IMPORTANT: On the scantron (answer sheet), you MUST clearly fill your name, your student number, section number, and test form (white cover = test form A; yellow cover = test form B). Use a #2 pencil.

There are 25 questions on this exam. Check that you have done all of the problems and filled in the first 25 bubbles on the scantron. Your score will be reported in percent (max 100%).

Exam policy

- Calculators with text-programmable memory are not allowed.
- Relevant data and formulas, including the periodic table, are attached at the end of this exam.
- Your grade will be based only on what is on the scantron form.
- The answer key will be posted on the web after the exam (on the Exam Schedule page).
- You must turn in your cover sheet with your scantron answer form.

Hints

- As you read the question, underline or circle key words to highlight them for yourself. Avoid errors from "mis-reading" the question.
- Pay attention to units and magnitudes (decimal places) of numbers obtained from calculations.
- There is no penalty for guessing.
1. What is the most likely product of the radioactive decay of $^{137}$Cs?

A. $^1_{1}$p
B. $^0_{-1}$e
C. $^1_{0}$n
D. $^4_{2}$He
E. $^0_{1}$e

2. In a breeder reaction $^{238}_{92}$U absorbs a neutron to form $^{239}_{92}$U. After this nuclei undergoes 2 $\beta$ decays, what is the product?

A. $^{239}_{93}$Np
B. $^{237}_{91}$Pa
C. $^{239}_{91}$Pa
D. $^{237}_{92}$U
E. $^{239}_{94}$Pu

3. Which one of the following statements about the rate constant $k$ is false?

A. $k$ is dependent on concentration of the reactants.
B. $k$ increases with increasing temperature.
C. $k$ decreases with increasing activation energy.
D. $k$ can be increased by adding a catalyst.
E. the reaction rate is directly proportional to $k$. 

4. A catalyst

(i) lowers the overall enthalpy of the reaction.
(ii) lowers the activation energy of the forward reaction only.
(iii) raises the activation energy of the reverse reaction only.
(iv) lowers the activation energy of both the forward and reverse reactions.

Correct answer is

A. (i) only
B. (ii) only
C. (iii) only
D. (iv) only
E. (i) and (ii)

5. The following data were measured for the reaction

\[ \text{BF}_3 \text{ (g) } + \text{NH}_3 \text{ (g)} \rightarrow \text{F}_3\text{BNH}_3 \text{ (g)} \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>BF(_3) (M)</th>
<th>NH(_3) (M)</th>
<th>Initial rate (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.250</td>
<td>0.250</td>
<td>0.2130</td>
</tr>
<tr>
<td>2</td>
<td>0.250</td>
<td>0.125</td>
<td>0.1065</td>
</tr>
<tr>
<td>3</td>
<td>0.350</td>
<td>0.100</td>
<td>0.1193</td>
</tr>
<tr>
<td>4</td>
<td>0.175</td>
<td>0.100</td>
<td>0.0596</td>
</tr>
</tbody>
</table>

Determine the rate law for the reaction.

A. \( \text{rate} = k[\text{BF}_3] \)
B. \( \text{rate} = k[\text{NH}_3] \)
C. \( \text{rate} = k[\text{BF}_3][\text{NH}_3] \)
D. \( \text{rate} = k[\text{BF}_3]^2[\text{NH}_3] \)
E. \( \text{rate} = k[\text{BF}_3][\text{NH}_3]^2 \)
6. Consider the following reaction

$$A + B + C \rightarrow D \quad \text{Rate} = k[A][B]^2$$

Which of the following will **not** increase the reaction rate?

A. Increasing the concentration of $A$.
B. Increasing the concentration of $B$.
C. Increasing the concentration of $C$.
D. Adding a catalyst to the reaction mixture.
E. Raising the reaction temperature.

7. The rate of a reaction increases with increasing temperature because the

A. reactant molecules collide less frequently.
B. reactant molecules collide with greater energy.
C. activation energy is lowered.
D. reactant molecules collide in the right orientation.
E. the concentration of the reactant molecules increases.

8. Which of the following statements concerning the nuclear reactor is (are) **false**?

1. Pure $^{235}$U is used as the fuel in the reactor.
2. The control rods present in the reactor absorb excess neutrons.
3. Even during "melt-down", the reactor cannot explode like a nuclear bomb.
4. Water can be used as a coolant for the reactor core.

A. 1 only
B. 3 only
C. 1 and 3
D. 4 only
E. 3 and 4
9. Consider the following reaction:

\[ A + B \rightarrow C + D \]

The consumption of both reactants A and B was monitored over time, and the reaction was found to be zero order in A and second order in B. Which plot best resembles the results of the experiment?
10. The following diagrams represent mixtures of NO (g) and O₂ (g). These two substances react as follows:

\[ 2 \text{ NO} (g) + \text{O}_2 (g) \rightarrow 2 \text{ NO}_2 (g) \]

It has been determined experimentally that the rate is second order in NO and first order in O₂. Based on this fact, rank the following mixtures in order of increasing initial rate.

A. 1 > 2 > 3  
B. 1 > 3 > 2  
C. 2 > 3 > 1  
D. 3 > 1 > 2  
E. 3 > 2 > 1
11. Based on the reaction coordinate diagram below, which of the following statements are true?

i. The reaction is endothermic.
ii. There are two transition states and three intermediates.
iii. This reaction occurs in three steps.
iv. The second step of this reaction is the slow step.

A. i only.
B. i and ii.
C. ii and iii.
D. iii and iv.
E. ii, iii, and iv.
12. The half-life of $^{90}$Sr, a byproduct of nuclear weapons development, is 28.8 years. If 50.0 g of $^{90}$Sr is released into the groundwater from a nuclear waste storage site, how long will it take for the mass of the sample to be reduced to 1.56 g?

A. 70.0 years
B. 97.0 years
C. 135 years
D. 144 years
E. 200 years

13. For the third-order reaction shown below, the rate constants are $1.44 \times 10^{-2} \text{ M}^{-2}\text{s}^{-1}$ at $35^\circ\text{C}$, and $3.91 \times 10^{-2} \text{ M}^{-2}\text{s}^{-1}$ at $45^\circ\text{C}$. Calculate the activation energy for this reaction.

$$\text{HNO}_2(\text{aq}) + \text{NO}_3^- (\text{aq}) + \text{H}^+(\text{aq}) \rightarrow 2\text{NO}_2(\text{aq}) + \text{H}_2\text{O}(\ell)$$

A. 32.5 kJ/mol
B. 153 kJ/mol
C. 1.31 kJ/mol
D. 81.3 kJ/mol
E. 0.75 kJ/mol

14. What is the binding energy per nucleus of $^{235}\text{U}$ (a radioactive isotope of uranium)?

The mass of the $^{235}\text{U}$ nucleus is 235.0439 amu.

A. $1.679 \times 10^{17}$
B. $1.679 \times 10^{14}$
C. $5.437 \times 10^{-21}$
D. $2.788 \times 10^{-10}$
E. $3.500 \times 10^{-8}$
15. The following reaction describes the oxidation of nitric oxide to form nitrogen dioxide, a contributor in the formation of acid rain:

\[ 2 \text{NO} (g) + \text{O}_2 (g) \rightarrow 2 \text{NO}_2 (g) \]

The reaction was monitored at room temperature in a series of experiments to obtain the following kinetic data:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [NO] (M)</th>
<th>Initial [O\textsubscript{2}] (M)</th>
<th>Initial rate (M/s)</th>
</tr>
</thead>
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<tr>
<td>1</td>
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<td>0.0500</td>
<td>0.438</td>
</tr>
<tr>
<td>2</td>
<td>0.0250</td>
<td>0.0250</td>
<td>0.219</td>
</tr>
<tr>
<td>3</td>
<td>0.0500</td>
<td>0.0250</td>
<td>0.875</td>
</tr>
</tbody>
</table>

What is the rate constant for this reaction?

A. \(1.40 \times 10^4\) M\(^{-2}\) s\(^{-1}\)  
B. \(2.30 \times 10^{-3}\) M\(^{-2}\) s\(^{-1}\)  
C. \(1.81\) M\(^{-1}\) s\(^{-1}\)  
D. \(3.93 \times 10^3\) s\(^{-1}\)  
E. \(1.42\) M\(^{-1}\) s\(^{-1}\)

16. The isotope \(^{172}\text{Ta}\) undergoes decay by positron emission. After 2 hr, 1/16 of the initial amount of \(^{172}\text{Ta}\) remains undecayed. What is the half-life of this isotope?

A. 15 min  
B. 30 min  
C. 45 min  
D. 60 min  
E. 90 min
17. The plot below shows the change in concentration during the decomposition of NaN₃. How long would it take for the initial concentration of NaN₃ to drop to 40.0% of its original concentration?

![Graph showing the change in concentration during the decomposition of NaN₃.](image)

\[ y = -0.0275x - 0.5933 \]

\[ R^2 = 0.99984 \]

A. 149 sec  
B. 18.6 sec  
C. 25.2 sec  
D. 134 sec  
E. 33.3 sec

18. The isotope $^{55}_{26}$Fe has a neutron-to-proton ratio slightly lower than the belt of stability. What decay process is the isotope likely to undergo in order to become more stable?

(i) electron capture  
(ii) positron emission  
(iii) α -particle emission

A. (i) only  
B. (ii) only  
C. (iii) only  
D. either (i) or (ii)  
E. either (ii) or (iii)
19. What is the relationship between the rate of disappearance of A and the rate of appearance of B?

![Graph showing concentration over time for concentrations labeled [A] and [B].]

A. \(-\frac{\Delta[A]}{\Delta t} = \frac{\Delta[B]}{\Delta t}\)
B. \(-\frac{\Delta[A]}{\Delta t} = \frac{1}{2} \frac{\Delta[B]}{\Delta t}\)
C. \(-\frac{\Delta[A]}{\Delta t} = \frac{1}{3} \frac{\Delta[B]}{\Delta t}\)
D. \(-\frac{\Delta[A]}{\Delta t} = 3 \frac{\Delta[B]}{\Delta t}\)
E. \(-\frac{\Delta[A]}{\Delta t} = 2 \frac{\Delta[B]}{\Delta t}\)
20. The rate law for the reaction: \(2H_2(g) + 2NO(g) \rightarrow N_2(g) + 2H_2O(g)\) is
\[\text{Rate} = k[H_2][NO]^2\]

Which of the following mechanisms can be ruled out based on the observed rate law?

<table>
<thead>
<tr>
<th>Mechanism I</th>
<th>Mechanism II</th>
<th>Mechanism III</th>
</tr>
</thead>
<tbody>
<tr>
<td>(H_2 + NO \rightarrow H_2O + N) (slow)</td>
<td>(H_2 + 2NO \rightarrow N_2O + H_2O) (slow)</td>
<td>(2NO \leftrightarrow N_2O_2) (fast)</td>
</tr>
<tr>
<td>(N + NO \rightarrow N_2 + O) (fast)</td>
<td>(N_2O + H_2 \rightarrow N_2 + H_2O) (fast)</td>
<td>(N_2O + H_2 \rightarrow N_2O + H_2O) (slow)</td>
</tr>
<tr>
<td>(O + H_2 \rightarrow H_2O) (fast)</td>
<td></td>
<td>(N_2O + H_2 \rightarrow N_2 + H_2O) (fast)</td>
</tr>
</tbody>
</table>

A. Mechanism I only  
B. Mechanism II only  
C. Mechanism III only  
D. Mechanisms I and III  
E. Mechanisms II and III

21. \(^{14}\text{C}\) can be used in medicine as a radioactive tracer. If a labeled medicine has an activity of \(3.70 \times 10^5\) dps, how many \(^{14}\text{C}\) atoms are in the sample? The half-life for \(^{14}\text{C}\) is \(t_{1/2} = 5.73 \times 10^3\) years. (HINT: There are \(3.1557 \times 10^7\) s per year.)

A. \(9.65 \times 10^{16}\)  
B. \(2.12 \times 10^{18}\)  
C. \(6.70 \times 10^{16}\)  
D. \(4.64 \times 10^{14}\)  
E. \(3.06 \times 10^{18}\)
22. Consider the reaction

\[ 4 \text{PH}_3 (g) \rightarrow 6 \text{H}_2 (g) + \text{P}_4 (g) \]

A flask is charged with 1.00 mol of PH\(_3\) (g) in a total volume of 1.00 L. The following data is collected:

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moles of PH(_3)</td>
<td>1.00</td>
<td>0.67</td>
<td>0.45</td>
<td>0.30</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Between t = 10 sec and t = 30 sec, what is the average rate of appearance of H\(_2\)?

A. 0.028 M/s  
B. 0.021 M/s  
C. 0.0053 M/s  
D. 0.015 M/s  
E. 0.036 M/s

23. Hydrogen sulfide (H\(_2\)S) is a common and troublesome pollutant in industrial wastewater. One way to remove H\(_2\)S is to treat the water with chlorine, in which case the following reaction occurs:

\[ \text{H}_2\text{S} (aq) + \text{Cl}_2 (aq) \rightarrow \text{S} (s) + 2 \text{Cl}^- (aq) + 2 \text{H}^+ (aq) \]

The rate of this reaction is first order in each reactant. The rate constant for the disappearance of H\(_2\)S at 28 °C is \(3.5 \times 10^{-2}\) M\(^{-1}\)s\(^{-1}\). If at a given time the concentration of H\(_2\)S is \(2.0 \times 10^{-4}\) M and that of Cl\(_2\) is 0.0025 M, what is the rate of appearance of Cl\(^-\)?

A. \(1.8 \times 10^{-8}\) M/s  
B. \(3.5 \times 10^{-8}\) M/s  
C. \(5.4 \times 10^{-8}\) M/s  
D. \(9.0 \times 10^{-8}\) M/s  
E. \(8.1 \times 10^{-8}\) M/s
24. The decomposition of NO\(_2\) was studied at 656 K and the data was plotted below:

![Graph](image)

The y-intercept of the plot is 9.20, and the slope of the line is 10.16. If the experiment is repeated with an initial NO\(_2\) concentration of 0.200 M, how long would it take to decompose half of the NO\(_2\)?

A. 15.1 sec  
B. 5.62 sec  
C. 1.39 sec  
D. 0.492 sec  
E. 0.068 sec

25. The activation energy of an uncatalyzed reaction is 200 kJ/mol. After adding a catalyst, the activation energy is lowered to 50 kJ/mol. Assuming that the frequency factor remains the same, how much faster is the catalyzed reaction than the uncatalyzed reaction at 85 °C?

A. \(2.0 \times 10^{-22}\) times faster.  
B. \(2.0 \times 10^{12}\) times faster.  
C. \(8.0 \times 10^{21}\) times faster.  
D. \(8.0 \times 10^{-22}\) times faster.  
E. They will be the same rate.
1. Standard Electrode Potentials

Half-reaction | $E^\circ$ (V) |
--- | --- |
$F_2(g) + 2e^- \rightarrow 2F^-(aq)$ | 2.87 |
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightarrow 2H_2O(l)$ | 1.776 |
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$ | 1.359 |
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$ | 1.23 |
$Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$ | 0.065 |
$Ag^+(aq) + e^- \rightarrow Ag(s)$ | 0.799 |
$Fe^3+(aq) + e^- \rightarrow Fe^2+(aq)$ | 0.771 |
$O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O_2(aq)$ | 0.68 |
$I_2(s) + 2e^- \rightarrow 2I^-(aq)$ | 0.536 |
$Cu^+(aq) + e^- \rightarrow Cu(s)$ | 0.521 |
$Sn^4+(aq) + 2e^- \rightarrow Sn^2+(aq)$ | 0.154 |
$Cu^2+(aq) + 2e^- \rightarrow Cu(s)$ | 0.153 |
$SO_4^{2-}(aq) + H_2O(l) + 2e^- \rightarrow SO_3^{2-}(aq) + 2OH^-(aq)$ | 0.93 |
$Mn^2+(aq) + 2e^- \rightarrow Mn(s)$ | 1.18 |
$Al^3+(aq) + 3e^- \rightarrow Al(s)$ | 1.66 |
$Mg^2+(aq) + 2e^- \rightarrow Mg(s)$ | 2.37 |
$Na^+(aq) + e^- \rightarrow Na(s)$ | 2.71 |
$Ca^2+(aq) + 2e^- \rightarrow Ca(s)$ | 2.87 |
$Li^+(aq) + e^- \rightarrow Li(s)$ | 3.05 |

2. Constants

| | |
--- | --- |
$R = 8.314 \text{ J mol}^{-1}\text{K}^{-1}$ | |
$R = 0.0821 \text{ L-atm mol}^{-1}\text{K}^{-1}$ | |
$F = 96,485 \text{ coulombs/mol electrons}$ | |
$h = 6.62606876 \times 10^{-34} \text{ J-s}$ | |
$mass_{\text{1 atom}} = 1.0086649 \text{ amu}$ | |
$mass_{\text{1 amu}} = 1.0072765 \text{ amu}$ | |
$1 \text{ g} = 6.02214 \times 10^{23} \text{ mol}$ | |
$1 \text{ amp} = 1 \text{ coul sec}^{-1}$ | |
$Avogadro's \text{ no.} = 6.02214 \times 10^{23} \text{ mol}^{-1}$ | |
$c = 2.99792458 \times 10^{8} \text{ m sec}^{-1}$ | |
$1 \text{ m} = \frac{kg \text{ m}^2 \text{ sec}^{-2}}{C-V}$ | |
$K_p = K_c (RT)^{\Delta n}$ | |
$E = mc^2$ | |
$E = h \nu$ | |
$\lambda \nu = E$ | |
$\lambda = \frac{E}{\nu}$ | |
$\sigma$ | |
$\pi$ | |
$\pi^*$ | |
$\sigma^*$ | |
$\nu$ | |
$\Delta \nu$ | |
$\Delta \nu = \nu_f - \nu_i$ | |
$\Delta \nu = E_{\text{exc}} - E_{\text{ground}}$ | |
$\Delta \nu = \frac{\Delta E}{\nu}$ | |
$\Delta \nu = \frac{E_{\text{exc}} - E_{\text{ground}}}{\nu}$ | |
$\Delta \nu = \frac{E_{\text{exc}} - E_{\text{ground}}}{\nu}$ | |
$\Delta \nu = \frac{E_{\text{exc}} - E_{\text{ground}}}{\nu}$ | |
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## PERIODIC TABLE of the ELEMENTS

### MAIN GROUPS

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### TRANSITION METALS

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### LANTHANOID AND ACTINOIDS

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