PART A: MULTIPLE CHOICE AND MATCHING (24 KU)

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1. A rate of reaction is usually obtained by measuring
   a. the rate at which products are consumed
   b. the rate at which reactants are produced
   c. the rate at which reactants are consumed
   d. the temperature of the solution
   e. the mass and volume of the products

2. What is the overall rate of change in the combustion reaction of propane if the initial volume of propane is 5.0 L and after 20 minutes of burning is 3.6 L?
   a. $7.0 \times 10^{-2}$ L/min
   b. 14.3 L/min
   c. $4.5 \times 10^{-2}$ L/min
   d. 22.2 L/min
   e. none of the above

3. What is the average rate of production of H₂ in the reaction of zinc with hydrochloric acid if after 30 s the volume of hydrogen gas is 20 mL, and after 1 minute, the volume is 62 mL?
   a. 62 mL/s
   b. 1.4 mL/s
   c. 62 mL/min
   d. either a or b
   e. either b or c

4. Within a reaction with 2 reactants and 2 products, the reaction rate can be measured with respect to
   a. all 4 substances
   b. 3 of the substances
   c. 2 of the substances
   d. only 1 of the substances
   e. not enough information to determine

5. What property would be appropriate to measure the reaction rate in the reaction between magnesium and hydrochloric acid?
   a. change in conductivity
   b. change in mass
   c. change in colour
   d. change in pressure
   e. change in volume

6. Which of the following is not a factor that controls the rate of the reaction
   a. chemical nature of the reactants
   b. concentration of the reactants
   c. the number of products formed
   d. surface area
   e. temperature

7. Generally, temperature affects the rate of a reaction in which of the following ways?
   a. increasing the temperature reduces the rate of the reaction
   b. decreasing the temperature decreases the rate of the reaction
   c. increasing the temperature increases the rate of the reaction
   d. both a and b are correct
   e. both b and c are correct

8. The presence of a catalyst is thought to increase the rate of a reaction by
   a. changing the products that are formed in the reaction
   b. decreasing the enthalpy change of the reaction
   c. increasing the enthalpy change of the reaction
   d. decreasing the activation energy of the reaction
   e. increasing the activation energy of the reaction
9. If for the reaction, \( aX + bY \rightarrow \text{products} \), the rate law is determined to be \( r = k[X]^1[Y]^5 \), then the order of the reaction is which of the following?
   a. 1
   b. 2
   c. 3
   d. 4
   e. 5

10. If for the reaction \( aX + bY \rightarrow \text{products} \), the rate law is determined to be \( r = k[X]^4[Y]^0 \), then
   a. the order of the reaction is 0
   b. increasing the concentration of Y will have no effect on the rate
   c. increasing the concentration of X will have no effect on the rate
   d. increasing the concentration of Y will increase the rate of the reaction
   e. there is no way to determine the value of \( k \)

11. The following diagram represents a kinetic energy distribution at two temperatures.

   ![Diagram of kinetic energy distribution]

   In comparing the two temperatures, it is obvious that
   a. \( T_1 > T_2 \)
   b. \( T_2 > T_1 \)
   c. \( T_1 \approx T_2 \)
   d. \( T_1 = T_2 \)
   e. it cannot be determined

12. The amount of energy required for a reaction to begin is known as
   a. enthalpy change
   b. reaction energy
   c. activation energy
   d. kinetic energy
   e. potential energy

13. The activated complex
   a. is an unstable molecule
   b. has the maximum potential energy possible
   c. may continue on to produce products
   d. may revert to reactants
   e. all of the above

14. If a reaction can be broken down into a reaction mechanism, then the steps of the reaction mechanism are known as
   a. stages of reaction
   b. activated complexes
   c. reaction progress
   d. elementary steps
   e. primary equations

15. The rate determining step is
   a. the first step in a reaction mechanism
   b. the last step in a reaction mechanism
   c. the slowest step in a reaction mechanism
   d. the fastest step in a reaction mechanism
   e. the only step in a reaction mechanism
16. Consider the above reaction mechanism. The rate-determining step of this reaction is
a. elementary step 1
b. elementary step 2
c. elementary step 3
d. elementary steps 2 and 3
e. impossible to tell from this information

17. Consider the above reaction mechanism. The reaction intermediates are formed in
a. elementary step 1
b. elementary step 2
c. elementary step 3
d. elementary steps 1 and 2
e. impossible to tell from this information

18. Consider the above reaction mechanism. The rate-law equation from this reaction would be
a. \( r = k[HBr][O_2] \)
b. \( r = k[HOBr]^2 \)
c. \( r = k[HBr][O_2] \)
d. \( r = k[HOBr][HBr] \)
e. impossible to tell from this information

Match these terms with the descriptions below. A term can be used more than once or not at all.

a. reaction intermediates
b. activation energy
c. rate-determining step
d. effective collision
e. elementary step
f. reaction mechanism
g. catalyst
h. rate law
i. ineffective collision
j. temperature

19. a measure of the average kinetic energy of the particles

20. involve particles that rebound essentially unchanged by a collision

21. a step in a reaction mechanism that involves only a 1, 2, or 3 particle collision

22. a series of elementary steps that make up an overall reaction

23. the slowest step in a reaction mechanism

24. molecules formed as short-lived products in reaction mechanisms
PART A: MULTIPLE CHOICE & MATCHING (24 Marks)

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24.

PART B: SHORT ANSWER

1. Plot a typical rate of reaction graph (Concentration of Reactant vs. Time) and indicate how to determine both average and instantaneous rate of reaction. (3 marks)

2. What is the rate law? (3 marks)

3. What are the key concepts of the collision theory? (2 marks)

4. How is the rate-determining step related to the rate-law equation? Give an example to illustrate this relationship. (2 marks)

5. How can the effect of temperature on the rate of the reaction be explained by collision theory? (2 marks)

6. How can the effect of a catalyst on a reaction be explained by collision theory? (2 marks)
1. a) Use the following data to calculate the rate law for the system. (3 marks)

\[ NO_{(g)} + H_{2(g)} \rightarrow HNO_{2(g)} \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>NO (mol/L)</th>
<th>H2 (mol/L)</th>
<th>Initial Rate of Reaction (mol/(L·s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.001</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>2</td>
<td>0.002</td>
<td>0.004</td>
<td>0.008</td>
</tr>
<tr>
<td>3</td>
<td>0.003</td>
<td>0.004</td>
<td>0.018</td>
</tr>
<tr>
<td>4</td>
<td>0.004</td>
<td>0.001</td>
<td>0.008</td>
</tr>
<tr>
<td>5</td>
<td>0.004</td>
<td>0.002</td>
<td>0.016</td>
</tr>
<tr>
<td>6</td>
<td>0.004</td>
<td>0.003</td>
<td>0.024</td>
</tr>
</tbody>
</table>

b) Calculate the rate constant. (3 marks)

c) Calculate reaction rate when [NO]=[H2]=0.20 mol/L. (3 marks)

d) Propose a possible reaction mechanism. Explain your thinking. (3 marks)
MULTIPLE CHOICE

1. ANS: C  REF:  K/U  OBJ:  6.1  STO:  EC2.01
2. ANS: A  REF:  I  OBJ:  6.1  STO:  EC2.06
3. ANS: B  REF:  I  OBJ:  6.1  STO:  EC2.06
4. ANS: E  REF:  K/U  OBJ:  6.1  STO:  EC1.03
5. ANS: E  REF:  K/U  OBJ:  6.1  STO:  EC1.03
8. ANS: D  REF:  K/U  OBJ:  6.2  STO:  EC1.04
9. ANS: C  REF:  K/U  OBJ:  6.3  STO:  EC1.03
10. ANS: B  REF:  K/U  OBJ:  6.3  STO:  EC1.03
12. ANS: C  REF:  K/U  OBJ:  6.4  STO:  EC2.01
13. ANS: E  REF:  K/U  OBJ:  6.4  STO:  EC2.01
14. ANS: D  REF:  K/U  OBJ:  6.4  STO:  EC1.06
15. ANS: C  REF:  K/U  OBJ:  6.4  STO:  EC1.06
16. ANS: A  REF:  K/U  OBJ:  6.4  STO:  EC1.06
17. ANS: D  REF:  K/U  OBJ:  6.4  STO:  EC1.06
18. ANS: C  REF:  K/U  OBJ:  6.4  STO:  EC1.06

MATCHING

19. ANS: J  REF:  K/U  OBJ:  6.3  STO:  EC2.01
20. ANS: I  REF:  K/U  OBJ:  6.4  STO:  EC2.01
21. ANS: E  REF:  K/U  OBJ:  6.4  STO:  EC2.01
22. ANS: F  REF:  K/U  OBJ:  6.4  STO:  EC2.01
23. ANS: C  REF:  K/U  OBJ:  6.4  STO:  EC2.01
24. ANS: A  REF:  K/U  OBJ:  6.4  STO:  EC2.01

HORT ANSWER

25. ANS:

On this graph, the average rate of reaction over a time period is the absolute value of the slope of the secant drawn between the two points.
26. **ANS:**
The rate, \( r \), will always be proportional to the product of the initial concentrations of the reactants, where these concentrations are raised to some exponential values. This can be expressed as:

\[
r \propto \left( [A]^a \cdot [B]^b \right)
\]

27. **ANS:**
- a chemical system consists of particles that are in constant random motion at various speeds (KMT)
- a chemical reaction must involve collisions of particles with each other or the walls of the container
- an effective collision is one that has sufficient energy and correct orientation of the colliding particles so that bonds can be broken and new bonds formed
- ineffective collisions involve particles that rebound from the collision, essentially unchanged in nature
- the rate of a given reaction depends on the frequency of collisions and the fraction of those collisions that are effective

28. **ANS:**
there is a direct correlation between the exponents in the rate equation and the equation coefficients in the rate-determining step (e.g., if then the rate-determining step of the reaction is)

\[ r = k[HBr][Cl_2] \]

**ANS:**
- an increase in temperature has a dramatic effect on the rate of reaction, because temperature affects both the collision frequency and the fraction of collisions that have enough energy to be effective collisions
- particles moving with higher kinetic energy (temperature=average kinetic energy) are more likely to have enough energy to overcome the activation energy of the reaction

**ANS:**
- the catalyst does not increase the number of collisions; however, it increases the fraction of collisions that are effective by lowering the activation energy of the reaction
- since the activation energy is lower, the number of collisions that have enough energy to overcome the activation energy is thus increased; therefore, more effective collisions

**ANS:**
From the equation we can write the partial rate law as

\[ r_{NO} = k[HNO][H] \]

Using experiments 1 and 2, the concentration jumps from 0.001 to 0.002 moles/L. IT DOUBLES!! The rates for these same experiments. The rate jumps from 0.002 to 0.008 moles/L seconds. IT QUADRUPLED!!.

The exponential constant 'm' for the [NO] is the mathematical relationship between these two values. i.e.

\[ 2^m = 4 \text{ therefore } m = 2 \text{ because } 2^2 = 4 \]
Look at experiments 4 and 5. The $\text{H}_2$ concentration DOUBLES and the rate DOUBLES.

$2^n = 2$ therefore $n = 1$ since $2^1 = 2$

So the rate law expression can be rewritten as

\[
\text{rate} = k \ [\text{NO}]^2 \ [\text{H}_2]^1
\]

Now to determine the value of 'k'. Choose any one of the experiments.

Using experiment 1. Using the rate law, above fill in the values from the data table.

\[
0.002 \text{ mol/L sec} = k \ (0.001 \text{ mol/L})^2 \times (0.004 \text{ mol/L})
\]

\[
0.002 \text{ mol/L sec} = k \ (0.000001 \text{ mol}^2/\text{L}^2) \times (0.004 \text{ mol/L})
\]

\[
0.002 \text{ mol/L sec} = k \times 0.000 \ 000 \ 009 \text{ mol}^3/\text{L}^3
\]

\[
k = 0.002 \text{ mol/L sec}
\]

\[
0.000 \ 000 \ 004 \text{ mol}^3/\text{L}^3
\]

\[
= 500,000 \text{ sec/mol}^2 \text{ L}^2 \text{ or sec mol}^{-2} \text{ L}^{-2}
\]

**Therefore the rate law equation for this reaction is**

\[
\text{rate} = 500,000 \text{ sec mol}^{-2} \text{ L}^{-2} \ [\text{NO mole/L}]^2 \ [\text{H}_2 \text{ mol/L}]
\]

REF: I OBJ: 6.3 STO: EC2.06