Theory-Marking Scheme
[Marking Scheme] Rapid and Visual Nucleic Acid Testing for COVID-19

## 1.1 (1.0 pt)

(d)

## 1.2 (1.0 pt)

(a)

## Theory-Marking Scheme

## 1.3 (4.0 pt)

The volume of a gold nanoparticle:
$V_{N P}=\frac{4}{3} \pi\left(\frac{D}{2}\right)^{3}=\frac{4}{3} \times 3.14 \times\left(\frac{30.0 \times 10^{-7}}{2}\right)^{3}=1.41 \times 10^{-17} \mathrm{~cm}^{3}$ or $1.41 \times 10^{-23} \mathrm{~m}^{3}$
The mass of a gold nanoparticle:
1 point
$m_{N P}=\rho V_{N P}=19.3 \times 1.41 \times 10^{-17}=2.72 \times 10^{-16} \mathrm{~g}$
The number of gold atoms in each particle:
2 point
$N=\frac{m_{N P}}{A W_{A u}} \cdot N_{A}=\frac{2.72 \times 10^{-16}}{197.0} \times 6.022 \times 10^{23}=8.31 \times 10^{5}$
OR
4 points
$N=\frac{V_{N P}}{V_{\text {atom }}}=\frac{\pi \rho N_{A} D^{3}}{6 M}=\frac{3.14 \times 19.3 \times 6.022 \times 10^{23} \times\left(30.0 \times 10^{-7}\right)^{3}}{6 \times 197.0}=8.34 \times 10^{5}$
OR
The volume of a gold nanoparticle:
1 point
$V_{N P}=\frac{4}{3} \pi\left(\frac{D}{2}\right)^{3}=\frac{4}{3} \times 3.14 \times\left(\frac{30.0 \times 10^{-7}}{2}\right)^{3}=1.41 \times 10^{-17} \mathrm{~cm}^{3}$ or $1.41 \times 10^{-23} \mathrm{~m}^{3}$
The mass of each gold atom:
$m=\frac{A W_{A u}}{N_{A}}=\frac{197.0}{6.022 \times 10^{23}}=3.271 \times 10^{-22} \mathrm{~g}$
The volume of each gold atom:
1 point
$V_{\text {atom }}=\frac{m}{\rho}=\frac{3.271 \times 10^{-22}}{19.3}=1.69 \times 10^{-23} \mathrm{~cm}^{3}$
The number of gold atoms in each particle:
1 point
$N=\frac{V_{N P}}{V_{\text {atom }}}=\frac{1.41 \times 10^{-17}}{1.69 \times 10^{-23}}=8.34 \times 10^{5}$
4 points in total
-1 point for calculating error.

## Theory-Marking Scheme

## 1.4 (4.0 pt)

The total number of gold atoms:
$N_{\text {Total }}=\frac{5.2 \times 10^{-3}}{394} \times 6.022 \times 10^{23}=7.9 \times 10^{18}$
The concentration of gold nanoparticles:
2 points
$C=\frac{N_{\text {Total }}}{N V N_{A}}=\frac{7.9 \times 10^{18}}{8.34 \times 10^{5} \times 100 \times 10^{-3} \times 6.022 \times 10^{23}}=1.6 \times 10^{-10} \mathrm{~mol} \mathrm{~L}^{-1}$
The extinction coefficient:
1 points
-

1 points
$\varepsilon=\frac{A}{l C}=\frac{0.800}{1 \times 1.6 \times 10^{-10}}=5.0 \times 10^{9} \mathrm{Lmol}^{-1} \mathrm{~cm}^{-1}$
4 points in total
-1 point for each calculating error.
1.5 (4.0 pt)

$$
\begin{array}{ll}
A_{1}=\varepsilon l C_{1}=\varepsilon l \frac{0.10 C_{x}}{1.0}=0.400 & 1 \text { point } \\
A_{2}=\varepsilon l C_{2}=\varepsilon l \frac{0.10 C_{x}+2.0 \times 0.10}{1.0}=0.900 & 1 \text { point }
\end{array} \quad \text { OR } \quad \frac{0.400}{0.900}=\frac{\frac{0.10 C_{x}}{1.0}}{\frac{0.10 C_{x}+2.0 \times 0.10}{1.0}} \quad 2 \text { points }
$$

$C_{x}=1.6 \mu \mathrm{gmL}^{-1}$
4 points in total
-1 point for calculating error.

2 points

## Theory-Marking Scheme

## [Marking Scheme] Chromium in Ancient and Modern Times

## 2.1 (2.0 pt)

A: 8 B: 16
2 points in total, each correct assignment 1 point
2.2 (1.0 pt)

Fe (or iron)

## 2.3 (6.0 pt) <br> $\mathrm{Fe}^{3+}: 7, \mathrm{Cr}^{3+}: 9$

## Solution 1:

Assume there are $x$ Fe ions (including $\mathrm{Fe}^{2+}$ and $\mathrm{Fe}^{3+}$ ) and $y \mathrm{Cr}^{3+}$ ions in a cubic cell, then

$$
\frac{x}{y}=\frac{63.6 \times(52.00 \times 2+16.00 \times 3)}{36.4 \times(55.85 \times 2+16.00 \times 3)}
$$

which gives the result: $\frac{x}{y}=1.66$
Considering that the total amount of the cations in each crystal cell is 24 , it can be obtained

$$
(1+1.66) y=24
$$

which gives the result: $y \approx 9$
Thus, the amount of $\mathrm{Fe}^{3+}$ occupying the octahedral vacancies is

$$
16-9=7
$$

## Solution 2:

Assume there are $x$ Fe ions (including $\mathrm{Fe}^{2+}$ and $\mathrm{Fe}^{3+}$ ) in the final compound, then, the number of $\mathrm{Cr}^{3+}$ should be $3-x$ because the summary of $\mathrm{A}+\mathrm{B}$ should be 3 in $\mathrm{AB}_{2} \mathrm{O}_{4}$, and the formula of the compound should be $\mathrm{Fe}_{x} \mathrm{Cr}_{3-x} \mathrm{O}_{4}$, then

$$
\frac{x}{3-x}=\frac{63.6 \times(52.00 \times 2+16.00 \times 3)}{36.4 \times(55.85 \times 2+16.00 \times 3)}=\frac{5}{3}
$$

which gives the result: $x=1.875$
Accordingly, $\mathrm{Fe}^{2+}$ in the tetrahedral vacancies is 1 , and the number of $\mathrm{Fe}^{3+}$ in the octahedral vacancies is

$$
x-1=1.875-1=0.875
$$

and the number of $\mathrm{Cr}^{3+}$ occupying the octahedral is
$3-x=3-1.875=1.125$
In one unit cell, there are $8 \mathrm{Fe}^{2+}$, thus the numbers of $\mathrm{Fe}^{3+}$ and $\mathrm{Cr}^{3+}$ are

$$
\frac{8}{1} \times 0.875=7 \quad \text { and } \quad \frac{8}{1} \times 1.125=9
$$

respectively.
6 points in total
2 points for the correct molar ratio of $\mathrm{Fe} / \mathrm{Cr}$
1 point for the correct result of the amount of $\mathrm{Cr}^{3+}$
1 point for the correct result of the total amount of Fe
1 point for the correct result of the amount of $\mathrm{Fe}^{3+}$
1 point for the correct result of the number of $\mathrm{Fe}^{3+}$ and $\mathrm{Cr}^{3+}$ in the $\mathbf{B}$ sites of one unit cell

## Theory-Marking Scheme

2.4 (1.0 pt)
$\mathrm{Na}_{2} \mathrm{CrO}_{4}$

## 2.5 (2.0 pt)

$\mathrm{Na}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}+2 \mathrm{H}_{2} \mathrm{SO}_{4} \rightarrow 2 \mathrm{CrO}_{3}+\mathrm{H}_{2} \mathrm{O}+2 \mathrm{NaHSO}_{4}$
Ionic form is acceptable.
-1 point if the stoichiometry is incorrect.
2.6 (1.0 pt)
(A)
2.7 ( 1.0 pt )
(B)
2.8 (5.0 pt)


CFSE $=0-E_{\text {octa }}=0-\left[\left(-2 / 5 \Delta_{\mathrm{o}}\right) \times 3+3 / 5 \Delta_{\mathrm{o}}\right]=3 / 5 \Delta_{\mathrm{o}}=9600 \mathrm{~cm}^{-1}$
5 points in total
1 point for the correct energy level of the five $3 d$ orbitals in octahedral crystal field.
1 point for the correct electron configuration on the energy level lines.
1 point for the correct equation of CFSE.
1 point for the result of CFSE with $\Delta_{0}$.
1 point for the result of CFSE with $\mathrm{cm}^{-1}$.

## Theory-Marking Scheme

$$
\begin{aligned}
& 2.9(2.0 \mathrm{pt}) \\
& \mu=\sqrt{4(4+2)} \mu_{\mathrm{B}}=4.9 \mu_{\mathrm{B}}
\end{aligned}
$$

2 points

## Theory-Marking Scheme

## [Marking Scheme] Capture and Transformation of Carbon Dioxide

```
3.1 (2.0 pt)
A: \(\mathrm{CaCO}_{3}\)
B: CaO
2 points in total; 1 point for each
```

$$
\begin{aligned}
& 3.2(5.0 \mathrm{pt}) \\
& \text { step 1: }(2 \mathrm{a}) 2 \mathrm{NaOH}+\mathrm{CO}_{2} \longrightarrow \mathrm{Na}_{2} \mathrm{CO}_{3}+\mathrm{H}_{2} \mathrm{O} \\
& \text { or } 2 \mathrm{OH}^{-}+\mathrm{CO}_{2} \longrightarrow \mathrm{CO}_{3}^{2-}+\mathrm{H}_{2} \mathrm{O} \\
& \text { (2b) } \mathrm{NaOH}+\mathrm{CO}_{2} \longrightarrow \mathrm{NaHCO}_{3} \\
& \text { or } \mathrm{OH}^{-}+\mathrm{CO}_{2} \longrightarrow \mathrm{HCO}_{3}^{-} \\
& \text {or } \mathrm{Na}_{2} \mathrm{CO}_{3}+\mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O} \longrightarrow 2 \mathrm{NaHCO}_{3} \\
& \text { or } \mathrm{CO}_{3}^{2-}+\mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O} \longrightarrow 2 \mathrm{HCO}_{3}^{-}
\end{aligned}
$$

step 2: (2c) $\quad \mathrm{Na}_{2} \mathrm{CO}_{3}+\mathrm{Ca}(\mathrm{OH})_{2} \longrightarrow \mathrm{CaCO}_{3}+2 \mathrm{NaOH}$
(2d) $\quad \mathrm{NaHCO}_{3}+\mathrm{Ca}(\mathrm{OH})_{2} \longrightarrow \mathrm{CaCO}_{3}+\mathrm{NaOH}+\mathrm{H}_{2} \mathrm{O}$
step 3: (2e) $\mathrm{CaCO}_{3} \longrightarrow \mathrm{CaO}+\mathrm{CO}_{2}$
5 points in total; 1 point for each equation (2a) $\sim(2 e)$
3.3 (2.0 pt)

A: $\quad \mathrm{H}_{2} \rightarrow 2 \mathrm{H}^{+}+2 \mathrm{e}^{-}$
$\mathrm{C}: \quad 2 \mathrm{H}_{2} \mathrm{O}+2 \mathrm{e}^{-} \rightarrow \mathrm{H}_{2}+2 \mathrm{OH}^{-}$
2 points in total; 1 point for each equation

$$
\begin{array}{ll}
3.4(3.0 \mathrm{pt}) \\
\mathbf{1} & \mathrm{H}^{+}+\mathrm{CO}_{3}^{2-} \longrightarrow \mathrm{HCO}_{3}^{-} \\
\mathbf{2} & \mathrm{H}^{+}+\mathrm{HCO}_{3}^{-} \longrightarrow \mathrm{H}_{2} \mathrm{CO}_{3} \\
\mathbf{3} & \mathrm{H}_{2} \mathrm{CO}_{3} \longrightarrow \mathrm{H}_{2} \mathrm{O}+\mathrm{CO}_{2} \\
3 & \text { points in total; } 1 \text { point for each equation. }
\end{array}
$$

## Theory-Marking Scheme

## 3.5 (2.0 pt)

[ $\checkmark$ ] (a)
] (b)
] (c)
$[\checkmark]$ (d)
] (e)

2 points in total; 1 point for each correct selection.
If wrong item(s) is/are included, -1 point for each till the total point is zero, no negative score.
3.6 ( 8.0 pt )

Rate of $\mathrm{H}^{+}$production:
$r\left(\mathrm{H}^{+}\right)=60 \mathrm{~s} \mathrm{~min}^{-1} \times 2.00 \mathrm{~A} /\left(96485 \mathrm{C} \mathrm{mol}^{-1}\right) \quad 2$ points
$=1.24 \times 10^{-3} \mathrm{~mol} \mathrm{~min}^{-1}=1.24 \mathrm{mmol} \mathrm{min}^{-1} \quad 1$ point
Input rate of $\mathrm{HCO}_{3}^{-}$to zone B :
$r\left(\mathrm{HCO}_{3}^{-}\right)=0.10 \mathrm{~mol} \mathrm{~L}^{-1} \times 10.0 \mathrm{~mL} \mathrm{~min}^{-1}=1.0 \mathrm{mmol} \mathrm{min}^{-1}$
Input rate of $\mathrm{CO}_{3}^{2-}$ to zone B :
$r\left(\mathrm{CO}_{3}^{2-}\right)=0.050 \mathrm{~mol} \mathrm{~L}^{-1} \times 10.0 \mathrm{~mL} \mathrm{~min}^{-1}=0.50 \mathrm{mmol} \mathrm{min}^{-1} \quad 1$ point
$\mathrm{H}^{+}+\mathrm{CO}_{3}^{2-} \longrightarrow \mathrm{HCO}_{3}^{-} \quad \mathrm{H}^{+}+\mathrm{HCO}_{3}^{-} \longrightarrow \mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O}$
The amount of dissolved $\mathrm{CO}_{2}$ in the flow:
$10.0 \mathrm{~mL} \mathrm{~min}^{-1} \times 0.033 \mathrm{~mol} \mathrm{~L}^{-1}=0.33 \mathrm{mmol} \mathrm{min}^{-1} \quad 1$ point
Rate of $\mathrm{CO}_{2}$ production:
$r\left(\mathrm{CO}_{2}\right)=r\left(\mathrm{H}^{+}\right)-r\left(\mathrm{CO}_{3}^{2-}\right)-0.33 \mathrm{mmol} \mathrm{min}^{-1} \quad 2$ points
$=1.24 \mathrm{mmol} \mathrm{min}^{-1}-0.50 \mathrm{mmol} \mathrm{min}^{-1}-0.33 \mathrm{mmol} \mathrm{min}^{-1}=0.41 \mathrm{mmol} \mathrm{min}^{-1} \quad 1$ point

8 points in total
Some of the steps in the derivation and in the calculation may be taken implicitly or simultaneously. As long as they are correct, full marks will be scored for each of the partial steps.
$3.7(2.0 \mathrm{pt})$
$\mathrm{Zn}_{24}\left(\mathrm{C}_{4} \mathrm{H}_{5} \mathrm{~N}_{2}\right)_{36}^{12+}$ or $\mathrm{Zn}_{24}\left(\mathrm{C}_{4} \mathrm{H}_{5} \mathrm{~N}_{2}\right)_{60}{ }^{12-}$
2 points in total
Expression $\mathrm{Zn}_{24}(\mathrm{mIm})_{36}^{12+}$ or $\mathrm{Zn}_{24}(\mathrm{mIm})_{60}{ }_{6}^{12-}$ is acceptable.

## Theory-Marking Scheme

## 3.8 (2.0 pt) <br> $\mathrm{Zn}_{12}\left(\mathrm{C}_{4} \mathrm{H}_{5} \mathrm{~N}_{2}\right)_{24}$

2 points in total
Expression $\mathrm{Zn}_{12}(\mathrm{mIm})_{24}$ or $\mathrm{Zn}_{12} \mathrm{C}_{96} \mathrm{H}_{120} \mathrm{~N}_{48}$ is acceptable.

$$
\begin{aligned}
& 3.9(5.0 \mathrm{pt}) \\
& \begin{aligned}
M_{\mathrm{Zn}\left(\mathrm{C}_{4} \mathrm{H}_{5} \mathrm{~N}_{2}\right)_{2}} & =[65.38+(12.01 \times 4+1.01 \times 5+14.02 \times 2) \times 2] \mathrm{g} \mathrm{~mol}^{-1}=227.6 \mathrm{~g} \mathrm{~mol}^{-1} \\
S= & \frac{2 \times 4 \pi r^{2} \times N_{A} \times 1 \mathrm{~g}}{12 \times M_{\mathrm{Zn}\left(\mathrm{C}_{4} \mathrm{H}_{5} \mathrm{~N}_{2}\right)_{2}}} \\
& 1 \text { point } \\
= & \frac{2 \times 4 \times 3.14 \times\left(\frac{1.16 \times 10^{-9} \mathrm{~m}}{2 \times[65.38+(12.01 \times 4+1.01 \times 5+14.01 \times 2) \times 2] \mathrm{g} \mathrm{~mol}^{-1}}\right)^{2} \times 6.02 \times 10^{23} \mathrm{~mol}^{-1} \times 1 \mathrm{~g}}{12 \times 5 \times 10^{5}} \mathrm{~m}^{2}=1.86 \times 10^{3} \mathrm{~m}^{2}
\end{aligned} \\
& =
\end{aligned}
$$

4 points: 2 point for the correct formula (1 point for the coefficient 2 ), 1 for properly introducing data, 1 for correct calculation result.

5 points in total.
Some of the steps in the derivation and in the calculation may be taken implicitly or simultaneously. As long as they are correct, full marks will be scored for each of the partial steps.

## Theory-Marking Scheme

3.10 (7.0 pt)

Volume of one spherical cage:
$V_{\text {Cage }}=(4 / 3) \times 3.14 \times(1.16 \mathrm{~nm} / 2)^{3}=0.817 \mathrm{~nm}^{3} \quad 1$ point
Volume of the unit cell:

$$
V_{\text {cell }}=(1.632 \mathrm{~nm})^{3}=4.347 \mathrm{~nm}^{3} \quad 1 \text { point }
$$

Porosity:

$$
R=2 \times V_{\text {Cage }} / V_{\text {cell }}=2 \times 0.817 \mathrm{~nm}^{3} / 4.347 \mathrm{~nm}^{3}=0.376 \quad 2 \text { points }
$$

1 point for the coefficient 2

$$
\begin{aligned}
V_{\mathrm{p}} & =\frac{2 \times V_{\text {cage }} \times N_{\mathrm{A}} \times 1 \mathrm{~g}}{12 \times M_{\mathrm{Zn}\left(\mathrm{C}_{4} H_{5} \mathrm{~N}_{2}\right)_{2}}}=\frac{\frac{4}{3} \pi r^{3} \times N_{\mathrm{A}} \times 1 \mathrm{~g}}{6 \times M_{\mathrm{Zn}\left(\mathrm{C}_{4} \mathrm{H}_{5} \mathrm{~N}_{2}\right)_{2}}} \\
& =\frac{0.817 \times 10^{-21} \mathrm{~cm}^{3} \times 6.02 \times 10^{23} \mathrm{~mol}^{-1} \times 1 \mathrm{~g}}{6 \times 227.6 \mathrm{~g} \mathrm{~mol}^{-1}}=0.360 \mathrm{~cm}^{3} \quad 3 \text { points }
\end{aligned}
$$

3 points: 1 for the correct formula, 1 for properly introducing data; 1 for correct calculation result
7 points in total.
Some of the steps in the derivation and in the calculation may be taken implicitly or simultaneously. As long as they are correct, full marks will be scored for each of the partial steps.

```
3.11 (2.0 pt)
I (b)
II (d)
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2 points in total, 1 point for each correct selection.

```
3.12 (2.0 pt)
Zn(\mp@subsup{C}{4}{}\mp@subsup{\textrm{H}}{5}{}\mp@subsup{\textrm{N}}{2}{}\mp@subsup{)}{2}{}+\mp@subsup{\textrm{CO}}{2}{}+\mp@subsup{\textrm{H}}{2}{}\textrm{O}\longrightarrow\mp@subsup{\textrm{ZnCO}}{3}{}+2\mp@subsup{\textrm{C}}{4}{}\mp@subsup{\textrm{H}}{6}{}\mp@subsup{\textrm{N}}{2}{}
or }\textrm{Zn}(\textrm{mIm}\mp@subsup{)}{2}{}+\mp@subsup{\textrm{CO}}{2}{}+\mp@subsup{\textrm{H}}{2}{}\textrm{O}\longrightarrow\mp@subsup{\textrm{ZnCO}}{3}{}+2\textrm{HmIm
2 points in total
```


## Theory-Marking Scheme

## [Marking Scheme] A New Journey for Ancient Sulfur

## 4.1 (2.0 pt)

$3 \mathrm{FeS}_{2}+2 \mathrm{O}_{2} \xrightarrow{\Delta} 6 \mathrm{~S}+\mathrm{Fe}_{3} \mathrm{O}_{4}$ or $12 \mathrm{FeS}_{2}+8 \mathrm{O}_{2} \xrightarrow{\Delta} 3 \mathrm{~S}_{8}+4 \mathrm{Fe}_{3} \mathrm{O}_{4}$

No penalty will be given if the heating symbol on the reaction arrow is missing -1 point if the stoichiometry is incorrect.
4.2 ( 4.0 pt )
(a) $\mathrm{Na}_{2} \mathrm{SO}_{3}+\mathrm{I}_{2}+\mathrm{H}_{2} \mathrm{O} \longrightarrow \mathrm{Na}_{2} \mathrm{SO}_{4}+2 \mathrm{HI}$
(2 points)
or
$\mathrm{SO}_{3}^{2-}+\mathrm{I}_{2}+\mathrm{H}_{2} \mathrm{O} \longrightarrow \mathrm{SO}_{4}^{2-}+2 \mathrm{H}^{+}+2 \mathrm{I}^{-}$
(b) $2 \mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}+\mathrm{I}_{2} \longrightarrow \mathrm{Na}_{2} \mathrm{~S}_{4} \mathrm{O}_{6}+2 \mathrm{NaI} \quad$ (2 points)
or
$2 \mathrm{~S}_{2} \mathrm{O}_{3}^{2-}+\mathrm{I}_{2} \longrightarrow \mathrm{~S}_{4} \mathrm{O}_{6}^{2-}+2 \mathrm{I}^{-}$

No partial point will be given if NaOH is present for (a).
No partial point will be given if the oxidation product is not $\mathrm{Na}_{2} \mathrm{~S}_{4} \mathrm{O}_{6}$ or $\mathrm{S}_{4} \mathrm{O}_{6}^{2-}$ for (b).
-1 point if the stoichiometry is incorrect for each equation.

```
4.3 (4.0 pt)
\(0.05122 \mathrm{~mol} \mathrm{~L}^{-1} \times 50.00 \mathrm{~mL}=2.561 \mathrm{mmol}^{(1 \text { point) }}\)
\(\frac{1}{2} \times 0.1012 \mathrm{~mol} \mathrm{~L}^{-1} \times 18.47 \mathrm{~mL}=0.9346 \mathrm{mmol}\)
\((2.561 \mathrm{mmol}-0.9346 \mathrm{mmol}) \times 10^{-3} \times 20 \times 32.06 \mathrm{~g} \mathrm{~mol}^{-1}=1.043 \mathrm{~g} \quad\) ( 1 point)
\(\frac{1.043 \mathrm{~g}}{(1.043 \mathrm{~g}+17.6 \mathrm{~g})} \times 100 \%=5.59 \%\)
(1 point)
4 points in total
For each calculation, consider whether the logic for solving this question is correctly established;
If not, no points will be given.
-1 point if the answer is not correct due to miscalculation.
If the calculation is based on the incorrect equation answered in 4.2 (b), no penalty will be given when the calculation is correct.
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## Theory-Marking Scheme

$4.4(3.0 \mathrm{pt})$
(a) $\mathrm{S}_{8}+16 \mathrm{Li}^{+}+16 \mathrm{e}^{-} \longrightarrow 8 \mathrm{Li}_{2} \mathrm{~S} \quad$ (2 points)
(b) $\mathrm{Li} \longrightarrow \mathrm{Li}^{+}+\mathrm{e}^{-}$or $16 \mathrm{Li} \longrightarrow 16 \mathrm{Li}^{+}+16 \mathrm{e}^{-} \quad$ (1 point)

3 points in total
No partial point will be given if the cathode and anode reactions are reversed.
-1 point if the stoichiometry is incorrect for (a).
No penalty will be given if the equation is written as $S+2 e^{-} \longrightarrow S^{2-}$ for (a).
No penalty will be given if the equation is written as $\mathrm{S}+2 \mathrm{Li}^{+}+2 \mathrm{e}^{-} \longrightarrow \mathrm{Li}_{2} \mathrm{~S}$ for (a).
No penalty will be given if $\mathrm{e}^{-}$is written as e .
$4.5(1.0 \mathrm{pt})$
$\frac{8 \times 32.06}{16 \times 6.941}=2.3$

1 point in total
0.5 point will be given if the ratio is presented in reverse order.

No penalty will be given if the ratio is in reverse order but the cathode and the anode are correctly identified.

## Theory-Marking Scheme

## 4.6 (5.0 pt)

The total energy of the LIB is $3.8 \mathrm{~V} \times 3.110 \mathrm{Ah} \times 3600 \mathrm{~s} / \mathrm{h}=4.25 \times 10^{4} \mathrm{~J}$
Energy consumed by the mobile phone per hour is $\frac{4.25 \times 10^{4} \mathrm{~J}}{22 \mathrm{~h}}=1.93 \times 10^{3} \mathrm{Jh}^{-1}$
The capacity of the ideal lithium-sulfur battery pack is

$$
\frac{23 \mathrm{~g} \times 16 \times 96485 \mathrm{C} \mathrm{~mol}^{-1}}{8 \times 32.06 \mathrm{~g} \mathrm{~mol}^{-1}}=\frac{23 \mathrm{~g} \times 2 \times 96485 \mathrm{C} \mathrm{~mol}^{-1}}{32.06 \mathrm{~g} \mathrm{~mol}^{-1}}=1.4 \times 10^{5} \mathrm{C}
$$

The total energy of the ideal lithium-sulfur battery pack is
$4.2 \mathrm{~V} \times 1.4 \times 10^{5} \mathrm{C}=5.9 \times 10^{5} \mathrm{~J}$
After a full charge, the new battery pack can provide energy for the phone to play videos
continuously for: $\frac{5.9 \times 10^{5} \mathrm{~J}}{1.93 \times 10^{3} \mathrm{Jh}^{-1}}=306 \mathrm{~h}$
(1 point)

## 5 points in total

For each calculation, consider whether the logic for solving this question is correctly established;
If not, no points will be given.
-1 point if the answer is not correct due to miscalculation.
-1 point if any other unit than asked unit is used in the answer.
No penalty will be given if the result is 301 h without rounded calculations.
4.7 (2.0 pt)
$(2 \mathrm{n}-2) \mathrm{Li}+\mathrm{Li}_{2} \mathrm{~S}_{\mathrm{n}} \longrightarrow \mathrm{nLi}_{2} \mathrm{~S}$
-1 point if the stoichiometry is incorrect.
No penalty will be given if n is written as 3-8 and the stoichiometry is correct.

## Theory-Marking Scheme

$$
\left.\left.\left.\begin{array}{l}
4.8(4.0 \mathrm{pt}) \\
\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})(\mathrm{DME}) \longrightarrow \mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})(\mathrm{DME}) \\
\Delta G_{\mathrm{I} \rightarrow \mathrm{II}}^{\ominus}=\Delta G_{\mathrm{d} 1}^{\ominus}(\mathrm{I})-\Delta G_{\mathrm{d} 1}^{\ominus}(\mathrm{II})=20.68 \mathrm{~kJ} \mathrm{~mol}^{-1}-18.92 \mathrm{~kJ} \mathrm{~mol}^{-1}=1.76 \mathrm{~kJ} \mathrm{~mol}^{-1} \\
\text { or } \\
\Delta G_{\mathrm{I} \rightarrow \mathrm{II}}^{\ominus}=\Delta G_{\mathrm{dr}}^{\ominus}(\mathrm{I})-\Delta G_{\mathrm{d} r}^{\ominus}(\mathrm{II})=45.13 \mathrm{~kJ} \mathrm{~mol}^{-1}-43.37 \mathrm{~kJ} \mathrm{~mol}^{-1}=1.76 \mathrm{~kJ} \mathrm{~mol}^{-1} \\
\text { (1 point) } \\
\Delta G_{\mathrm{I} \rightarrow \mathrm{II}}^{\ominus}=-R T \ln K_{\mathrm{I} \rightarrow \mathrm{II}}^{\ominus} \\
K_{\mathrm{I} \rightarrow \mathrm{II}}^{\ominus}=\exp \left(-\frac{1.76 \mathrm{~kJ} \mathrm{~mol}^{-1} \times 1000}{8.314 \mathrm{Jmol}^{-1} \mathrm{~K}^{-1} \times 298.15 \mathrm{~K}}\right)=0.492 \\
K_{\mathrm{I} \rightarrow \mathrm{II}}^{\ominus}=\frac{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right] / c^{\ominus}}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right] / c^{\ominus}}=\frac{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]}=0.492
\end{array} \text { (1 point) }\right) \text { (1 point) }\right) \text { (1 point) }\right)
$$

4 points in total
For each calculation, consider whether the logic for solving this question is correctly established; If not, no points will be given.
-1 point if the answer is not correct due to miscalculation.

## Theory-Marking Scheme

```
4.9 ( 5.0 pt )
\(\frac{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]}=0.492,\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]=0.492\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]\)
```

$\mathrm{Li}_{2} \mathrm{~S}_{6} \longrightarrow \mathrm{Li}^{+}+\mathrm{LiS}_{6}^{-}$
$K_{\mathrm{d} 1}^{\ominus}=\frac{\left[\mathrm{Li}^{+}\right]\left[\mathrm{LiS}_{6}^{-}\right]}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}\right]}=\frac{\left[\mathrm{Li}^{+}\right]\left[\mathrm{LiS}_{6}^{-}\right]}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]+\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]}$
(1 point)
$K_{\mathrm{d} 1}^{\ominus}=\frac{\left[\mathrm{Li}^{+}\right]\left[\mathrm{LiS}_{6}^{-}\right]}{1.492\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]}=\frac{K_{\mathrm{d} 1}^{\ominus}(\mathrm{I})}{1.492}$
(1 point)
or
$K_{\mathrm{d} 1}^{\ominus}=\frac{\left[\mathrm{Li}^{+}\right]\left[\mathrm{LiS}_{6}^{-}\right]}{3.03\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]}=\frac{K_{\mathrm{d} 1}^{\ominus}(\mathrm{II})}{3.03}$
or
$K_{\mathrm{d} 1}^{\ominus}=\frac{\left[\mathrm{Li}^{+}\right]\left[\mathrm{LiS}_{6}^{-}\right]}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]+\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]}=\frac{1}{\frac{1}{K_{\mathrm{d} 1}^{\ominus}(\mathrm{I})}+\frac{1}{K_{\mathrm{d} 1}^{\ominus}(\mathrm{II})}}$
$\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I}) \longrightarrow \mathrm{Li}^{+}+\mathrm{LiS}_{6}^{-}, \Delta G_{\mathrm{d} 1}^{\ominus}(\mathrm{I})=-R T \ln K_{\mathrm{d} 1}^{\ominus}(\mathrm{I})$
(1 point)
$K_{\mathrm{d} 1}^{\ominus}(\mathrm{I})=\exp \left(-\frac{20.68 \mathrm{~kJ} \mathrm{~mol}^{-1} \times 1000}{8.314 \mathrm{~J} \mathrm{~mol}^{-1} \mathrm{~K}^{-1} \times 298.15 \mathrm{~K}}\right)=2.37 \times 10^{-4}$
(1 point)
or

$$
\begin{aligned}
& \mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II}) \longrightarrow \mathrm{Li}^{+}+\mathrm{LiS}_{6}^{-}, \Delta G_{\mathrm{d} 1}^{\ominus}(\mathrm{II})=-R T \ln K_{\mathrm{d} 1}^{\ominus}(\mathrm{II}) \\
& K_{\mathrm{d} 1}^{\ominus}(\mathrm{II})=\exp \left(-\frac{18.92 \mathrm{~kJ} \mathrm{~mol}^{-1} \times 1000}{8.314 \mathrm{~J} \mathrm{~mol}^{-1} \mathrm{~K}^{-1} \times 298.15 \mathrm{~K}}\right)=4.84 \times 10^{-4} \\
& K_{\mathrm{d} 1}^{\ominus}=\frac{2.37 \times 10^{-4}}{1.492}=1.59 \times 10^{-4}
\end{aligned}
$$

or
$K_{\mathrm{d} 1}^{\ominus}=\frac{4.84 \times 10^{-4}}{3.03}=1.59 \times 10^{-4}$
or


5 points in total
For each calculation, consider whether the logic for solving this question is correctly established; If not, no points will be given.
-1 point if the answer is not correct due to miscalculation.

## Theory-Marking Scheme

4.10 (4.0 pt)

$$
\left[\mathrm{Li}_{2} \mathrm{~S}_{6}\right]>\left[\mathrm{LiS}_{6}^{-}\right]>\left[\mathrm{LiS}_{3}^{*}\right]>\left[\mathrm{S}_{6}^{2-}\right]
$$

$\mathrm{LiS}_{6}^{-}(\mathrm{DME}) \longrightarrow \mathrm{Li}^{+}(\mathrm{DME})+\mathrm{S}_{6}^{2-}(\mathrm{DME})$
$\Delta G_{\mathrm{d} 2}^{\ominus}=-R T \ln K_{\mathrm{d} 2}^{\ominus}, K_{\mathrm{d} 2}^{\ominus}=\exp \left(-\frac{100.55 \mathrm{~kJ} \mathrm{~mol}^{-1} \times 1000}{8.314 \mathrm{~J} \mathrm{~mol}^{-1} \mathrm{~K}^{-1} \times 298.15 \mathrm{~K}}\right)=2.418 \times 10^{-18}$
$\mathrm{Li}_{2} \mathrm{~S}_{6} \rightarrow 2 \mathrm{LiS}_{3}^{\bullet}$
$K_{\mathrm{dr}}^{\ominus}=\frac{\left[\mathrm{LiS}_{3}^{\bullet}\right]^{2}}{\left[\mathrm{Li}_{2} \mathrm{~S}_{6}\right]}=\frac{\left[\mathrm{LiS}_{3}^{\bullet}\right]^{2}}{\left.\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]+\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{II})\right]}=\frac{\left[\mathrm{LiS}_{3}^{\bullet}\right]^{2}}{1.492\left[\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I})\right]}=\frac{K_{\mathrm{dr}}^{\ominus}(\mathrm{I})}{1.492}$
$\mathrm{Li}_{2} \mathrm{~S}_{6}(\mathrm{I}) \rightarrow 2 \mathrm{LiS}_{3}^{\bullet}, \Delta G_{\mathrm{dr}}^{\ominus}(\mathrm{I})=-R T \ln K_{\mathrm{dr}}^{\ominus}(\mathrm{I})$
$K_{\mathrm{dr}}^{\ominus}(\mathrm{I})=\exp \left(-\frac{45.13 \mathrm{~kJ} \mathrm{~mol}^{-1} \times 1000}{8.314 \mathrm{~J} \mathrm{~mol}^{-1} \mathrm{~K}^{-1} \times 298.15 \mathrm{~K}}\right)=1.24 \times 10^{-8}$
$K_{\mathrm{dr}}^{\ominus}=\frac{1.24 \times 10^{-8}}{1.492}=8.31 \times 10^{-9}$

4 points in total
+1 point if $\left[\mathrm{Li}_{2} \mathrm{~S}_{6}\right]$ is in the first blank, but (2),(3),(4) and $\left[\mathrm{LiS}_{6}^{-}\right],\left[\mathrm{LiS}_{3}^{\circ}\right],\left[\mathrm{S}_{6}^{2-}\right]$ are not in one-to-one correspondence.
(2), (3), (4) and $\left[\mathrm{LiS}_{6}^{-}\right],\left[\mathrm{LiS}_{3}^{\bullet}\right],\left[\mathrm{S}_{6}^{2-}\right]$ must be in one-to-one correspondence, e.g. -2 points if $\left[\mathrm{LiS}_{3}^{\bullet}\right]>$ $\left[\mathrm{LiS}_{6}^{-}\right]>\left[\mathrm{S}_{6}^{2-}\right]$.

## Theory-Marking Scheme

4.11 (6.0 pt)




$$
\begin{array}{ll}
\Delta G_{1}^{\ominus}=\Delta G_{\mathrm{g}}^{\ominus}+\Delta G_{\mathrm{s} 1}^{\ominus} & \text { (1 point) } \\
\Delta G_{2}^{\ominus}=\Delta G_{\mathrm{g}}^{\ominus}+\Delta G_{\mathrm{s} 2}^{\ominus} & \text { (1 point) }  \tag{2}\\
(2)-(1): \Delta G_{2}^{\ominus}-\Delta G_{1}^{\ominus}=\Delta G_{\mathrm{s} 2}^{\ominus}-\Delta G_{\mathrm{s} 1}^{\ominus} \\
\mathrm{Li}(\text { metal }) \longrightarrow \mathrm{Li}^{+}\left(\mathrm{H}_{2} \mathrm{O}\right)+\mathrm{e}^{-}, \Delta G_{1}^{\ominus}=n F E^{\ominus}\left(\mathrm{Li}^{+}\left(\mathrm{H}_{2} \mathrm{O}\right) / \mathrm{Li}\right) \\
\mathrm{Li}(\text { metal }) \longrightarrow \mathrm{Li}^{+}(\mathrm{DME})+\mathrm{e}^{-}, \Delta G_{2}^{\ominus}=n F E^{\ominus}\left(\mathrm{Li}^{+}(\mathrm{DME}) / \mathrm{Li}\right) & \text { (1 point) } \\
n F E^{\ominus}\left(\mathrm{Li}^{+}(\mathrm{DME}) / \mathrm{Li}\right)=n F E^{\ominus}\left(\mathrm{Li}^{+}\left(\mathrm{H}_{2} \mathrm{O}\right) /{\mathrm{Li})-\Delta G_{\mathrm{s} 1}^{\ominus}+\Delta G_{\mathrm{s} 2}^{\ominus}}^{\left.\left.96 \mathrm{~mol}^{-1}\right)\right] \times 1000}=-3.016 \mathrm{~V}\right. & \text { (1 point) } \\
E^{\ominus}\left(\mathrm{Li}^{+}(\mathrm{DME}) / \mathrm{Li}\right)=-3.040-\frac{\left[\left(-116.9 \mathrm{~kJ} \mathrm{~mol}^{-1}\right)-\left(-114.6 \mathrm{~kJ} \mathrm{~mol}^{-1}\right) \times 1\right. \text { point) }}{9648 \mathrm{C} \mathrm{~mol}^{-1}}
\end{array}
$$

6 points in total
For each calculation, consider whether the logic for solving this question is correctly established. If not, no points will be given.
-1 point if the answer is not correct due to miscalculation.

## Theory-Marking Scheme

4.12 ( 5.0 pt )

Assume $\left[\mathrm{S}_{4}^{2-}\right]=c_{1}$, the original concentration of $\mathrm{Li}_{2} \mathrm{~S}$ is $c_{0}$
According to the charge balance:

$$
\begin{align*}
& 2 c_{0}=1 \times\left[\mathrm{S}_{3}^{\bullet-}\right]+2 \times\left[\mathrm{S}_{4}^{2-}\right]+2 \times\left[\mathrm{S}_{5}^{2-}\right]+2 \times\left[\mathrm{S}_{6}^{2-}\right]+2 \times\left[\mathrm{S}_{7}^{2-}\right]+2 \times\left[\mathrm{S}_{8}^{2-}\right] \\
& 2 c_{0}=17.50 c_{1}+1.00 \times 2 c_{1}+4.50 \times 2 c_{1}+55.00 \times 2 c_{1}+5.00 \times 2 c_{1}+0.75 \times 2 c_{1}=150 c_{1} \\
& c_{0}=75 c_{1}
\end{align*}
$$

According to the material balance:
$c_{0}+\frac{4.81 \mathrm{mg}}{32.07 \mathrm{~g} \mathrm{~mol}^{-1} \times 10.00 \mathrm{~mL}}$
$=17.50 \times 3 c_{1}+1.00 \times 4 c_{1}+4.50 \times 5 c_{1}+55.00 \times 6 c_{1}+5.00 \times 7 c_{1}+0.75 \times 8 c_{1}$
(1 point)
$75 c_{1}+0.0150 \mathrm{mmol}^{-1}=450 c_{1}$
(1 point)
$c_{1}=4.00 \times 10^{-5} \mathrm{mmol}_{\mathrm{mL}^{-1}}$
$m\left(\mathrm{Li}_{2} \mathrm{~S}\right)=75 \times 4.00 \times 10^{-5} \mathrm{mmol} \mathrm{mL}^{-1} \times 10.00 \mathrm{~mL} \times 45.96 \mathrm{~g} \mathrm{~mol}^{-1}=1.38 \mathrm{mg}$
(1 point)

5 points in total
For each calculation, consider whether the logic for solving this question is correctly established. If not, no points will be given.
-1 point if the answer is not correct due to miscalculation.

## Theory-Marking Scheme

## [Marking Scheme] Interconversion among Nitrogen Oxides

| $15 \%$ of the total |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Question | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 5.10 | Total |  |  |  |  |  |  |  |
| Points | 4 | 4 | 2 | 4 | 3 | 8 | 4 | 6 | 4 | 6 | $\mathbf{4 5}$ |  |  |  |  |  |  |  |
| Score |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

## 5.1 (4.0 pt)

Using the definition of $K_{c 1}=\frac{\left[\mathrm{N}_{2} \mathrm{O}_{2}\right]}{[\mathrm{NO}]^{2}},\left[\mathrm{~N}_{2} \mathrm{O}_{2}\right]=K_{\mathrm{c} 1}[\mathrm{NO}]^{2}$ is obtained.
Thus, $r_{+}=k_{2}\left[\mathrm{~N}_{2} \mathrm{O}_{2}\right]\left[\mathrm{O}_{2}\right]=k_{2} K_{c 1}[\mathrm{NO}]^{2}\left[\mathrm{O}_{2}\right]$

4 points in total
1 point for the correct expression of $K_{c 1}$
1 point for the expression of $r_{+}$with $\left[\mathrm{N}_{2} \mathrm{O}_{2}\right]$ and $\left[\mathrm{O}_{2}\right]$
1 point for the correct $\left[\mathrm{N}_{2} \mathrm{O}_{2}\right]$
1 point for the correct $r_{+}$
5.2 (4.0 pt)

Combining $K_{c 1}=\exp (M-N / T), k_{2}=A_{2} \exp \left(-\frac{E_{\mathrm{a}, 2}}{R T}\right)$ and $k_{+}=k_{2} K_{c 1}$,
$k_{+}=k_{2} K_{c 1}=A_{2} \exp \left(-\frac{E_{\mathrm{a}, 2}}{R T}\right) \exp \left(M-\frac{N R}{R T}\right)=A_{2} \exp (M) \exp \left(-\frac{E_{\mathrm{a}, 2}+N R}{R T}\right)$.
Comparing this equation with Arrhenius equation,
$A_{+}=A_{2} \exp (M)$ and $E_{\mathrm{a}+}=E_{\mathrm{a}, 2}+N R$ are obtained.

4 points in total
1 point for the correct expression of $k_{2}$
1 point for the correct expression of $k_{+}$with $E_{\text {a,2 }}, A_{2}, M$ and $N$
1 point for the correct expression of $A_{+}$
1 point for the correct expression of $E_{\text {a+ }}$

## 5.3 (2.0 pt)

Calculation:
According to Arrhenius equation, $\ln \frac{k_{+}\left(T_{2}\right)}{k_{+}\left(T_{1}\right)}=\frac{E_{\mathrm{a}+}}{R}\left(\frac{1}{T_{1}}-\frac{1}{T_{2}}\right)$ is obtained.
Thus, $k_{+}(700 \mathrm{~K})=6.86 \times 10^{5} \mathrm{~L}^{2} \mathrm{~mol}^{-2} \mathrm{~min}^{-1}$

2 points in total
If $k_{+}(700 \mathrm{~K})$ is incorrect due to miscalculation, 1 point will be deducted.

## Theory-Marking Scheme

## 5.4 (4.0 pt)

## Calculation:

Because $\Delta_{\mathrm{r}} H_{\mathrm{m}}^{\ominus}$ and $\Delta_{\mathrm{r}} S_{\mathrm{m}}^{\ominus}$ do not change with temperature,
$\Delta_{r} H_{m}^{\ominus}(600 \mathrm{~K})$
$=\Delta_{r} H_{m}^{\ominus}(298 \mathrm{~K})$
$=2 \Delta_{f} H_{m}^{\ominus}\left(\mathrm{NO}_{2}, 298 \mathrm{~K}\right)-\Delta_{f} H_{m}^{\ominus}(\mathrm{NO}, 298 \mathrm{~K})-\Delta_{r} H_{m}^{\ominus}\left(\mathrm{O}_{2}, 298 \mathrm{~K}\right)$
$=-116.4 \mathrm{~kJ} \mathrm{~mol}^{-1}$
$\Delta_{r} S_{m}^{\ominus}(600 \mathrm{~K})$
$=\Delta_{r} S_{m}^{\ominus}(298 \mathrm{~K})$
$=2 S_{m}^{\ominus}\left(\mathrm{NO}_{2}, 298 \mathrm{~K}\right)-2 S_{m}^{\ominus}(\mathrm{NO}, 298 \mathrm{~K})-S_{m}^{\ominus}\left(\mathrm{O}_{2}, 298 \mathrm{~K}\right)$
$-146.6 \mathrm{~J} \mathrm{~K}^{-1} \mathrm{~mol}^{-1}$
For a thermostatic process, $\Delta G=\Delta H-T \Delta S$, thus $\Delta_{\mathrm{r}} G_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})=-28.44 \mathrm{~kJ} \mathrm{~mol}^{-1}$
Using the equation of $K_{p}^{\ominus}=\exp \left(-\Delta_{\mathrm{r}} G_{\mathrm{m}}^{\ominus} / R T\right), K_{p}^{\ominus}(600 \mathrm{~K})=299.2$ is obtained.

4 points in total
1 point for the correct value of $\Delta_{\mathrm{r}} H_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$
1 point for the correct value of $\Delta_{\mathrm{r}} S_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$
1 point for the correct value of $\Delta_{\mathrm{r}} G_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$ or the correct relationship among $\Delta_{\mathrm{r}} H_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$, $\Delta_{\mathrm{r}} S_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$ and $K_{p}^{\ominus}(600 \mathrm{~K})$
1 point for the correct value of $K_{p}^{\ominus}(600 \mathrm{~K})$
If any miscalculation exists, 1 point will be deducted.

## 5.5 (3.0 pt)

## Calculation:

Using the equation of $\Delta_{\mathrm{r}} U_{\mathrm{m}}^{\ominus}=\Delta_{\mathrm{r}} H_{\mathrm{m}}^{\ominus}-\sum \nu R T$ and $\sum \nu$ value of $-1\left(\nu_{\mathrm{NO}_{2}}-\nu_{\mathrm{NO}}-\nu_{\mathrm{O}_{2}}=2-2-1=-1\right)$, $\Delta_{\mathrm{r}} U_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})=-111.4 \mathrm{~kJ} \mathrm{~mol}^{-1}$ is obtained.

3 points in total
1 point for the correct relationship between $\Delta_{\mathrm{r}} U_{\mathrm{m}}^{\ominus}$ and $\Delta_{\mathrm{r}} H_{\mathrm{m}}^{\ominus}$
1 point for the correct value of $\Sigma \nu$
1 point for the correct value of $\Delta_{\mathrm{r}} U_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$
If $\Delta_{\mathrm{r}} U_{\mathrm{m}}^{\ominus}(600 \mathrm{~K})$ is incorrect due to miscalculation, 0.5 points will be deducted

## Theory-Marking Scheme

## 5.6 (6.0 pt)

## Calculation:

When chemical equilibrium is reached, $K_{c}=\frac{\left[\mathrm{NO}_{2}\right]_{\mathrm{eq}}^{2}}{[\mathrm{NO}]_{\mathrm{eq}}^{2}\left[\mathrm{O}_{2}\right]_{\mathrm{eq}}}$ and $r_{-\mathrm{eq}}=r_{+\mathrm{eq}}$.
Thus, $r_{-\mathrm{eq}}=r_{+\mathrm{eq}}=k_{+}[\mathrm{NO}]_{\mathrm{eq}}^{2}\left[\mathrm{O}_{2}\right]_{\mathrm{eq}}=k_{+} \frac{\left[\mathrm{NO}_{2}\right]_{\mathrm{eq}}^{2}}{K_{c}}=k_{-}\left[\mathrm{NO}_{2}\right]_{\mathrm{eq}}^{2}$
Therefore, $r_{-}=k_{-}\left[\mathrm{NO}_{2}\right]^{2}$
Using the equation of $K_{c}=K_{p}^{\ominus}\left(\frac{R T}{p^{\ominus}}\right)^{-\sum_{\mathrm{B}} \nu_{\mathrm{B}}}$ and $K_{p}^{\ominus}(600 \mathrm{~K})$ value of $299.2, K_{c}=1.49 \times 10^{4} \mathrm{~L} \mathrm{~mol}^{-1}$ is obtained.
According to $k_{-}=k_{+} / K_{c}$, the value of $k_{-}$is calculated to be $44.4 \mathrm{~L} \mathrm{~mol}^{-1} \mathrm{~min}^{-1}$ If the $K_{p}^{\ominus}(600 \mathrm{~K})$ value is used as 350.0, the result should be 38.0.

8 points in total
1 point for the consideration of $r_{- \text {eq }}=r_{+ \text {eq }}$
2 points for the correct expression of $r_{-}$
1 point for the correct relationship among $k_{+}, K$ and $k_{-}$
4 points for the correct value of $k_{-}$
If $K_{p}^{\ominus}$ instead of $K_{c}$ is used, 2 points will be deducted
If $k_{-}$is incorrect due to miscalculation, 1 point will be deducted

## 5.7 (4.0 pt)

Calculation:
According to the stoichiometry of the reaction and setting $p_{\mathrm{NO}_{2}}=0.8 p_{0}, p_{\mathrm{NO}}=0.2 p_{0}$ and $p_{\mathrm{O}_{2}}=0.1 p_{0}$ are obtained.

$$
K_{p}^{\ominus}=\frac{\left(p_{\mathrm{NO}_{2}} / p^{\ominus}\right)^{2}}{\left(p_{\mathrm{NO}} / p^{\ominus}\right)^{2}\left(p_{\mathrm{O}_{2}} / p^{\ominus}\right)}=\frac{\left(0.8 p_{0} / p^{\ominus}\right)^{2}}{\left(0.2 p_{0} / p^{\ominus}\right)^{2}\left(0.1 p_{0} / p^{\ominus}\right)}=\frac{160 p^{\ominus}}{p_{0}}
$$

Therefore, $p_{0}=53.5 \mathrm{kPa} . \quad p_{\text {total }}=p_{\mathrm{NO}_{2}}+p_{\mathrm{NO}}+p_{\mathrm{O}_{2}}=1.1 p_{0}=58.8 \mathrm{kPa}$
If the $K_{p}^{\ominus}(600 \mathrm{~K})$ value is used as 350.0 , the result of 50.3 kPa is obtained.
4 points in total
1 point for the expression of $K_{p}^{\ominus}$. If $p^{\ominus}$ is omitted, no penalty.
1 point for the correct ratio among $p_{\mathrm{NO}_{2}}, p_{\mathrm{NO}}$ and $p_{\mathrm{O}_{2}}$
2 points for the correct value of $p_{\text {total }}$
If $p_{\text {total }}$ is incorrect due to miscalculation, 1 point will be deducted

## Theory-Marking Scheme

## 5.8 ( 6.0 pt )

The given mechanism involves a pre-equilibrium:
$r_{\mathrm{S}+1}=r_{\mathrm{S}-1}, k_{\mathrm{S}+1}\left[\mathrm{O}_{2}\right] \theta_{v}^{2}=k_{\mathrm{S}_{-1}} \theta_{\mathrm{O}}^{2}, \theta_{\mathrm{O}} / \theta_{v}=\left(k_{\mathrm{S}+1}\left[\mathrm{O}_{2}\right] / k_{\mathrm{S}-1}\right)^{0.5}$
$r_{\mathrm{S}+2}=r_{\mathrm{S}-2}, k_{\mathrm{S}+2}[\mathrm{NO}] \theta_{v}=k_{\mathrm{S}-2} \theta_{\mathrm{NO}}, \theta_{\mathrm{NO}} / \theta_{v}=k_{\mathrm{S}+2}[\mathrm{NO}] / k_{\mathrm{S}-2}$
$r_{\mathrm{S}+4}=r_{\mathrm{S}-4}, k_{\mathrm{S}_{+4}} \theta_{\mathrm{NO}_{2}}=k_{\mathrm{S}_{-4}}\left[\mathrm{NO}_{2}\right] \theta_{v}, \theta_{\mathrm{NO}_{2}} / \theta_{v}=k_{\mathrm{S}_{-4}}\left[\mathrm{NO}_{2}\right] / k_{\mathrm{S}_{+4}}$
Because $\theta_{v}+\theta_{\mathrm{NO}}+\theta_{\mathrm{NO}_{2}}+\theta_{\mathrm{O}}=1$, using the ratios among these coverages,
$\theta_{v}=\frac{1}{1+\left(k_{\mathrm{S}+1}\left[\mathrm{O}_{2}\right] / k_{\mathrm{S}-1}\right)^{0.5}+k_{\mathrm{S}+2}[\mathrm{NO}] / k_{\mathrm{S}-2}+k_{\mathrm{S}_{-4}}\left[\mathrm{NO}_{2}\right] / k_{\mathrm{S}+4}}$ is obtained.
6 points in total
1 point for the correct expression of $\theta_{0} / \theta_{v}$
1 point for the correct expression of $\theta_{\mathrm{NO}} / \theta_{v}$
1 point for the correct expression of $\theta_{\mathrm{NO} 2} / \theta_{v}$
1 point for the utilization of the normalized condition
2 points for the correct expression of $\theta_{v}$
If no derivation is provided, 6 points for the correct expression of $\theta_{v}$
One of the numerator and the four parts of the denominator of this expression is wrong, 4 points; two of them are wrong, 2 points; three or more are wrong, 0 point.

## 5.9 (4.0 pt)

(B)

4 points for choosing (B)
2 points for choosing (A)
0 points for other choices
5.10 (6.0 pt)
(B)

6 points for choosing (B)
0 points for other choices

## Theory-Marking Scheme

## [Marking Scheme] Enabling Phosphines

```
6.1 (3.0 pt)
R
3 points in total;
3 \text { points for assigning as R}
```

6.2 ( 6.0 pt )


A
$\mathbf{A}^{\prime}$

6 points in total.
3 points for each;
no points if any structure containing $\mathrm{C}=\mathrm{P}$ is given:




6.3 ( 8.0 pt )


B' $^{\prime}$

$\mathbf{C}^{\prime}$

8 points in total.
4 points for each.
Reasonable resonance structures of $\mathbf{B}$ ' and $\mathbf{C}$ ' are also acceptable.
1 point is given if structures with two methyl esters or two ethyl esters.

## Theory-Marking Scheme

6.4 ( 5.0 pt )


6

5 points in total.
2 points if the isomerized structure is given:

6.5 (6.0 pt)


P2

6 points in total.
6 points for 4 correct asterisks, 1.5 points for each;
-1.5 points for every wrong asterisk till 0 points.

```
6.6 (3.0 pt)
90:10
3 points in total;
3 points for the correct answer: 90/10 or 9/1 or 9
```


## Theory-Marking Scheme

6.7 (5.0 pt)
(d)

5 points in total;
5 points for choosing (d)

## Theory-Marking Scheme

## Organic Molecules in Life

7.1 (12.0 pt)


7


9


12

12 points in total.
4 points for each;
2 points for the enantiomer of 9 , or the structure missing the chirality is given;
2 points if the enol form of 12 is given:


## Theory-Marking Scheme

7.2 (8.0 pt)


15


16

8 points in total.
4 points for each;
4 points for the resonance structures of 15 or if azide is written as $\mathrm{N}_{3}$ :


$\mathrm{N}=\mathrm{N}=\mathrm{N}$



2 points for its protonated form:


1 point if the nitrosonation on the nitrogen linked to carbonyl is given:


## Theory-Marking Scheme

7.3 (12.0 pt)




12 points in total.
4 points for the isomers of 21:



2 points if the form of NGP is given:


1 point if the second protein is added at the $\beta$ position of amide group, and no double punishment for 24 and 25.

## [Marking Scheme] Amazing Chiral Spiro Catalyst

8.1 (16.0 pt)



1



4


2


5

16 points in total.
4 points for each correct structure as shown above.
4 points if the cis isomer of 1 is given
2 points if the regioisomer of 4 is given
8.2 (2.0 pt)
(c)

2 points in total;
2 points for choosing (c)

```
8.3 (2.0 pt)
(b)
2 points in total;
2 points for choosing (b)
```


## Theory-Marking Scheme

8.4 (2.0 pt)

Ir(III) or +3
2 points in total;
2 points for $\operatorname{Ir}(\mathrm{III})$ or +3
8.5 (2.0 pt)

6
2 points in total;
2 points for 6
8.6 (8.0 pt)


15


16

8 points in total.
4 points for each;
2 points for correct skeleton, missing or wrong stereochemistry;
2 points if the regioisomer of $\mathbf{1 6}$ is given
8.7 (2.0 pt)
(b)

2 points in total;
2 points for choosing (b)
8.8 (2.0 pt)
(a)

2 points in total;
2 points for choosing (a)

## Theory-Marking Scheme

[Marking Scheme] Total Synthesis of Capitulactone

| $9 \%$ of the total |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Question | 9.1 | 9.2 | 9.3 | 9.4 | Total |
| Points | 24 | 2 | 16 | 2 | $\mathbf{4 4}$ |
| Score |  |  |  |  |  |

9.1 (24.0 pt)




11

24 points in total.
4 points for each;
2 points for each structure of 8,9 or 11 with missing or wrong stereochemistry.
9.2 (2.0 pt)
(d)

2 points in total;
2 points for choosing (d)
9.3 (16.0 pt)

15

16

18

19

16 points in total.
4 points for each;
2 points if structure with missing or wrong stereochemistry is given.

## Theory-Marking Scheme


9.4 (2.0 pt)
(b)

2 points in total;
2 points for choosing (b)

