Science Olympiad Division C

CHEMISTRY LAB

DO NOT TURN THE PAGE UNTIL INSTRUCTED TO DO SO

Total Time: 50 Minutes
Part I: 15 Multiple Choice Questions
Part II: 5 Free Response Questions

General Instructions

- All answers and written responses must be indicated on the provided Answer Sheet.
- You are to proceed freely between Part I and Part II.
- It is suggested that you spend 20 minutes on Part I and 30 minutes on Part II.
- A Periodic Table is provided on the inside cover of this test booklet.
- You may write in this test booklet.

Scoring

- Multiple Choice: 2 Points for each correct answer. 0 Points for each incorrect answer or omission.
- Free Response: Point values are indicated next to each question. 40 Points total.

TEAM NAME

COMPETITOR NAMES

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 †**Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

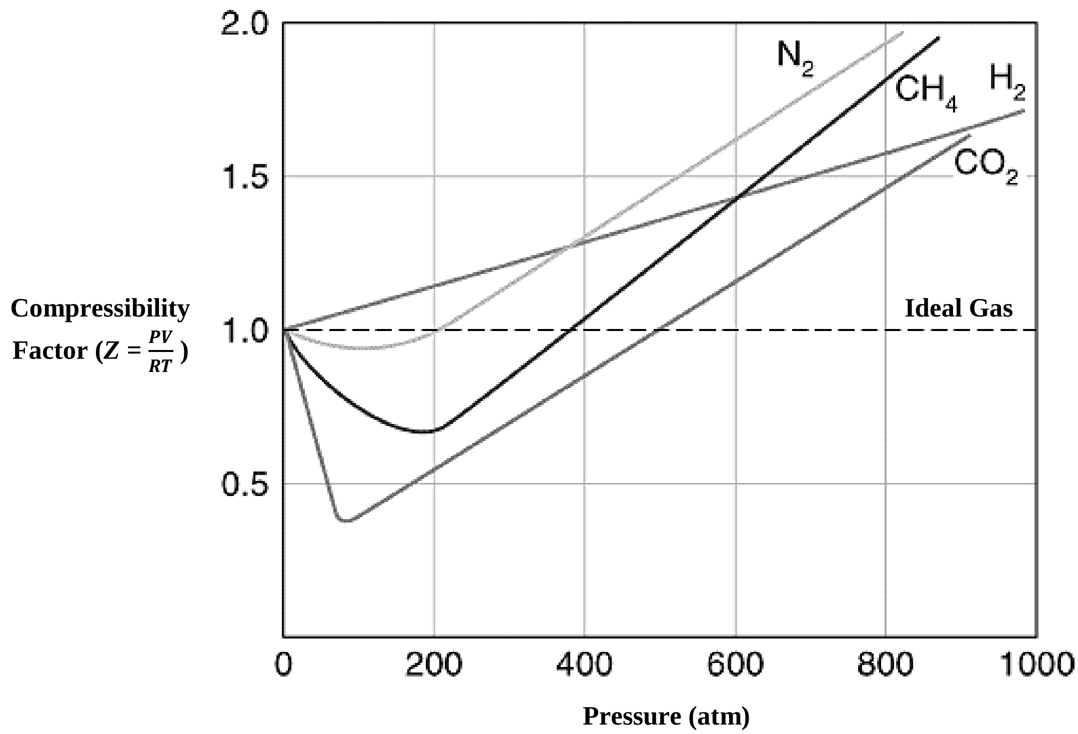
*Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
†Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Part I: Multiple Choice

1. Gaseous samples of argon, oxygen, and nitrogen are stored in identical containers at the same temperature and pressure. Which of the following statements is true?

(A) The sample of argon has the greatest mass.
(B) The sample of oxygen has the greatest mass.
(C) The sample of nitrogen has the greatest mass.
(D) All three samples have identical masses.

2. The graph below compares the behavior of four real gases against an ideal gas as pressure increases. Assume that temperature and number of moles of each gas are constant.



Notice that, at high pressures, the compressibility factor of each real gas is greater than the compressibility factor of an ideal gas. Which of the following assumptions of kinetic theory best accounts for this discrepancy?

(A) Collisions are elastic.
(B) Interparticle forces are negligible.
(C) Particles move in straight lines.
(D) Particle volumes are negligible.

3. For a given sample of gas, Charles's Law states that:

(A) pressure and volume are inversely proportional at constant temperature
(B) volume and temperature are inversely proportional at constant pressure
(C) pressure and volume are directly proportional at constant temperature
(D) volume and temperature are directly proportional at constant pressure

4. Ammonia gas and hydrogen chloride gas are introduced simultaneously at opposite ends of the 75 cm long empty tube shown below. When in contact, these gases react to form solid ammonium chloride.

NH_3 → **75 cm Long Tube** ← HCl

Ammonium chloride will form approximately what length, in cm, from the left end of the tube?
(A) 24
(B) 38
(C) 45
(D) 51

Questions 5 – 7: One method used to manufacture ammonia is the Haber Process. Samples of nitrogen gas and hydrogen gas are combined in the reaction $N_2\,(g) + 3H_2\,(g) \rightarrow 2NH_3\,(g)$.

5. Suppose that the rate of formation of ammonia is 34 g s^{-1}. What is the rate of consumption, in mol s^{-1}, of hydrogen gas?
(A) 1.3
(B) 2.0
(C) 3.0
(D) 5.7

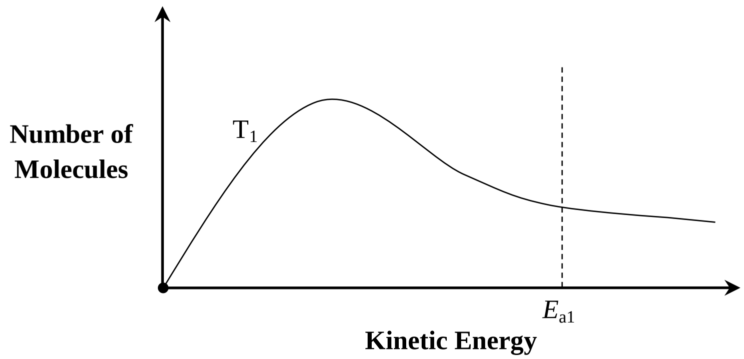
6. 14.0 g of nitrogen gas and 8.00 g of hydrogen gas are injected into an evacuated 15.0 L sealed container at 700. K. If the limiting reagent is exhausted completely, what is the final pressure, in atm, inside the container?
(A) 13.3
(B) 15.2
(C) 17.1
(D) 19.0

7. The Haber Process is traditionally catalyzed by iron; however, a researcher is exploring the use of silver as a replacement for iron. The following data give the initial reaction rates of the Haber Process, catalyzed by silver, at various partial pressures of nitrogen gas and hydrogen gas. Each trial is carried out at the same temperature.

Trial	P_{N_2} (atm)	P_{H_2} (atm)	**Initial Rate of Formation of Ammonia** (atm s^{-1})
1	1.0	2.0	7.0×10^{-3}
2	2.0	4.0	2.8×10^{-2}
3	2.0	0.50	4.4×10^{-4}

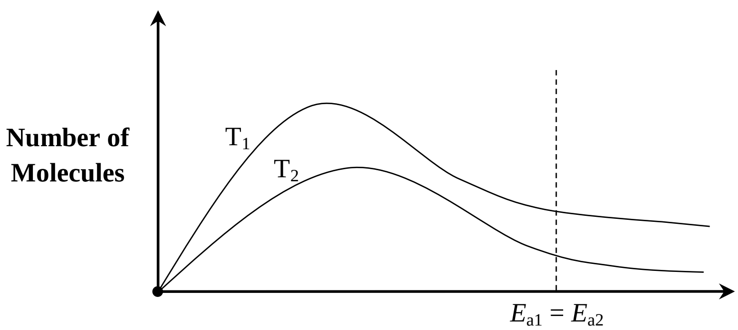
Which of the following gives the rate law for this reaction?
(A) $k(P_{H_2})^2$ = Rate
(B) $k(P_{N_2})(P_{H_2})^2$ = Rate
(C) $k(P_{N_2})^2(P_{H_2})^2$ = Rate
(D) $k(P_{N_2})(P_{H_2})^3$ = Rate

8. The graph below shows the kinetic energy distribution for a reactant at temperature T_1. The activation energy of the reaction at T_1 is denoted by E_{a1}.

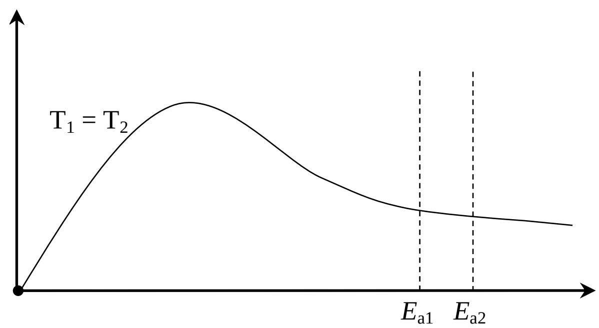


Suppose the temperature of the reactant is decreased from T_1 to T_2. The activation energy of the reaction at T_2 is denoted by E_{a2}. Which of the following depicts possible graphs of T_2 and E_{a2}?

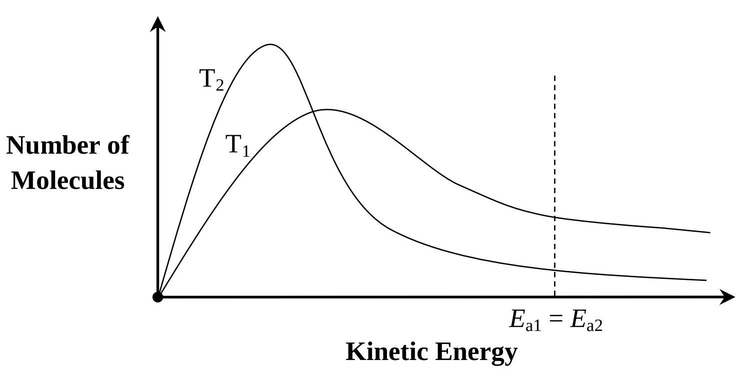
(A)



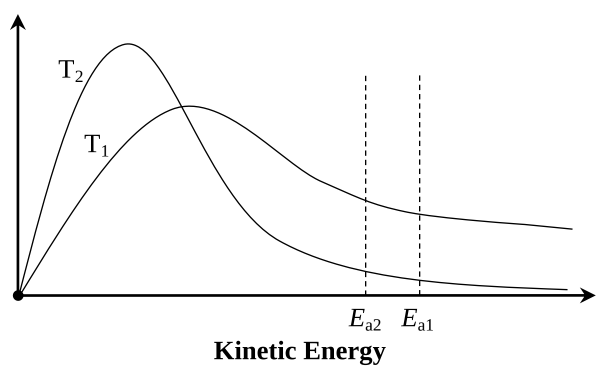
(B)



(C)



(D)



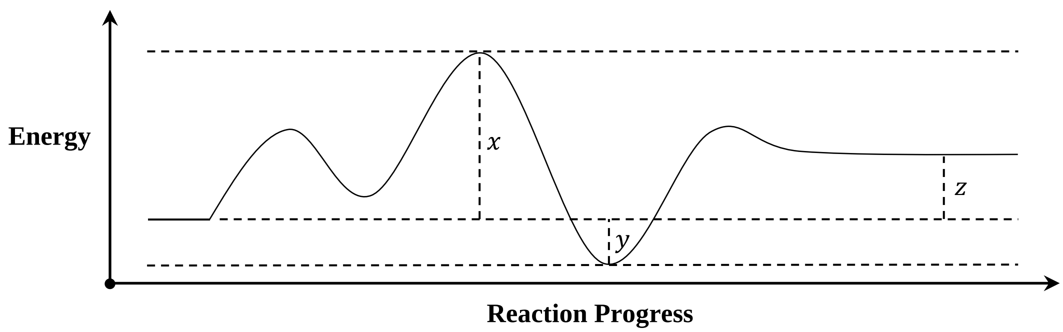
9. An experiment is conducted to determine the amount of hydrogen gas evolved when a strip of zinc metal is reacted with hydrochloric acid. The hydrogen gas is collected in a graduated cylinder filled with water that has been inverted into a water bath. Which of the following experimental errors will cause the calculated amount of hydrogen gas evolved to be greater than the actual amount evolved?

(A) The zinc metal strip is only partially submerged in the hydrochloric acid.
(B) The hydrochloric acid is contaminated with dissolved sodium chloride.
(C) The measured temperature of the water is below the actual temperature.
(D) The inverted graduated cylinder is held at a slight angle.

10. 35.5 g of liquid benzene, C_6H_6, is stored in an evacuated 10.0 L container at 20.0 °C. What mass, in g, of benzene will remain in the liquid state when equilibrium is established, given that the vapor pressure of benzene at 20.0 °C is 14.0 kPa?

(A) 26.8
(B) 31.1
(C) 32.7
(D) 35.4

Questions 11 – 12: Shown below is the reaction coordinate diagram for an unknown chemical reaction.



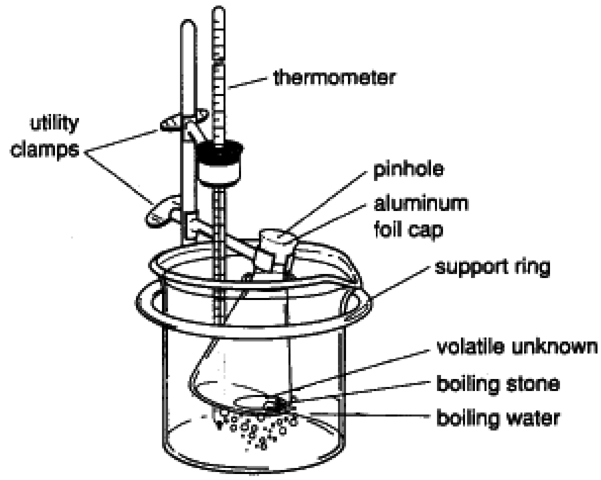
11. Which of the following gives the numbers of transition states and intermediates in the forward reaction?

	Activated Complexes	Intermediates
(A)	5	4
(B)	3	4
(C)	3	2
(D)	2	3

12. Which of the following expressions represents the activation energy of the reverse reaction?

(A) z
(B) $x - z$
(C) $x + y$
(D) $x + y - z$

13. The diagram below depicts a common experimental procedure to determine which property of a volatile liquid?



(A) molar mass
(B) normal boiling point
(C) critical temperature
(D) density

14. The half-life of radioactive isotopes is independent of concentration. This suggests that the reaction order for radioactive decay is:
(A) zero
(B) half
(C) one
(D) two

15. The rate constant of a reaction triples when the temperature is increased from 230 K to 280 K. The activation energy of this reaction, in kJ mol^{-1}, is:
(A) 1.4
(B) 6.6
(C) 12
(D) 17

Part II: Free Response

16. The van der Waals equation for a real gas is given by

$$\left(P + \frac{an^2}{V^2}\right)(V - bn) = nRT$$

where a and b are constants specific to individual gaseous substances and P and V are the measured pressure and volume, respectively, of the real gas.

(a) (2 Points) Specify two conditions under which the van der Waals equation deviates most significantly from the ideal gas equation.

(b) (3 Points) Water, H_2O, has an a value of 5.46 L^2 atm mol^{-2}. Predict whether the a value of methane, CH_4, is less than or greater than that of water. Justify your answer.

(c) (3 Points) The table below gives the b values of four noble gases.

Noble Gas	$\boldsymbol{b}$ (L mol^{-1})
Neon	0.0171
Argon	0.0322
Krypton	0.0398
Xenon	0.0510

Notice that the b values increase as the atomic numbers of the noble gases increase. Account for this observation on the basis of atomic structure.

17. Solid aluminum hydroxide and gaseous hydrogen sulfide are formed when aluminum sulfide powder is sprinkled into liquid water.

(a) (2 Points) Write a balanced chemical equation for this reaction. Include state symbols.

(b) (5 Points) 50.0 g of aluminum sulfide is reacted with excess water inside a sealed 8.50 L jar. The temperature is held at 65.0 °C and the initial pressure is 0.970 atm. Calculate the percent yield if the final pressure is 4.04 atm. Assume that the solvation of hydrogen sulfide in water is negligible and disregard the volume inside the jar occupied by water.

18. Phosgene is formed from chlorine and carbon monoxide according to reaction Cl_2 (*g*) + CO (*g*) → Cl_2CO (*g*). In the presence of a heterogeneous catalyst, the reaction proceeds by the following mechanism.

I:	$Cl_2 \leftrightarrow 2Cl$	(fast equilibrium)
II:	$Cl + CO \rightarrow ClCO$	(slow)
III:	$ClCO + Cl \leftrightarrow Cl_2CO$	(fast equilibrium)

(a) (3 Points) Derive the rate law for the overall reaction.

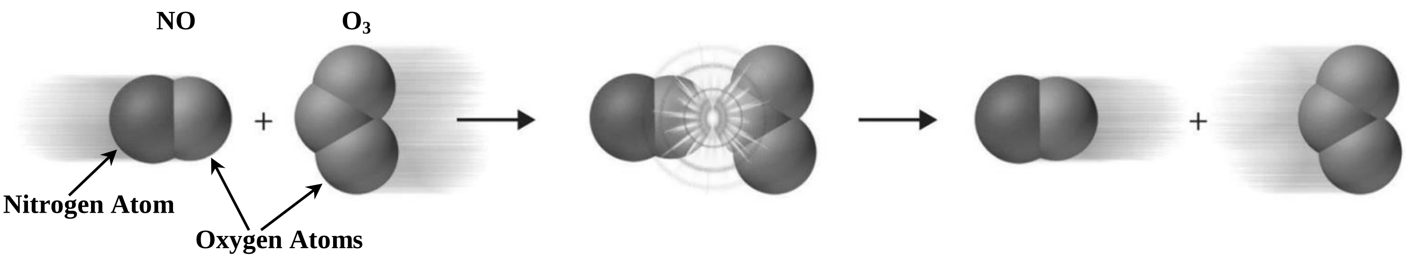
(b) (3 Points) The initial rate of reaction at a certain temperature is 6.0×10^{-3} mol s^{-1} when $[Cl_2]$ = 4.0 *M* and [CO] = 1.0 *M*. Determine the value of the rate constant at this temperature. Include units.

19. Explain each of the following on the basis of kinetic theory and other factors that affect reaction rate.

(a) (3 Points) An enormous block of dry ice sublimes fastest when broken into small chunks rather than when left whole.

(b) (3 Points) Aqueous hydrogen peroxide decomposes slowly when pure but decomposes rapidly when mixed with crushed manganese (IV) oxide, a catalyst.

(c) (3 Points) Nitrogen oxide and ozone react to form nitrogen dioxide and oxygen; however, the collision depicted below does not result in a reaction even though its kinetic energy exceeds activation energy.



20. Researchers hypothesize that potassium hydroxide and bromoethane engage in an S_N2 reaction according to the net ionic equation OH^- (*aq*) + CH_3CH_2Br (*aq*) → Br^- (*aq*) + CH_3CH_2OH (*aq*). Experiments are carried out to determine kinetic properties of this reaction.

(a) (5 Points) The researchers have the following materials available to measure substance concentrations.

- pH meter
- spectrophotometer
- phenolphthalein
- solid silver nitrate
- litmus paper
- thymol blue

Briefly describe two distinct methods involving these materials that could be used to determine the average rate of reaction over a given time interval.

(b) (5 Points) Bromoethane is dissolved in a solution containing a significant excess of potassium hydroxide. The concentration of bromoethane is measured as the reaction progresses.

Time After Start of Reaction (s)	**[CH_3CH_2Br]** (*M*)
0.00	0.200
5.51	0.170
9.39	0.151
16.24	0.123

Determine the reaction order with respect to bromoethane.

Chemistry Lab

Answer Sheet

Team Name: ______________________________

Competitor Names: ______________________________

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______
8. ______
9. ______
10. ______
11. ______
12. ______
13. ______
14. ______
15. ______

16. (a) ______________________________

(b) ______________________________
____
____
____
____

(c) ______________________________
____
____
____
____

17. (a) ______________________________

(b)

18. **(a)**

(b)

19. **(a)**

(b)

(c)

20. **(a)** **Method 1**:

Method 2:

(b)

Chemistry Lab

Answer Key

1. A

2. D

3. D

4. C

5. C

6. A

7. A

8. C

9. C

10. B

11. C

12. B

13. A

14. C

15. C

16. **(a)** 1: high pressure
1: low temperature
(b) 1: the a value of methane is lower
2: CH_4 has weaker intermolecular forces than does H_2O because CH_4 is nonpolar while H_2O is polar (has hydrogen bonding)
(c) 1: the b value relates to particle volume (can be stated or implied)
2: atomic radius increases down a group due to increased electron shielding (additional energy levels)

17. **(a)** $Al_2S_3\ (s) + 6H_2O\ (l) \rightarrow 2Al(OH)_3\ (s) + 3H_2S\ (g)$
1: chemical formulas and state symbols
1: balanced equation (coefficients may be in multiples)
(b) 1: 4.04 atm – 0.970 atm = 3.07 atm
2: substitution into ideal gas law
1: molar mass of Al_2S_3 conversion
1: 94.1 %

18. **(a)** 1: k_{2f}[Cl][CO] = Rate
1: $k_{1f}[Cl_2] = k_{1r}[Cl]^2$
1: $k[Cl_2]^{1/2}$[CO] = Rate (concentrations may instead be expressed as partial pressures)

(b) 1: $k(4.0)^{1/2}(1.0) = 6.0 \times 10^{-3}$
$k = 3.0 \times 10^{-3}\ M^{-1/2}\ s^{-1}$
1: value of k
1: units of k

19. **(a)** 2: breaking the dry ice block into small pieces increases total surface area (amount of dry ice molecules exposed)
1: increased number of collisions per second with (presumably) warmer atmospheric particles

(b) 2: catalysts provide and alternate reaction pathway with lower activation energy
1: greater fraction of collisions have enough kinetic energy to overcome activation energy
Alternate 1: by the Arrhenius Equation a lower E_a corresponds to a higher k

(c) 2: proper orientation of reactant molecules is required to reach transition state
1: in most cases the N atom in NO must collide with an O atom in O_3 to form NO_2

20. **(a)** Possible Methods: (1) measure change in pH directly using pH meter as OH^- reacts; (2) use two pieces of litmus paper to measure change in pH at two distinct times; (3) use spectrophotometer to measure change in indicator (phenolphthalein, thymol blue) absorption as OH^- reacts; (4) use $AgNO_3$ to precipitate AgBr as Br^- forms and measure the mass of AgBr produced
1: mention of rate of change of OH^- and / or Br^- (can be stated or implied)
2: first method procedure and explanation
2: second method procedure and explanation (must be different than first)

(b) 1: calculation of slope to determine average rate
3: determination of linear plot by tests of logarithmic and inverse (if necessary) transformations
1: first-order in bromoethane