipitates which form are barium sulfate ( $\text{BaSO}_4$ ) and barium carbonate ( $\text{BaCO}_3$ ).



$$M(\text{BaSO}_4) = 233 \frac{\text{g}}{\text{mol}}$$

$$M(\text{BaCO}_3) = 197 \frac{\text{g}}{\text{mol}}$$

$$n(\text{BaCO}_3) = \frac{8.4}{100} \cdot \frac{10}{60} = 0.014\text{mol}$$

$$m(\text{BaCO}_3) = 2.758\text{g}$$

$$m(\text{BaSO}_4) = 5.78 - 1.918 = 3.022\text{g}$$

$$n(\text{SO}_4^{2-}) = \frac{3.022}{233} = 0.013\text{mol}$$

$$m(\text{SO}_4^{2-}) = 0.013 \cdot 96 = 1.24\text{g}$$

Percentage-wise, it is equal to  $\frac{1.24}{10} \cdot 100\% = 12.4\%$

So, the answer is **A**.



### (P) Question 5 – Rolling cylinder

The MAXIMUM allowed value of the friction force is  $F_{f,\max} = \mu N = \mu Mg \cos \alpha = 604.08\text{N}$ .

The hypothetical frictionless acceleration is  $a = g \sin \alpha = 5.62 \text{ m s}^{-2}$ , so the real acceleration, taking the gyration factor into account is  $a' = \frac{5.62}{1.5} = 3.75 \text{ m s}^{-2}$ . Since  $a' < a$ , the friction force decelerates the cylinder, thus, it acts up the inclined plane.

Writing Newton's second law along the surface of the plane,  $Ma' = Mg \sin \alpha - F_f$ , from which we get  $F_f = M(g \sin \alpha - a') = 402.84\text{N} < F_{f,\max}$ , so the situation is possible.

So, the correct answer option is option **B**.



### (P) Question 6 – Bringing the rocks up

Taking into account the limitations of the bucket, Dan needs to do a number of

$$N = \frac{M}{m_{\text{lim}}} = \frac{5000}{200} = 25 \text{ lifts.}$$

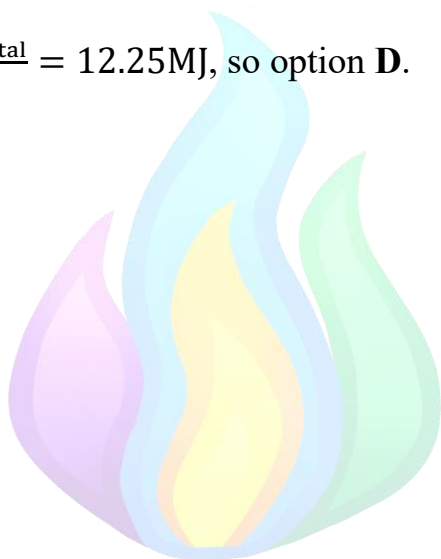
The work done for one lift, consists of two parts:

- The work required for lowering the bucket,  $W_{\text{down}} = Fh = m_0gh = 49\text{kJ} = 0.049\text{MJ}$
- The work required for lifting the bucket,  $W_{\text{up}} = (m_0 + m_{\text{lim}})gh = 0.147\text{MJ}$

$$W_{\text{trip}} = W_{\text{up}} + W_{\text{down}} = 0.196\text{MJ}$$

$$W_{\text{total}} = NW_{\text{trip}} = 4.90\text{MJ}$$

$$W_{\text{total}} = \eta E \Rightarrow E = \frac{W_{\text{total}}}{\eta} = 12.25\text{MJ}, \text{ so option D.}$$



### (C) Question 7 - Analyzing the rocks

The correct answer is **A** because:

Statement A: Right. According to the Le Chatelier's principle when the concentration of  $\text{CH}_3\text{COO}^-$  increases the equilibrium shifts to the direction that cancels the initial action. So, the equilibrium will shift to the left.

Statement B: This statement is wrong because it does not follow the Le Chatelier principle.

Statement C: The  $K_a$  is not dependent on the concentration but only affected by the temperature

Statement D: The equilibrium constant does not increase nor decrease with the change of concentration



## (B) Question 8 – Joseph

Let us analyze each of the answer options:

- A. Antibiotics are not substances made to alter gene transcription processes, instead they are meant to kill the bacteria. There are two types of antibiotics - bactericidal antibiotics, which directly kill the bacteria by several processes (such as inhibiting cell wall formations) and bacteriostatic antibiotics, which prevent the bacteria from multiplying, by blocking processes that are vital to multiplying - cephalexin is a bactericidal antibiotic
- B. Antibiotic resistant forms of bacteria isn't a rare phenomenon, it occurs regularly so there must be a cause for it, it doesn't just happen "by chance". The mutation does appear randomly, but the fact that the mutated *Staphylococcus* persisted has a biological explanation
- C. Option C is incorrect because conjugation transfers genes to individual bacteria but does not eliminate susceptible ones or drive population-wide dominance on its own. The rapid change in the overall population occurs because cephalexin selectively kills the non-resistant bacteria, allowing the resistant strain to outcompete them and take over.
- D. This is the correct explanation. Mutations arise very often in nature. When a mutation gives individuals a significant advantage, they are the ones that procreate more and the advantageous characteristic becomes the norm - this is one of the basic mechanisms of evolution

The correct answer is option **D**.

### (B) Question 9 – More visitors

The fact that carriers exist, immediately points to a recessive disease. The fact that an affected individual (II 1) can have healthy offsprings, leads us to the conclusion that the disease is X-linked recessive, so II 1 (a male) isn't actually homozygous, but hemizygous (male with an affected X chromosome). With regards to III 1's offspring, the parents have genotypes  $X'X$  and  $XY$ , where  $X'$  is the affected X chromosome.

We can make the following Punnett square:

|      | X     | Y     |
|------|-------|-------|
| $X'$ | $X'X$ | $X'Y$ |
| X    | $XX$  | $XY$  |

We see that 50% of the girls are unaffected carriers, while 50% are completely unaffected and 50% of the boys are affected, while 50% aren't.

All this information corresponds to answer option **B**.

Note: The disease we had in mind is called G6PDD (glucose-6-phosphatase dehydrogenase deficiency), which is the most common enzyme deficiency anemia worldwide. It is caused by a lack of the enzyme G6PD, which protects red blood cells from reactive oxygen species. Most individuals with G6PDD can go asymptomatic their entire lives. However, in certain conditions, such as illness or the person taking certain drugs, it can lead to fatigue, jaundice, or, in some cases, hemoglobinuria.

There are other diseases that would've fit the description, but, regardless, the specific disease is irrelevant for solving the genetics problem.

## **(B) Question 10 – Dan gets hurt as well**

Let us analyze each of the answer options:

- A. The Na/K pump does polarize the cell membrane and its blocking would reduce the polarization. However, it removes 3 Na<sup>+</sup> ions from the cell and introduces 2 K<sup>+</sup> ions (hence the mnemonic NOKIA 321 - 3 Na<sup>+</sup> Out, 2 K<sup>+</sup> In, 1 ATP used), so the positive charge builds up on the outer face of the membrane, not on the inner face - option A is wrong
- B. Depolarization is the action that leads to an action potential - immediate depolarization would create a permanent action potential rather than a permanent rest potential - the rest potential is maintained by the Na/K pump, not destroyed by it - option B is wrong
- C. As explained for option A, the rest potential (the effective polarization of the membrane) is maintained by the expulsion of Na<sup>+</sup> from the cell. Over time, a Na<sup>+</sup> gradient builds towards the extracellular environment. When the neuron is depolarized (to create action potential), Na<sup>+</sup> rushes back in passively. If lidocaine blocks that, there is no more depolarization, no more action potential so no more pain sensation - option C is correct
- D. The exact mechanism of repolarization is beyond the scope of the IJSO (you can read the note below). However, if repolarization were to become impossible, the neuron would be in a permanent depolarized state - the argument becomes the same as that from option B - option D is wrong

Hence, we found that option **C** is the correct one

Note regarding question 10:

The Na/K pump acts (as explained in option A) towards the polarization of the cell membrane (kind of like a capacitor). This builds up 3 gradients:

- An electrical potential gradient (positive potential on the outside, negative potential on the inside)
- Two chemical gradients ( $[Na^+]_{out} > [Na^+]_{in}$  and  $[K^+]_{out} < [K^+]_{in}$ )

The Na/K pump acts actively, against the chemical gradients. The state maintained by this pump is called the rest state, where the potential difference between the faces of the membrane is around -70mV (the rest potential). Right now, the voltage-gated Na channels ( $Na_v$ ) and the voltage-gated K channels ( $K_v$ ) are closed. If a stimulus makes the potential a little bit less negative, a feedback loop starts:

- The small change slightly opens the  $Na_v$  channels
- $Na^+$  starts passively rushing in, according to the chemical gradient
- The potential becomes even less negative
- More  $Na^+$  rushes in the cell, until the potential can even become positive

What's the role of  $K_v$  channels in all this? They open just like  $Na_v$  channels, but with one crucial difference - way more slowly. By the time  $K_v$  channels are opened, the cell is almost depolarized.  $K^+$  ions start rushing out of the cell (according to the chemical gradient), polarizing the cell membrane again - repolarization. After the potential reaches its rest value, both  $Na_v$  and  $K_v$  channels close (the  $K_v$  channels again with a little delay, creating a brief period where the potential is more negative than the rest one - hyperpolarization), leaving only the Na/K pump work - the rest state is once again established.

There is a bit more nuance to this, but this is already more than enough for the IJSO.

### (C) Question 11 – Cave collapse

Zn is in the anode so it gets oxidized. At the cathode, we have reduction. One reduction process we would think could happen is copper reduction. However, there are basically no  $\text{Cu}^{2+}$  ions, so this reaction can't take place. The actual reduction is the reduction of hydrogen ions (protons) to  $\text{H}_2$  gas.

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = 0 - (-0.76) = 0.76\text{V}$$

One potato battery produces approximately 0.76 V and so we can power only a light bulb.

So, the answer is **A**



### (C) Question 12 – Emergency fuel

The heat absorbed by the water is

$$Q = mc\Delta T$$

$$Q = 159 \cdot 4.18 \cdot (47 - 22) = 16615.5 \text{ J} = 16.62 \text{ kJ}$$

$$n(\text{fuel}) = \frac{1.13}{76.7} = 0.0147 \text{ mol}$$

The enthalpy of reaction is negative, since the combustion is exothermic.

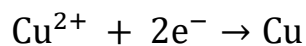
$$\text{Its value is } \Delta H = -\frac{Q}{n} = -\frac{16.62}{0.0147} = -1130 \frac{\text{kJ}}{\text{mol}}$$

So, the correct answer is option **D**.

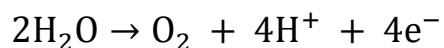


### (C) Question 13 – Electrolysis

The reaction taking place in the cathode is a reduction:



In the anode the water gets oxidized and the reaction taking place is:



So the gas released is oxygen

$$Q = I \cdot \Delta t = 2 \cdot (40 \cdot 60 + 15) = 4830 \text{ C}$$

1 mol of  $\text{e}^{-}$  is 96500 C (Faraday constant)

$$n_{\text{e}^{-}} = \frac{Q}{F} = 0.05 \text{ mol}$$

There's one mole of oxygen per 4 moles of electrons so:

$$n(\text{O}_2) = \frac{n_{\text{e}^{-}}}{4} = 0.0125 \text{ mol}$$

$$\text{Then, } V = 0.0125 \cdot 22.4 = 0.28 \text{ L}$$

So, the answer is **C**.

## (P) Question 14 – The astronomy camp

Circular movement in a gravitational field is governed by the equilibrium between the gravitational and the centrifugal force:

$$m \frac{v^2}{r} = \frac{GMm}{r^2} \Rightarrow v = \sqrt{\frac{GM}{r}} \Rightarrow v \sim r^{-\frac{1}{2}}$$

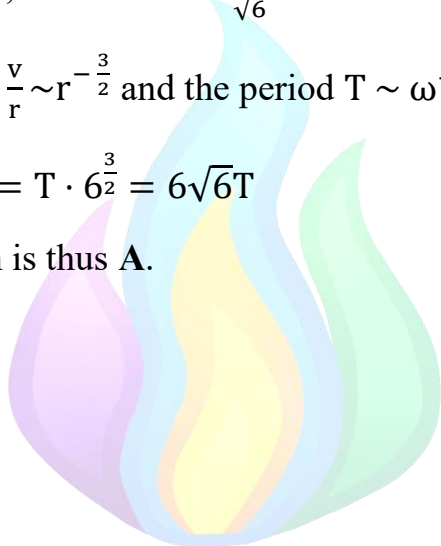
One key takeaway from this is the fact that the velocity does not depend on the mass of the satellite - from now on, we can just ignore the fact that the mass of the satellite halved.

Since  $v \sim r^{-\frac{1}{2}}$  and  $r' = 6r$ , we have  $v' = \frac{v}{\sqrt{6}}$

The angular velocity  $\omega = \frac{v}{r} \sim r^{-\frac{3}{2}}$  and the period  $T \sim \omega^{-1} \sim r^{\frac{3}{2}}$ .

Again, since  $r' = 6r$ ,  $T' = T \cdot 6^{\frac{3}{2}} = 6\sqrt{6}T$

The correct answer option is thus **A**.



### (P) Question 15 – The basalt columns

Let's denote the porosity by  $p$ .

$$p = \frac{V_{\text{air}}}{V_{\text{total}}} = \frac{V_{\text{initial}} - V_{\text{final}}}{V_{\text{initial}}} = \frac{V_{\text{initial}} - V_{\text{initial}}(1 + \gamma(T - T_0))}{V_{\text{initial}}} = \gamma(T_0 - T)$$
$$\Rightarrow T_0 = T + \frac{p}{\gamma} \approx 1000^\circ\text{C}$$

Option C is correct.

