Physics MCQ Exam Solution

1. A box with a weight of 100 N is at rest on a horizontal surface. The coefficient of kinetic
friction and the coefficient of static friction between the box and the surface are \( \mu_k = 0.400 \)
and \( \mu_s = 0.500 \), respectively. If the force \( F = 42.0 \text{ N} \) is applied on the box as shown in the
figure, what is the magnitude and direction of the friction acting on the box?

A. 40.0 N to the left  
B. 42.0 N to the left  
C. 50.0 N to the left  
D. 50.0 N to the right

Solution

Correct Choice: B

Maximum static friction: \( f_{s,\text{max}} = \mu_s N = 0.500 \times 100 \text{ N} = 50.0 \text{ N} > F \)

Therefore, the box doesn’t move. \( \Sigma F_x = 0 \)

The static friction in this case is \( f_s = 42.0 \text{ N} \) to the left.
2. Which object has the greatest magnitude of the acceleration? Assume that all objects move with constant acceleration in straight line.

   A. A vehicle accelerates from rest to 100 km/h within 4.00 s.
   B. A rock during a free fall near the surface of the Earth.
   C. A vehicle with an initial speed of 60.0 km/h comes to rest in 3.20 s.
   D. A vehicle starting from rest takes 6.50 s to cover a distance of 250 m.

Solution

Correct Choice: D

A. \( a = \frac{\Delta v}{\Delta t} = \frac{(100 - 0) \times 1000 \text{ m}}{4.00 \times 60 \times 60 \text{ s}^2} = 6.94 \text{ m/s}^2 \)

B. \( a = g = 9.80 \text{ m/s}^2 \)

C. \( a = \frac{\Delta v}{\Delta t} = \frac{(0 - 60) \times 1000 \text{ m}}{3.200 \times 60 \times 60 \text{ s}^2} = -5.21 \text{ m/s}^2 \rightarrow |a| = 5.21 \text{ m/s}^2 \)

D. \( \Delta x = ut + \frac{1}{2} at^2 \rightarrow a = \frac{2\Delta x}{t^2} = \frac{2 \times 250 \text{ m}}{6.5^2 \text{ s}^2} = 11.8 \text{ m/s}^2 \) **the greatest value**
3. A bullet of mass \( m \) is shot into a stationary block of mass \( M \). The block rests on a frictionless floor and is attached to a massless spring with a spring constant \( k \). The bullet embeds itself in the block upon impact. Subsequently, the combined mass compresses the spring to a maximum displacement of \( x_{\text{max}} \), as illustrated in the figure. Determine the initial velocity \( u \) of the bullet in terms of \( m, M, k, \) and \( x_{\text{max}} \).

\[
\begin{align*}
\text{A.} & \quad \frac{x_{\text{max}}}{m} \sqrt{k(m + M)} \\
\text{B.} & \quad \frac{(m + M)}{m} x_{\text{max}} \sqrt{\frac{k}{m}} \\
\text{C.} & \quad x_{\text{max}} \sqrt{\frac{k}{m}} \\
\text{D.} & \quad x_{\text{max}} \sqrt{\frac{k}{m + M}}
\end{align*}
\]

**Solution**

**Correct Choice: A**

1. collision between the bullet and the block
   conservation of momentum:
   \[
   m u = (m + M) v \\
   v = \frac{m u}{m + M}
   \]  

2. The combined mass compresses the spring
   conservation of mechanical energy:
   kinetic energy of the combined mass = elastic potential energy
   \[
   \frac{1}{2} (m + M) v^2 = \frac{1}{2} k x_{\text{max}}^2
   \]
   \[
   v = x_{\text{max}} \sqrt{\frac{k}{m + M}}
   \]  
   Plug \( v \) from (1) into (3):
   \[
   u = \frac{m + M}{m} \times x_{\text{max}} \sqrt{\frac{k}{m + M}}
   \]
   \[
   u = (x_{\text{max}}/m) \sqrt{k(m + M)}
   \]
   This is the expression in choice A.
4. When placed in a liquid of density $\rho_A$, a sphere sinks and displaces a volume $V_A$ of liquid, as shown in the figure.

When placed in a liquid of density $\rho_B$, the same sphere floats with half of its volume appears over the surface of the liquid.

When placed in a liquid of density $\rho_C$, the same sphere floats.

Determine the magnitude of the buoyant force exerted by the liquid of density $\rho_C$ on the sphere.

A. $\rho_CV_A g$

B. $\frac{1}{2}\rho_AV_A g$

C. $\frac{1}{2}\rho_BV_A g$

D. Insufficient information

Solution

Correct Choice: C

When placed in a liquid of density $\rho_A$, a sphere sinks and displaces a volume $V_A$ of liquid.

 Obtained information: sphere's volume $V = V_A$

When placed in a liquid of density $\rho_B$, the same sphere floats with half of its volume appears over the surface of the liquid.

 Obtained information: the sphere floats, buoyant force = weight of the sphere

$$\rho_B \frac{V_A}{2} g = m_s g = \rho_s V_A g$$

density of the sphere: $\rho_s = \rho_B/2$

mass of the sphere: $m_s = \rho_B V_A/2$

When placed in a liquid of density $\rho_C$, the same sphere floats.

 Obtained information: the sphere floats, buoyant force = weight of the sphere

$$\frac{1}{2} \rho_B V_A g$$
5. Two identical LEDs are connected as shown in the circuit diagram. Each LED needs a current of 10.0 mA and a potential difference of 1.20 V to operate correctly. Calculate the resistance of a resistor $R$ for this circuit to operate under the conditions given above.

A. 330 $\Omega$
B. 390 $\Omega$
C. 660 $\Omega$
D. 780 $\Omega$

**Solution**

**Correct Choice: C**

Two LEDs are connected in series, the current through each of them are the same $I = 10.0$ mA.

$I = 10.0$ mA is also the current throughout the circuit.

Potential difference across two LEDs is: $1.20 + 1.20 = 2.40$ V.

Potential across the resistor is then: $9.00 - 2.40 = 6.60$ V.

Therefore, $R = \frac{\Delta V}{I} = \frac{6.60}{0.0100} = 660$ Ohms. *****
6. Identify the diagram that shows the **incorrect** direction of the induced current $I_{\text{ind}}$ in the conducting loop. In all the figures, the conducting loops are in $y$-$z$ plane and the currents are in the counter-clockwise direction when viewed from the positive $x$-axis.

A. 

B. 

C. 

D.
Solution

Correct Choice: B
7. The rectangular pool measuring 4.30 meters in width and 5.00 meters in depth is filled with water to the top. As shown in the figure, the 4.30-meter side aligns with the East-West direction. The pool is situated near the equator, where the Sun is directly overhead at noon. At approximately what time will the bottom of the pool begin to be entirely shaded? Given that the index of refraction of water is 1.33.

A. 3:00pm  
B. 3:30pm  
C. 4:00pm  
D. 4:30pm

Solution
Correct Choice: C

The bottom of the pool is completely shaded when the sunlight ray from the edge of the pool refract to the opposite corner. None of the light is incident on the bottom of the pool.

$$\theta_2 = \tan^{-1} \left( \frac{4.3}{5.0} \right) = 40.70^\circ$$

From Snell's law:
$$n_{\text{air}} \sin \theta_1 = n_{\text{water}} \sin \theta_2$$
$$\theta_1 = \sin^{-1} \left[ \frac{n_{\text{water}}}{n_{\text{air}}} \sin(40.70^\circ) \right] = 60.1^\circ \approx 60^\circ$$

The Sun moves 15° every an hour. 60° from directly overhead position takes 4 hours. Therefore, it's 4pm.
8. An insulated container holds 200 grams of solid thermoplastic. Heat is supplied to the thermoplastic at a constant rate of 400 J/s for 180 s. The temperature of the thermoplastic is measured and recorded, and the results are presented in the graph below. Consider the following statements:

![Graph showing temperature vs. time](image)

I. The specific heat of this thermoplastic is 2.00 kJ/kg K.
II. The melting point of this thermoplastic is 160°C.
III. After 120 seconds, only liquid form of the thermoplastic is in the container.
IV. The specific latent heat of fusion of this thermoplastic is 12.0 kJ/kg.

Which of these statements is true?
A. I and II only
B. II and III only
C. I, II and IV only
D. I, II and III only

**Solution**

**Correct Choice: A**

I. The specific heat can be obtained from 0 - 120 s in the graph. \( \Delta T = 120^\circ C \)

\[
c = \frac{Q}{m \Delta T} = \frac{400 \text{ J/s} \times 120 \text{ s}}{0.200 \text{ kg} \times 120^\circ C} = 2.00 \text{ kJ/kg} \cdot \text{K}
\]

II. The melting point is 160°C

III. After 120 seconds, the thermoplastic starts melting. There will be a mixture of liquid and solid thermoplastic in the container. X

IV. The latent heat is much greater than 12 kJ/kg. X
9. The graph below shows the displacement \( D \) of a medium at \( x = 0.0 \) cm as a function of time \( t \) for a wave traveling in the +x direction at a speed of 5.0 cm/s. Determine the wavelength of this wave.

\[
\begin{array}{c}
D \text{ (mm)} \\
\end{array}
\]

\[
\begin{array}{c}
-4 \hspace{1cm} -2 \hspace{1cm} 0 \hspace{1cm} 2 \hspace{1cm} 4 \hspace{1cm} 6 \\
\end{array}
\]

\[
\begin{array}{c}
2 \hspace{1cm} 4 \hspace{1cm} 6 \hspace{1cm} 8 \hspace{1cm} 10 \\
\end{array}
\]

A. 2.0 cm  
B. 5.0 cm  
C. 8.0 cm  
D. 10 cm  

**Solution**  
**Correct Choice: D**  
According to the graph, wave's period is \( T = 2.0 \) s. Then the frequency is \( f = 1/2.0 = 0.50 \) Hz.  
From \( v = f \lambda \), \( \lambda = v/f = 5.0/0.5 = 10 \) cm
10. A smartphone can be used as an acoustic stopwatch. It measures the time interval between two consecutive sound events captured by its microphone. The timing starts when the first sound pulse reaches the microphone and stops when the second sound pulse is detected.

In an experiment aimed at measuring the speed of sound in the air \( v = 340 \text{ m/s} \), two smartphones in acoustic stopwatch mode are placed with their microphones located at a distance \( l = 5.00 \text{ m} \) meters apart, as shown in Figure 1. During the measurement, one student claps next to the microphone of phone A, and a few seconds later, another student claps next to the microphone of phone B. Each clap triggers both phones but at different moments due to the time it takes for the sound waves to travel. What is the possible correct reading from phone A and phone B?

![Diagram of smartphones A and B with microphone and distance l = 5.00 m]

A. Phone A: 0.0147 s, Phone B: 0.0147 s  
B. Phone A: 2.0147 s, Phone B: 2.0000 s  
C. Phone A: 3.1000 s, Phone B: 3.1294 s  
D. Phone A: 2.1294 s, Phone B: 2.1000 s

**Solution**

**Correct Choice: D**

When one student claps next to the phone A, the phone A starts timing and \( l/v \) seconds later the phone B start timing. \( l/v \) is the propagation time of the sound wave from phone A to phone B.

Then the other student claps next to phone B, phone B stops timing and \( l/v \) seconds later the phone A stops timing.

Therefore, time duration shown in phone A is longer than in phone B, because the phone A starts timing first but stops later. The time duration in phone A is longer than in phone B by \( 2l/v = 0.0294 \text{s} \).
11. Use data from the table to answer the question.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>$K_a$ of indicator at $25^\circ$C</th>
<th>Color change (Acid to basic form)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromophenol blue</td>
<td>$1.4 \times 10^{-4}$</td>
<td>Yellow $\rightarrow$ Blue</td>
</tr>
<tr>
<td>Bromocresol green</td>
<td>$2.1 \times 10^{-3}$</td>
<td>Yellow $\rightarrow$ Blue</td>
</tr>
</tbody>
</table>

Colors of both bromophenol blue and bromocresol green turn yellow when the ratio of acid form: basic form is greater than 25:1, while they turn blue when the ratio of basic form: acid form is greater than 5:1. Both indicators are green in between the pH that corresponds to 25:1 and 5:1 ratios. What color could a solution of bromophenol blue appear if it is at the same pH as a solution of bromocresol green that appears green?

A. Blue  
B. Green  
C. Yellow or Green  
D. Green or Blue  

Solution:

\[
\text{HIn} + \text{H}_2\text{O} \rightleftharpoons \text{In}^- + \text{H}_3\text{O}^+
\]

(yellow) (Blue)

\[
K_a = \frac{[\text{In}^-][\text{H}_3\text{O}^+]}{[\text{HIn}]} \quad \ldots \ldots \ldots \text{(Eq.1)}
\]

Yellow $\Rightarrow$ $[\text{HIn}]/[\text{In}^-] > 25/1$
Blue $\Rightarrow$ $[\text{In}^-]/[\text{HIn}] > 5/1$

**pH of Bromocresol green to turn yellow using Eq.1**

\[
2.1 \times 10^{-3} = 5 \times [\text{H}_3\text{O}^+] / 25
\]

\[
[\text{H}_3\text{O}^+] = (2.1 \times 10^{-3})(25) = (5.25 \times 10^{-4})
\]

\[
\text{pH} = -\log([\text{H}_3\text{O}^+]) = -\log(5.25 \times 10^{-4})
\]

\[
\text{pH} = 4 - 0.72 = 3.28
\]

**pH of Bromocresol green to turn blue using Eq.1**

\[
2.1 \times 10^{-3} = 5 \times [\text{H}_3\text{O}^+] / 1
\]

\[
[\text{H}_3\text{O}^+] = (2.1 \times 10^{-3}) / 5 = (4.2 \times 10^{-4})
\]

\[
\text{pH} = -\log([\text{H}_3\text{O}^+]) = -\log(4.2 \times 10^{-4})
\]

\[
\text{pH} = 6 - 0.62 = 5.38
\]

*Therefore, pH range of Bromocresol green is*
\[
\text{yellow} \leftarrow 3.28 \rightarrow 5.38 \rightarrow \text{blue}
\]

range of green

\textbf{pH of Bromophenol blue to turn yellow using Eq.1}

\[
1.4 \times 10^4 = 1 \cdot [\text{H}_2\text{O}^+] \cdot 25
\]

\[
[\text{H}_2\text{O}^+] = (1.4 \times 10^4)(25) = 3.5 \times 10^3
\]

\[
\text{pH} = -\log[\text{H}_2\text{O}^+] = -\log(3.5 \times 10^3)
\]

\[
\text{pH} = 2.46
\]

\textbf{pH of Bromophenol blue to turn blue using Eq.1}

\[
1.4 \times 10^4 = 5 \cdot [\text{H}_2\text{O}^+] \cdot 1
\]

\[
[\text{H}_2\text{O}^+] = (1.4 \times 10^4)/5 = 2.8 \times 10^3
\]

\[
\text{pH} = -\log[\text{H}_2\text{O}^+] = -\log(2.8 \times 10^3)
\]

\[
\text{pH} = 4.55
\]

\textbf{Therefore, pH range of Bromophenol blue is}

\[
\text{yellow} \leftarrow 2.46 \rightarrow 4.55 \rightarrow \text{blue}
\]

range of green

\textbf{Compare the range of Bromocresol green & Bromophenol blue ⇒ pH of solution developing green color for Bromocresol green can cause Bromophenol blue to develop either Green or Blue}

\textbf{Bromophenol blue}

\[
\begin{array}{cc}
\text{Yellow} & \rightarrow 2.46 \\
3.28 & 5.38 \rightarrow \text{Blue}
\end{array}
\]

\textbf{Bromocresol green}

12. From the following observation under standard condition:

(i) Metal M dissolves in H$_2$SO$_4$ (aq), but not in HCl (aq)
(ii) Metal M displaces Ag$^+$ (aq), but not Sn$^+$ (aq)

when $2H^+ + 2e^- \rightarrow H_2$ \hspace{1cm} (E$^\text{red}$ = 0.00 V)

Sn$^{4+}$ + 2e$^- \rightarrow Sn^{2+}$ \hspace{1cm} (E$^\text{red}$ = 0.13 V)

SO$_2^{2-}$ + 4H$^+$ + 2e$^- \rightarrow SO_2 + H_2$O \hspace{1cm} (E$^\text{o}$ = 0.20 V)

Ag$^+$ + e$^- \rightarrow Ag$ \hspace{1cm} (E^\text{red} = 0.80 V)

\text{Estimate the E$^\text{red}$ from the half reaction M$^+$ (aq) + e$^-$ → M(s)}

A. \hspace{0.5cm} 0.00 V < E$^\text{o}$
B. \hspace{0.5cm} 0.00 V < E$^\text{o}$ < 0.13 V
Solution:

(i) M dissolves in H₂SO₄ but not in HCl which indicates that M doesn’t give e⁻ and H⁺

Which mean that Reduction potential (E_{red}^\circ) of M^{n⁺} + ne⁻ → M is higher than

\[2H^+ + 2e^- → H_2 \quad (E_{red}^\circ = 0.00 \text{ V})\]

Dissolution of M in H₂SO₄ indicates that M can give e⁻ to SO₄²⁻

From Reduction potential information

\[\text{SO}_4^{2-} + 4H^+ + 2e^- → \text{SO}_2 + \text{H}_2\text{O} \quad (E_{red}^\circ = 0.20 \text{ V})\]

So, \(E^\circ\) of M^{n⁺} + ne⁻ → M is less than 0.20 V

Therefore, (i) \(0 < E^\circ_{\text{Mn}+/\text{M}} < 0.20\)

(ii) M causes Ag⁺ to disappear, but not Sn²⁺

Which mean that \(E^\circ\) of M is lower than Ag⁺ + e⁻ → Ag (\(E^\circ = 0.80 \text{ V}\))

But higher than Sn³⁺ + 2e⁻ → Sn²⁺ (\(E^\circ = 0.13 \text{ V}\))

Therefore, (ii) \(0.13 < E^\circ_{\text{Mn}+/\text{M}} < 0.80\)

From both (i) & (ii)

\[0.13 < E^\circ_{\text{Mn}+/\text{M}} < 0.20\]
13. A sample of 0.5 g silver metal is obtained from two different silver sources. Source 1 has two stable isotopes, $^{107}\text{Ag}$ (106.91 g/mol) and $^{109}\text{Ag}$ (108.90 g/mol), with isotope abundance of 51.84% and 48.16%, respectively. Source 2 contains $^{107}\text{Ag}$ (106.91 g/mol) and $^{109}\text{Ag}$ (108.90 g/mol), with isotope abundance of 44.80% and 55.20%, respectively. If the isotope ratio ($^{107}\text{Ag}$: $^{109}\text{Ag}$) in the silver sample is 1:1, determine the percentage by mass of silver from source 2 in the sample.

A. 12%
B. 26%
C. 32%
D. 51%

Solution:

Average atomic weight of Ag from Source 1 = (106.91 g/mol)(0.5184) + (108.90 g/mol)(0.4816) = 55.422 + 52.444 = 107.868 g/mol

Average atomic weight of Ag from Source 2 = (106.91 g/mol)(0.4480) + (108.90 g/mol)(0.5520) = 47.896 + 60.113 = 108.009 g/mol

In the mixture => (mol of $^{107}\text{Ag}$)/(mol of $^{109}\text{Ag}$) = 1

\[
\frac{\text{mol of } ^{107}\text{Ag}(\text{No.1}) + \text{mol } ^{107}\text{Ag}(\text{No.2})}{\text{mol of } ^{109}\text{Ag}(\text{No.1}) + \text{mol } ^{109}\text{Ag}(\text{No.2})}
\]

mol of $^{107}\text{Ag}$(No.1) + mol of $^{107}\text{Ag}$(No.2) = mol of $^{109}\text{Ag}$(No.1) + mol of $^{109}\text{Ag}$(No.2)

if mass of Ag from source No.2 = x gram, then

\[
\frac{0.5184}{107.868} + \frac{x}{108.009} = \frac{0.4480}{107.868} + \frac{0.5520}{108.009}
\]

So,

\[
(2.403 \times 10^{-3})\text{mol} - (4.806 \times 10^{-3})\text{mol/g (x)} \times g + (4.148 \times 10^{-3})\text{mol/g (x)} g =
\]

\[
(2.232 \times 10^{-3})\text{mol} - (4.465 \times 10^{-3})\text{mol/g (x)} g + (5.111 \times 10^{-3})\text{mol/g (x)} g
\]
14. Assume that the reactor under the condition given below starts at vacuum, and then \( N_2 \) and \( H_2 \) are fed at constant rates of 2.0 g/min and 0.43 g/min for \( N_2 \) and \( H_2 \), respectively. Once 8.4 g of \( N_2 \) is accumulated in the reactor, ammonia is selectively removed from the reactor at a constant rate to maintain a chemical equilibrium within the reactor. If the equilibrium constant \( K_c \) of this reaction is 3.0 at this temperature, how many grams of ammonia present in the reactor at any given time?

\[
\left(2.400 \times 2.232 \times 10^{-3}\right) \text{ mol} \times \left(3.111 \times 4.800 \times 4.140 \times 10^{-3}\right) \text{ mol/g (x) g}
\]

\[
(0.171 \times 10^{-3}) \text{ mol} = (1.304 \times 10^{-3}) \text{ mol/g (x) g}
\]

\[
x = (0.171 \times 10^{-3}) \text{ mol} / (1.304 \times 10^{-3}) \text{ mol/g} = 0.131 \text{ g}
\]

Therefore, \( x \) from source No.2 = \( (0.131 \times 100) / 0.5 = 26.22% \approx 26% \)

At equilibrium, \( [N_2] = (8.4 \text{ g}) / (28.02 \text{ g/mol}) = 0.30 \text{ mol in a 1-L reactor.} \)

Since the reactor starts from vacuum, to which \( N_2 \) and \( H_2 \) are introduced at the rates of stoichiometric proportion, \( [H_2] = 3[N_2] \) at equilibrium.

We then have

A. 4.8 g
B. 8.4 g
C. 10 g
D. 14 g
3.0 = [NH₃]²⁺/([N₂][H₂])⁴⁺ = [NH₃]²⁺/([N₂][3(N₂)]²⁺) = [NH₃]²⁺/(27[N₂]⁴⁺)
Therefore,
[NH₃] = 9[N₂]² = 9(0.30)² = 0.81 mol/L = 14 g/L or 14 g in this reactor.

15. A student prepares a 1.0 M solution of PtCl₄·5NH₃. The student first tests the conductivity of the solution and it conducts electricity equivalent to the solution of 4.0 M of ions. The student titrates 10.00 cm³ of 1.0 M solution of PtCl₄·5NH₃ with a 1.5 M silver solution and 20.00 cm³ of 1.5 M Ag⁺ is required to reach the end point. A titration was performed to determine the amount of Cl⁻ in the solution according to this reaction.

Ag⁺ (aq) + Cl⁻ (aq) → AgCl (s)

What are the possible species in the prepared PtCl₄·5NH₃ solution?

A. [Pt(NH₃)₅ Cl]³⁺(aq) + 3Cl⁻ (aq)
B. [Pt(NH₃)₅ Cl]⁻ (aq) + 3NH₃(aq)
C. [Pt(NH₃)₅]⁺⁺(aq) + 4Cl⁻ (aq)
D. [Pt(NH₃)₅ Cl]₂⁺(aq) + 2Cl⁻ (aq) + NH₃(aq)

Solution: A) (molecular structure, stoichiometry, coordination compound)

[Pt(NH₃)₅ Cl]Cl₃ → [Pt(NH₃)₅ Cl]⁺⁺ (aq) + 3Cl⁻ (aq)
1 mol of the complex needs 3 mol of Ag⁺
So, there are 3 mol of free Cl⁻ ions for 1 mol of the complex
16. An element X is in the third period of the periodic table. The data for successive ionization energy of the element X are $\text{IE}_1 = 1012$ kJ/mol, $\text{IE}_2 = 1907$ kJ/mol, $\text{IE}_3 = 2914$ kJ/mol, $\text{IE}_4 = 4964$ kJ/mol, $\text{IE}_5 = 6274$ kJ/mol, $\text{IE}_6 = 21268$ kJ/mol, and $\text{IE}_7 = 25431$ kJ/mol. Which of the following statements is correct?

A. A chloride compound of the element could have molecular formula of $\text{XCl}_6$.

B. One chemical formula for the oxide of the element X is $\text{X}_4\text{O}_{10}$.

C. An aqueous solution any oxide of the element X would turn red litmus paper blue.

D. Only one unpaired electron can be found in the electron configuration of the ground state atom.

Solution:

$\text{X} = \text{P}; \text{IE}_1$-IE$_7$ the outermost valence electrons have lower IE than the inner-shell.  
A. incorrect; PCl$_5$ trigonal planar or PCl$_3$ trigonal bipyramidal
B. correct; P$_4$O$_6$, P$_4$O$_{10}$
C. incorrect; P$_4$O$_{10}$ + 6H$_2$O $\rightarrow$ 4H$_3$PO$_4$ turns blue litmus paper red
D. incorrect; both electrons have $n = 3, l = 1, m_l = -1$ with $m_s = \frac{1}{2}$ and $-\frac{1}{2}$, which means they are in the same orbital but spins oppositely. Electrons of P cannot be in the same orbital in the ground state (violates Hund’s rule).
17. If only $\alpha$ ($^4_2$He nucleus) and $\beta^-$ (e-) particles (electrons) are emitted during the following chains of natural radioactive decay:

i. $^{232}_{90}$Th $\rightarrow ^{208}_{82}$Pb

ii. $^{235}_{92}$U $\rightarrow ^{207}_{82}$Pb

iii. $^{237}_{93}$Np $\rightarrow ^{209}_{83}$Bi

iv. $^{238}_{92}$U $\rightarrow ^{206}_{82}$Pb

Which decay processes emit the fewest $\alpha$ and the most $\beta^-$ particles, respectively? (beta decay: $n \rightarrow p^+ + e^-$)

A. i) and ii)
B. iii) and iv)
C. i) and iv)
D. ii) and iii)

Solution:

i) $^{232}_{90}$Th $\rightarrow ^{208}_{82}$Pb + $^4_2$He + $^-_1$B

$232 = 208 + 4\alpha + \beta$

$232 = 208 + 4\alpha + \beta$

$90 = 82 + 2\alpha - \beta$

$\beta = 4$

ii) $\alpha = 7, \beta = 4$

iii) $\alpha = 7, \beta = 4$

iii) $\alpha = 8, \beta = 6$

18. 1,2-dichloroethane or ethylene dichloride (EDC) is a precursor to vinyl chloride which is used to produce polyvinyl chloride (PVC). Its structure is shown below.
The C–C bond rotation in EDC can occur almost freely. This can be thought of as having one CH₂Cl group stationary and having another CH₂Cl rotating around the C–C axis. Figure below shows the change of molecular structure as the function of C–C rotation angle (θ) viewed along the C–C bond.

The dipole moment is the quantitative measurement of how polar the molecule is. The dipole moment of the molecule can be calculated from the vector addition of bond polarity.

Which is the correct plot of dipole moment magnitude as the function of C–C rotation angle (θ)
C.

D.
19. A gas mixture with the total mass of 168 g consists of propane (C\textsubscript{3}H\textsubscript{8}), propene (C\textsubscript{3}H\textsubscript{6}), and propyne (C\textsubscript{3}H\textsubscript{4}). It is found that the mass percentage of propene in this gas mixture is 50%. Upon burning this mixed gas in the excess amount of oxygen, the mass of CO\textsubscript{2} produced from the complete combustion of propane is equal to that produced from the complete combustion of propyne. What is the mole fraction of propyne in this gas mixture?

A. 0.10
B. 0.25
C. 0.50
D. 0.75

\textbf{Solution:}

We already know that there are 84 g of propene.

Let the amount of propane = 84 – x g

And the amount of propyne = x g

Let y = the amount in grams of CO\textsubscript{2} produced from propane/propyne

For the combustion of propane: C\textsubscript{3}H\textsubscript{8} + 5O\textsubscript{2} \rightarrow 3CO\textsubscript{2} + 4H\textsubscript{2}O

Mol of C\textsubscript{3}H\textsubscript{8} = \frac{1}{3} \times \text{mole of CO}_2

\frac{84-x}{44.11} = \frac{1}{3} \times \frac{y}{44.01} \quad \text{......... (1)}

For the combustion of propyne: C\textsubscript{3}H\textsubscript{4} + 4O\textsubscript{2} \rightarrow 3CO\textsubscript{2} + 2H\textsubscript{2}O

Mol of C\textsubscript{3}H\textsubscript{4} = \frac{1}{3} \times \text{mole of CO}_2

\frac{x}{40.07} = \frac{1}{3} \times \frac{y}{44.01} \quad \text{......... (2)}

From (1) and (2), we obtain

\frac{84-x}{44.11} = \frac{x}{40.07}

\therefore \quad x = 40

Therefore, the mole fraction of propyne = \frac{40}{40 + \frac{84}{42} + \frac{44}{44}} = 0.25

20. A series of sulfate samples is to be analyzed by precipitation as BaSO\textsubscript{4}. If it is
known that the sulfate content in these samples ranges between 20% and 55%, what minimum sample mass should be taken to ensure that a precipitate mass no smaller than 0.200 g is produced?

A. 0.150 g  
B. 0.200 g  
C. 0.220 g  
D. 0.412 g

Solution:

Let \( S_w \) = mass of sample in grams

\[
M_{BaSO_4} = 233.4 \text{ g/mole} \quad M_{SO_4^{2-}} = 96.07 \text{ g/mole}
\]

\[
0.200 \text{ g} \ BaSO_4 \times \frac{1 \text{ mole} \ BaSO_4}{233.4 \text{ g}} \times \frac{1 \text{ mole} \ SO_4^{2-}}{1 \text{ mole} \ BaSO_4} = 8.57 \times 10^{-4} \text{ mole} \ SO_4^{2-}
\]

\[
8.57 \times 10^{-4} \text{ mole} \ SO_4^{2-} \times \frac{96.07 \text{ g} \ SO_4^{2-}}{\text{mole}} \times 100\% = 20\% \ SO_4^{2-}
\]

\[
S_w \text{ g sample} = \frac{8.57 \times 10^{-4} \text{ mole} \ SO_4^{2-} \times \frac{96.07 \text{ g} \ SO_4^{2-}}{\text{mole}} \times 100\%}{20\%} = 0.412 \text{ g sample}
\]
21. Scientists labeled membrane proteins (proteins that exist in the plasma membrane) of a mouse cell and a human cell with two different markers. Two cells were fused forming a hybrid cell. Initially, proteins on the hybrid cell’s surface were observed as state A. Normally, after incubating the cell at 37 °C for 1 hour, proteins from different sources would disperse throughout the surface of the cell as in state B.

However, if the cell took 2 hours to transform from state A to state B, which of the following could be the reason(s)?

I. Cell membrane possessed a greater unsaturated-to-saturated phospholipids ratio.
II. Incubation was carried out at 18 °C.

A. I only
B. II only
C. I and II
D. neither I nor II

Answer: B. II only

Explanation
| A. I only | ❌ | This is **incorrect**. A relatively greater unsaturated-to-saturated phospholipids ratio will increase membrane fluidity, hence shorter incubation time required for full protein dispersion. |
| B. II only | ✔️ | This is **correct**. At the temperature much lower than 37 °C, labelled proteins migrate more slowly due to increased viscosity/less fluidity of the membrane, thus, requiring more time to be fully dispersed throughout the entire surface of the cell. |
| C. I and II | ❌ | This is **incorrect**. |
| D. neither I nor II | ❌ | This is **incorrect**. |

**References**


22. The pedigree below illustrates the ABO blood type inheritance of two lineages.

![Pedigree Diagram](image)

Which statements are true according to the pedigree?

I. The baby IV-1 cannot be heterozygote.
II. The probability of III-5 to be a B-type is 0.5.
III. The genotype of II-1 can either be homozygous or heterozygous.
IV. If III-1 is married to an AB-type woman, there is a chance for a child to be B-type.

A. I and II
B. II and III
C. III and IV
D. II and IV

Answer: D. II and IV

Explanation
### Reference


### 23. The following figure shows the structure of a coronavirus. The virus is an RNA virus that has a lipid-rich envelope derived from the membrane of the host cell.
Which of the following statements is incorrect?

A. Chemical analysis should reveal carbohydrate as a component of the coronavirus.
B. Treatment of the coronavirus with ethanol should denature the viral proteins, rendering the virus non-infectious.
C. The N protein is expected to have a net negative charge.
D. The E and M proteins are expected to have hydrophobic amino acids on the surfaces that face the envelope.

Answer: C

Explanation
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Chemical analysis should reveal carbohydrate as a component of the coronavirus.</td>
<td>This is incorrect. The viral genome is a nucleic acid (RNA) that should contain ribose which is a carbohydrate. The proteins on the surface are glycosylated as well, thus contains carbohydrate.</td>
</tr>
<tr>
<td>B. Treatment of the coronavirus with ethanol should destroy lipid-rich membrane and denature the viral proteins, rendering the virus non-infectious.</td>
<td>This is incorrect. Alcohol should be able to denature the proteins. This is the scientific reasoning behind using alcohol as a disinfectant.</td>
</tr>
<tr>
<td>C. The N protein is expected to have a net negative charge.</td>
<td>This is correct. The genome is a nucleic acid that is negatively charged because of the phosphate groups in the backbone. Proteins that interact with nucleic acid are expected to have the opposite charge (net positive charge). In fact, the pI of the SARS-CoV-2 N protein is 10, thus it is positively charged at physiological pH.</td>
</tr>
<tr>
<td>D. The E and M proteins are expected to have hydrophobic amino acids on the surfaces that face the envelope.</td>
<td>This is incorrect. The E and M proteins reside in the envelope which is derived from the cell membrane, thus they are expected to have hydrophobic exteriors.</td>
</tr>
</tbody>
</table>

Reference

24. A person is sick from the COVID-19 virus. What kind of immunity does this person gain due to the infection and then retain after recovery?

A. Active immunity, innate immunity
B. Active immunity, acquired immunity
C. Passive immunity, innate immunity
D. Passive immunity, acquired immunity

Answer: B. Active immunity, acquired immunity

Explanation
<table>
<thead>
<tr>
<th>A. Active immunity, innate immunity</th>
<th>✗ This is incorrect.</th>
</tr>
</thead>
</table>
| B. Active immunity, acquired immunity | ✔ This is correct.  
Active immunity results when exposure to the pathogen (COVID-19 virus) directly triggers the immune system to produce the specific defense that is mediated by B cells and T cells to resist this pathogen.  
Acquired immunity is not present at birth.  
When a person’s immune system encounters pathogens and recognizes antigens, it learns to attack each antigen and begin to develop a memory for that antigen. |
| C. Passive immunity, innate immunity | ✗ This is incorrect.  
Passive immunity is a temporary adaptive immunity conferred by the transfer of antibodies from an immune individual to a non-immune one.  
Innate immunity is present at birth and does not have to be learned through exposure to a pathogen. It provides an immediate response to pathogens. Unlike acquired immunity, it has no memory of the encounters, does not remember specific antigens, and does not provide any ongoing protection against future infection. |
| D. Passive immunity, acquired immunity | ✗ This is incorrect. |

Reference

25. The figure below shows the biceps brachii, which is a muscle that flexes the lower arm. The arrows indicate the tension force acting on the lower arm bone.

Consider the following statements:

I. Biceps brachii can be voluntarily controlled.
II. The muscle cell of the biceps brachii must have a striated appearance with multiple nuclei.
III. The neurotransmitter released by the motor neurons involved in contraction of biceps brachii is glutamate.

Which statements (I-III) are correct?

A. I only
B. II only
C. I and II
D. I and III

Answer: C. I and II

Explanation
C. I and II

I is correct. Biceps brachii is a skeletal muscle (i.e., attaching to a bone) that can be voluntarily controlled from motor cortex.

II is correct. Skeletal muscle cell has striation and many nuclei.

D. I and III

III is incorrect. Motor neuron releases acetylcholine to control skeletal muscle contraction.

Reference


26. The diagram shows blood circulation in a fish. (1: gill circulation, 2: gill capillaries, 3: body capillaries, 4: systemic circulation)
Which of the following statements are correct?

I. P is a ventricle of the heart.
II. Blood in Q is oxygenated.
III. R is a vein.
IV. Blood pressure in S is higher than in R.

A. I and II
B. I and IV
C. II and III
D. III and IV

Answer: D. III and IV

Explanation
| A. I and II | This is incorrect. P is an atrium of the heart (receiving blood from circulation). Blood in Q is deoxygenated blood (before gas is exchanged at the gill). |
| B. I and IV | This is incorrect. P is an atrium of the heart (receiving blood from circulation). Blood pressure in S is higher than in R because blood flows from S to R. |
| C. II and III | This is incorrect. Blood in Q is deoxygenated blood (before gas is exchanged at the gill). R is a vein (conducting blood to the heart). |
| D. III and IV | This is correct. R is a vein (conducting blood to the heart). Blood pressure in S is higher than in R because blood flows from S to R. |

**Reference**


27. Water thyme (*Hydrilla* sp.) plants (1) are placed inside an upturned funnel (2) in a beaker (3) containing pond water (4) with a small amount of NaHCO₃ added. The end of the funnel is covered with a measuring cylinder (5) in which air (6) was trapped. A light bulb (7) is used as a light source.
Consider the following statements:

I. If more NaHCO₃ is added to the water, more bubbles could be observed.
II. If the light is changed from white to blue light at the same intensity, more bubbles could be observed.
III. If the light is changed from white to green light at the same intensity, more bubbles could be observed.
IV. After three hours of the experiment, the air inside the cylinder is mostly carbon dioxide.

Which statements (I-IV) are correct?

A. I only  
B. I and II  
C. II and III  
D. II and IV  

Answer: B. I and II  

Explanation
A. I only ✗ I only is incorrect.

B. I and II ✔ I is correct. In this experiment, bicarbonate from NaHCO₃ is the primary source of CO₂ for photosynthesis. Thus, adding more NaHCO₃ would result in the increase of O₂ production, which could be observed as more bubbles.

II is correct. White light mainly consists of blue, green and red light. The photosynthetic pigments of plants consist of chlorophylls and carotenoids which absorb white light (except green light). Blue light is absorbed by chlorophylls and has sufficient energy levels to activate photosystems. Therefore, if white light is changed to blue light, there should be more photosynthetic activity, resulting in more bubbles.

C. II and III ✗ III is incorrect. Green light is not absorbed by chlorophylls. Thus, there will be much fewer bubbles.

D. II and IV ✗ IV is incorrect. In photosynthesis, CO₂ is used, and O₂ is produced as a byproduct of the reaction. Thus, the air inside the cylinder is mostly O₂.

Reference


28. According to their development, type of flower, and the number of ovaries, fruits are classified into 3 types: 1. simple fruit, which develops from a solitary flower with a single carpel or several fused carpels; 2. aggregate fruit, which develops from a solitary flower with more than one separate carpel, each forming a fruit; and 3. multiple fruit, which develops from an inflorescence with many dense florets, and the ovary walls are fused together into one fruit. If the flower shown in the diagram is fertilized, which type of fruit will be developed? (1: stamen, 2: carpel, 3: pistil, 4: receptacle)
A. A simple fruit
B. An aggregate fruit
C. A multiple fruit
D. A fruit with many seeds

Answer: B. An aggregate fruit

Explanation
<table>
<thead>
<tr>
<th>Option</th>
<th>Correct/Incorrect</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. A simple fruit</td>
<td>✗</td>
<td>This is <strong>incorrect</strong>. Simple fruit develops from a solitary flower with a single ovary, e.g. mango.</td>
</tr>
<tr>
<td>B. An aggregate fruit</td>
<td>✔</td>
<td>This is <strong>correct</strong>. The flower in this figure is a solitary flower with many ovaries on the same receptacle which will develop into aggregate fruit, e.g. strawberry.</td>
</tr>
<tr>
<td>C. A multiple fruit</td>
<td>✗</td>
<td>This is <strong>incorrect</strong>. Multiple fruit develops from inflorescence with many dense florets in the same inflorescence, e.g. pineapple.</td>
</tr>
<tr>
<td>D. A fruit with many seeds</td>
<td>✗</td>
<td>This is <strong>incorrect</strong>. When this flower undergoes fertilization, each fruit will consist of a single seed.</td>
</tr>
</tbody>
</table>

**Reference**


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29. Most of the dinosaurs are members of two lineages, namely Ornithischia and Saurischia. Ornithischia includes the bird-hipped dinosaurs, while Saurischia includes the lizard-hipped dinosaurs. The cladogram illustrates the relationships of these lineages. Modern birds were apparently descended from the saurischians; however, they possess hips similar to those of the relatively unrelated ornithischians.
Which of the following correctly explains the hip similarity in birds and ornithischians?

A. Adaptive radiation of the modern birds
B. Convergent evolution with the ornithischians
C. Divergent evolution with the ornithischians
D. Descent with modification from a common ancestor of the saurischians

Answer  B. Convergent evolution with the ornithischians

Explanation
A. Adaptive radiation of the modern birds  
This is incorrect. Adaptive radiation is a process in which organisms diversify rapidly from an ancestral species into many new forms.

B. Convergent evolution with the ornithischians  
This is correct. Convergent evolution creates analogous structures that have similar form or function but were not present in the last common ancestor of those groups.

C. Divergent evolution with the ornithischians  
This is incorrect. Divergent evolution is the accumulation of differences between closely related populations within a species, sometimes leading to speciation.

D. Descent with modification from a common ancestor of the saurischians  
This is incorrect. Descent with modification is the process by which species accumulate differences from their ancestors as they adapt to different environments over time.

References


30. One of the suggested solutions to reduce greenhouse gas (GHG) emissions and climate
change for a more sustainable future is to find alternatives in our diets, such as switching to plant-based milk instead of cow’s milk. But are they really more environmentally friendly? Growing the crops and the production processes of these goods are not without their impacts. The environmental resources that are required for, and the GHG emissions that result from, production are important considerations. The following graphs show the global average of GHG emissions (kg CO₂), land use (m²) and water use (L) in the production of one liter of milk product.

Graphs:  
1. GHG emissions and land use of all milk products  
2. Water use of all milk products  
3. GHG emissions and land use of plant-based milk products  
4. Water use of plant-based milk products

![Graphs: GHG emissions and land use of all milk products](1)  
![Graphs: Water use of all milk products](2)  
![Graphs: GHG emissions and land use of plant-based milk products](3)  
![Graphs: Water use of plant-based milk products](4)

The width of the bars is not relevant in the analysis of the question.

Consider the proposed plant-based milk products’ suitability as alternatives to cow’s milk. Which of the following statements are supported by the data?
I. All of the proposed plant-based milk products are reasonable alternatives to cow’s milk.

II. Considering all factors, soy milk is the best alternative to cow’s milk.

III. Based on the percentage difference, almond milk is the worst alternative to cow’s milk overall.

IV. Compared to oat milk, cow’s milk is worse for the environment in terms of land use than it is in terms of water use.

V. Almond milk’s water requirements make it unviable as an alternative to cow’s milk.

VI. Oat milk is not the best alternative to cow’s milk for any given factor.

A. I, II, and IV

B. I, III, and VI

C. II, III, and IV

D. II, V, and VI

**Answer**  B. I, III, and VI

**Explanation**
| A. I, II, and IV | II is incorrect. Soy milk is best only in terms of water use, but not for either GHG emissions or land use.  
IV is incorrect. Compared to oat milk, cow’s milk is nine times worse in terms of land use, and 13 times worse in terms of water use. |
| --- | --- |
| ✔︎ | B. I, III, and VI  
I is correct. Compared to cow’s milk, all three plant-based milk products are associated with lower GHG emissions, land use, and water use.  
III is correct. Based on the percentage difference, although almond milk is best in terms of GHG emissions (just under half of soy) and land use (about half of oat), its extremely high water requirement of more than seven times that of oat milk negates the other benefits.  
VI is correct. None of oat milk’s impacts is the lowest. |
| ✔︎ | C. II, III, and IV  
II is incorrect. Soy milk is best only in terms of water use, but not for either GHG emissions or land use.  
IV is incorrect. Compared to oat milk, cow’s milk is nine times worse in terms of land use, and 13 times worse in terms of water use. |
| ✗ | D. II, V, and VI  
II is incorrect. Soy milk is best only in terms of water use, but not for either GHG emissions or land use.  
V is incorrect. All of almond milk’s impacts are still lower than those of cow’s milk. |

Reference
