

last name

first name

signature

1											18						
1 H 1.008											2 He 4.003						
3 Li 6.941	4 Be 9.012											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 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	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 65.38	31 Ga 69.72	32 Ge 72.64	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 101.07	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 121.76	52 Te 127.60	53 I 126.90	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 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (270)	108 Hs (270)	109 Mt (278)	110 Ds (281)	111 Rg (282)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (290)	116 Lv (293)	117 Ts (294)	118 Og (294)

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	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
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 (266)

constants

$R = 0.08206 \text{ L atm/mol K}$

$R = 0.08314 \text{ L bar/mol K}$

$R = 62.36 \text{ L Torr/mol K}$

$R = 8.314 \text{ L kPa/mol K}$

$R = 8.314 \text{ J/mol K}$

$N_A = 6.022 \times 10^{23} / \text{mol}$

conversions

$1 \text{ atm} = 760 \text{ torr}$

$1 \text{ atm} = 14.7 \text{ psi}$

$1 \text{ atm} = 101325 \text{ Pa}$

$1 \text{ atm} = 1.01325 \text{ bar}$

$1 \text{ bar} = 10^5 \text{ Pa}$

$^{\circ}\text{F} = ^{\circ}\text{C}(1.8) + 32$

$\text{K} = ^{\circ}\text{C} + 273.15$

conversions

$1 \text{ in} = 2.54 \text{ cm}$

$1 \text{ ft} = 12 \text{ in}$

$1 \text{ yd} = 3 \text{ ft}$

$1 \text{ mi} = 5280 \text{ ft}$

$1 \text{ lb} = 453.6 \text{ g}$

$1 \text{ ton} = 2000 \text{ lbs}$

$1 \text{ tonne} = 1000 \text{ kg}$

$1 \text{ gal} = 3.785 \text{ L}$

$1 \text{ gal} = 231 \text{ in}^3$

$1 \text{ gal} = 128 \text{ fl oz}$

$1 \text{ fl oz} = 29.57 \text{ mL}$

$1 \text{ Troy oz} = 31.104 \text{ g}$

water data

$C_{s,\text{ice}} = 2.09 \text{ J/g } ^{\circ}\text{C}$

$C_{s,\text{water}} = 4.184 \text{ J/g } ^{\circ}\text{C}$

$C_{s,\text{steam}} = 2.03 \text{ J/g } ^{\circ}\text{C}$

$\rho_{\text{water}} = 1.00 \text{ g/mL}$

$\rho_{\text{ice}} = 0.9167 \text{ g/mL}$

$\rho_{\text{seawater}} = 1.024 \text{ g/mL}$

$\Delta H_{\text{fus}} = 334 \text{ J/g}$

$\Delta H_{\text{vap}} = 2260 \text{ J/g}$

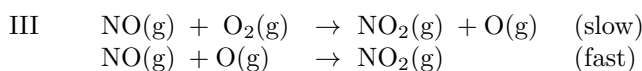
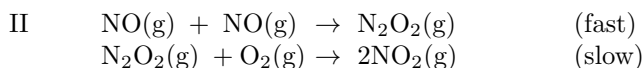
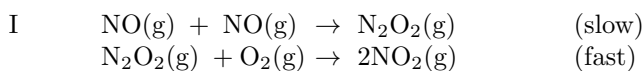
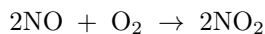
$k_f = 1.86 \text{ } ^{\circ}\text{C}/m$

$k_b = 0.512 \text{ } ^{\circ}\text{C}/m$

$K_w = 1.0 \times 10^{-14}$

This exam should have exactly 25 questions. Each question is equally weighted at 4 points each. You will enter your answer choices on the virtual bubbleseet after you have finished. Your score is based on what you submit on the virtual bubblesheet and not what is circled on the exam.

1. Consider the possible mechanisms for the following reaction:



Given that the empirical rate law for this reaction is found to be  $rate = k[\text{NO}]^2[\text{O}_2]$ . Which mechanism(s) is consistent with the rate law?

- a. I and III
- b. all three mechanisms are consistent
- c. II and III
- d. only II
- e. I and II
- f. only I
- g. only III

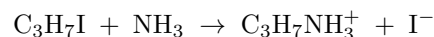
**Explanation:** only mechanism II predicts the stated empirical rate law.

2. The addition of a catalyst to a reaction will speed up the reaction by

- a. altering the mechanism and raising the activation energy.
- b. making the reaction more endothermic.
- c. shifting the equilibrium to favor the reactants.
- d. making the reaction more exothermic.
- e. altering the mechanism and lowering the activation energy.
- f. catalysts do not speed up reactions.
- g. shifting the equilibrium to favor the products.

**Explanation:** a catalyst alters the mechanism of a reaction and lowers the barrier of the rate limiting step.

3. Consider the following elementary reaction step that is a part of a kinetic mechanism:

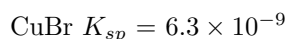
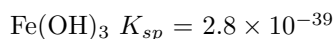
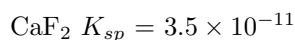
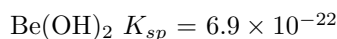


Classify the step type and give its predicted rate law.

- a. termolecular,  
 $rate = k[\text{C}_3\text{H}_7\text{I}][\text{NH}_3][\text{C}_3\text{H}_7\text{NH}_3^+]^{-1}[\text{I}^-]^{-1}$
- b. bimolecular,  $rate = k[\text{C}_3\text{H}_7\text{I}][\text{NH}_3]$
- c. bimolecular, cannot be determined from balanced equation
- d. unimolecular,  $rate = k[\text{C}_3\text{H}_7\text{I}]$
- e. bimolecular,  $rate = k[\text{C}_3\text{H}_7\text{I}]^2$

**Explanation:** the elementary step involves two molecules so this is a bimolecular step. The rate is predicted to be first order with respect to each molecule.

4. Rank the following salts in terms of their molar solubilities from smallest to largest:



- a.  $\text{Fe}(\text{OH})_3 < \text{Be}(\text{OH})_2 < \text{CuBr} < \text{CaF}_2$
- b.  $\text{Fe}(\text{OH})_3 < \text{Be}(\text{OH})_2 < \text{CaF}_2 < \text{CuBr}$
- c.  $\text{Be}(\text{OH})_2 < \text{Fe}(\text{OH})_3 < \text{CuBr} < \text{CaF}_2$
- d.  $\text{Be}(\text{OH})_2 < \text{Fe}(\text{OH})_3 < \text{CaF}_2 < \text{CuBr}$
- e.  $\text{CuBr} < \text{Be}(\text{OH})_2 < \text{Fe}(\text{OH})_3 < \text{CaF}_2$

**Explanation:** We are ranking the salts by their molar solubility, NOT their  $K_{sp}$ 's. Solve for the molar solubility for each salt by applying the correct  $K_{sp}$  relationship. After doing this, the correct ranking is found to be:  $\text{Fe}(\text{OH})_3 < \text{Be}(\text{OH})_2 < \text{CuBr} < \text{CaF}_2$ .

5. The reaction  $\text{NO}_2 + \text{CO} \rightarrow \text{NO} + \text{CO}_2$  is found to obey the following empirical rate law:

$$\text{rate} = k[\text{NO}_2][\text{CO}]$$

For this reaction, if you start with an initial concentration of CO that is much higher than the initial concentration of  $\text{NO}_2$  ( $[\text{CO}]_0 \gg [\text{NO}_2]_0$ ) then a plot of  $\ln[\text{NO}_2]$  will appear

- a. curved as the kinetics are 2nd order overall for the reaction.
- b. linear as the kinetics are now pseudo-1st order in  $\text{NO}_2$ .
- c. curved as the kinetics are 1st order in  $\text{NO}_2$ .
- d. linear with zero slope as the kinetics are now zero order in CO.

**Explanation:** the kinetics are 1st order in  $\text{NO}_2$ , and the conc of CO is so high that it effectively doesn't change thus making the reaction pseudo first order in  $\text{NO}_2$ . This means that the plot of  $\ln[\text{NO}_2]$  will be linear.

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6. Phosphorus-32 is a radioactive isotope of P that has a half-life of 14.33 days. What mass of P-32 is left after 43 days if you start with a sample containing 200 mg of P-32?

- a. 25 mg
- b. 12.5 mg
- c. 50 mg
- d. 37.5 mg
- e. 100 mg

**Explanation:** The half life of a radioactive decay process is the amount of time it takes for half the sample to decay. Radioactive decay is first order and therefore has a constant half live. Because 43 days is exactly 3 half-lives, the initial sample will be cut in half three times which is  $1/8$ .  $200/8 = 25$  mg.

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7. The Statue of Liberty, constructed mostly from copper, has corroded over time to develop a lovely bluish-green patina. One of the chemicals responsible for this patina is  $\text{Cu}(\text{OH})_2$  ( $K_{sp} = 2.2 \times 10^{-20}$ ). What is its molar solubility?

- a.  $6.7 \times 10^{-17}$  mol/L
- b.  $4.8 \times 10^{40}$  mol/L
- c.  $3.9 \times 10^{-13}$  mol/L
- d.  $1.8 \times 10^{-7}$  mol/L
- e.  $1.5 \times 10^{-10}$  mol/L

**Explanation:**  $\text{Cu}(\text{OH})_2$  is a 1:2 salt so  $K_{sp} = 4x^3$ . Plug in  $K_{sp} = 2.2 \times 10^{-20}$ , divide by 4 and take the cube root to find that  $x = 1.8 \times 10^{-7}$  mol/L.

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8. Solutions of stannous chloride are used in tin electroplating applications. You decide to make a saturated solution of  $\text{SnCl}_2$  to run some experiments. Which of the following is true?

- a.  $K_{sp} = [\text{Sn}^{2+}]^2[\text{Cl}^-]$
- b.  $[\text{Sn}^{2+}] = 0.5[\text{Cl}^-]$
- c.  $[\text{Sn}^{2+}] = 2[\text{Cl}^-]$
- d.  $[\text{Sn}^{2+}] = [\text{Cl}^-]$
- e.  $K_{sp} = [\text{Sn}^{2+}][\text{Cl}^-]$

**Explanation:** We can start by considering the  $K_{sp}$  expressions. We will realize that both choices are incorrect as  $K_{sp} = [\text{Sn}^{2+}][\text{Cl}^-]^2$  for stannous chloride. If we consider the answers about concentration, we will realize that the tin ion concentration has to be half whatever the chloride concentration is, so  $[\text{Sn}^{2+}] = 0.5[\text{Cl}^-]$ .

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9. A reaction with an activation energy of 69 kJ/mol takes 3 hours to reach completion when run at 25°C. At what temperature should this reaction be run in order to drop that time down to only 20 minutes?

- a. 51°C
- b. 77°C
- c. 37°C
- d. 44°C
- e. 150°C

**Explanation:** Use the Arrhenius equation knowing that the new temperature ( $T_2$ ) will give a rate constant that is 9 times larger than the one at  $T_1$ . This is because 20 minutes is  $1/9^{\text{th}}$  of 3 hours which means  $9\times$  faster. So  $k_2/k_1 = 9$ .

$$\ln 9 = \frac{69000}{8.314} \left( \frac{1}{298.15} - \frac{1}{T_2} \right)$$

Solving for  $T_2$  gives 323 K which is the same as 51°C.

10. What is the  $K_{sp}$  expression for sodium carbonate ( $\text{Na}_2\text{CO}_3$ )?

- a.  $K_{sp} = [\text{Na}^+]^2[\text{CO}_3^{2-}]^2$
- b.  $K_{sp} = [\text{Na}^+]^2[\text{C}^{4+}][\text{O}^{2-}]^3$
- c.  $K_{sp} = [\text{Na}^+][\text{CO}_3^{2-}]^2$
- d.  $K_{sp} = [\text{Na}^+][\text{CO}_3^{2-}]$
- e.  $K_{sp} = [\text{Na}^+]^2[\text{CO}_3^{2-}]$

**Explanation:**  $\text{Na}_2\text{CO}_3$  is a 2:1 salt, so we need to remember to square the  $[\text{Na}^+]$  term. This gives us  $K_{sp} = [\text{Na}^+]^2[\text{CO}_3^{2-}]$ .

11. Consider the following reaction:

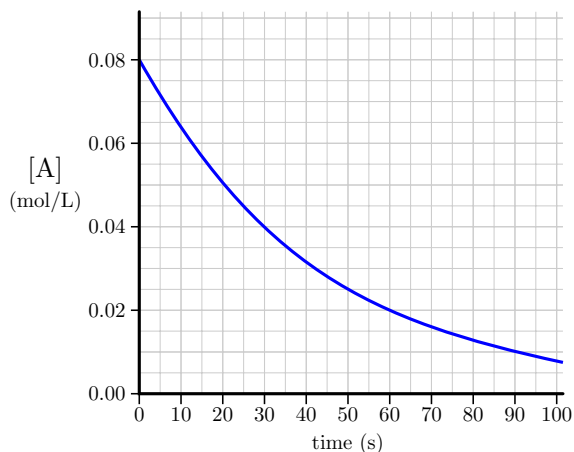


At a given time, water is being produced at a rate of 0.49 M/min for this reaction. What is the corresponding rate for HF during this time?

- a. -0.041 M/min
- b. 0.49 M/min
- c. 0.041 M/min
- d. -0.65 M/min
- e. 0.37 M/min
- f. -0.37 M/min
- g. 0.65 M/min
- h. -0.49 M/min

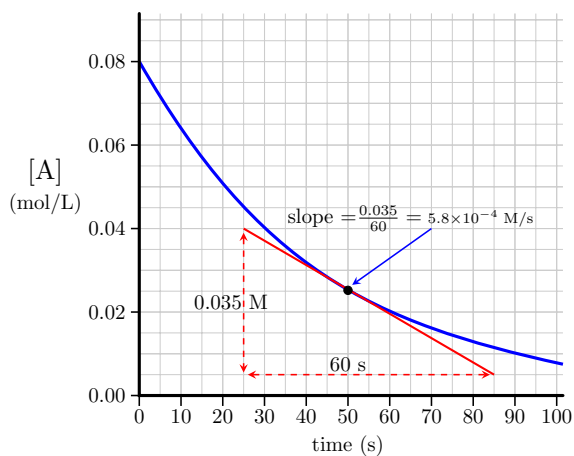
**Explanation:** The stoichiometric ratio of HF to  $\text{H}_2\text{O}$  is 12/9. 12/9 times 0.49 is 0.65. HF is a reactant and must be the opposite in sign as the products, therefore the rate of change in HF is -0.65 M/min.

12. (Part 1 of 2) Look at the concentration vs time plot to the right for a simple  $A \rightarrow B$  reaction scheme. What is the rate of the reaction at 50 seconds?



- a.  $1.1 \times 10^{-4}$  M/s
- b.  $1.8 \times 10^{-3}$  M/s
- c.  $4.8 \times 10^{-3}$  M/s
- d.  $5.8 \times 10^{-4}$  M/s
- e.  $1.5 \times 10^{-5}$  M/s
- f.  $7.5 \times 10^{-5}$  M/s

**Explanation:** The absolute value of the tangential slope at 50 seconds is  $5.8 \times 10^{-4}$  M/s. A line from (25s, 0.04M) to (85s, 0.005M) is a good version of the tangential line to use. This is shown below:



13. (Part 2 of 2) In reference to the concentration vs time plot in the previous question, what is the order for this reaction?

- a. second
- b. square-root
- c. third
- d. first
- e. zero

**Explanation:** Note the  $1/2$  life times to go from 0.08 M to 0.04 to 0.02 to 0.01. They are all 30 seconds which means constant half-life which means first order kinetics.

14. Kinetic rate laws are determined by:

- a. Measuring the number of collisions between molecules
- b. Measuring reaction rates while varying the concentration of reactants
- c. Measuring the equilibrium constant
- d. Using the coefficients of the balanced chemical reaction
- e. Analysis of the Arrhenius equation

**Explanation:** Kinetic rate laws are determined by measuring reaction rates at varying concentration of reactants. The coefficients of the balanced chemical reaction do not necessarily indicate the observed kinetics. Measuring the number of collisions between molecules is practically speaking impossible, but if we could, we would still need to know something about the probability of a collision leading to a successful reaction. The equilibrium constant will give us the ratio of rate constants at equilibrium, but we cannot get actual values from this. The Arrhenius equation relates rate constants at various temperatures, but we cannot calculate a rate constant with it alone.

15. The reaction  $A + B \rightarrow 2C$  has the rate equation  $rate = k[B]^2$ . Which is NOT true about this reaction?

- a. The mechanism for this reaction could have only a single-step.
- b. The reaction rate will remain constant even if you increase the concentration of reactant A.
- c. Increasing the temperature would increase the reaction rate.
- d. Increasing the concentration of reactant B will increase the reaction rate.

**Explanation:** The reaction is zeroth order in A and second order in B, so the concentration of B will affect the rate of reaction but the concentration of A will not. If this reaction was an elementary, one-step reaction, the rate law would have to be  $rate = k[A][B]$ .

16. A certain reaction has an activation energy of 252 kJ/mol. As you decrease the temperature the reaction rate will \_\_\_\_\_ and the activation energy will \_\_\_\_\_.

- a. increase; decrease
- b. decrease; decrease
- c. decrease; increase
- d. decrease; stay the same
- e. increase; increase
- f. increase; stay the same

**Explanation:** Reaction rates decrease with decreasing temperature because fewer molecules will have enough energy to make it over the activation energy barrier.

17. Venetian ceruse ( $PbCO_3$ ) is a white pigment which was used in the 16th century as a cosmetic, often leading to lead poisoning for the user. At a given temperature, the molar solubility of  $PbCO_3$  is  $1.9 \times 10^{-6}M$ , what is the value of  $K_{sp}$ ?

- a.  $7.4 \times 10^{-14}$
- b.  $2.7 \times 10^{-17}$
- c.  $1.5 \times 10^{-13}$
- d.  $3.6 \times 10^{-12}$
- e.  $1.9 \times 10^{-6}$

**Explanation:**  $PbCO_3$  is a 1:1 salt so  $K_{sp} = x^2 = (1.9 \times 10^{-6})^2 = 3.6 \times 10^{-12}$ . Note this is not a "standard"  $K_{sp}$  value because it has a higher solubility due to being at a higher temperature.

18.  $CuCl$  has a  $K_{sp} = 1.7 \times 10^{-7}$ . In which of the following will it be most soluble?

- a. Pure water.
- b. A 0.075 M aqueous solution of  $CuNO_3$ .
- c. Cannot be determined from the information given.
- d.  $CuCl$  will have the same solubility in all three of these solutions.
- e. A 0.25 M solution of  $NaCl$ .

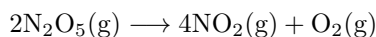
**Explanation:** The common ion effect will reduce the solubility of  $CuCl$  if any  $Cu^+$  or  $Cl^-$  are already in solution. Thus, a  $CuNO_3$  or  $NaCl$  solution will reduce the solubility of  $CuCl$ , making it most soluble in pure water.

19. 17th century processes for the production of felt for use in hats used dilute solutions of mercury nitrate. As a result, mercury poisoning was widespread in hatters of the time, leading to the idiom 'mad as a hatter'. Anyway, what is the net ionic equation for the reaction of aqueous solutions of  $Hg(NO_3)_2$  and  $Na_2S$ ?

- a.  $Na^+(aq) + NO_3^-(aq) \rightarrow NaNO_3(aq)$
- b. No reaction occurs because no precipitate is formed.
- c.  $Hg^{2+}(aq) + 2S^{2-}(aq) \rightarrow HgS_2(s)$
- d.  $Hg^{2+}(aq) + S^{2-}(aq) \rightarrow HgS(s)$
- e.  $2Hg^{2+}(aq) + S^{2-}(aq) \rightarrow Hg_2S(s)$

**Explanation:** All sodium cation and nitrate anion salts are typically soluble. Additionally, nearly all metal sulfide salts are insoluble. With this information in hand, we can predict that the potential products upon perform a salt metathesis would be sodium nitrate (soluble) and mercury sulfide (insoluble). If we remove all the spectator ions (the ones that remain soluble) we find the net ionic equation:  $Hg^{2+}(aq) + S^{2-}(aq) \rightarrow HgS(s)$ .

20. For the reaction

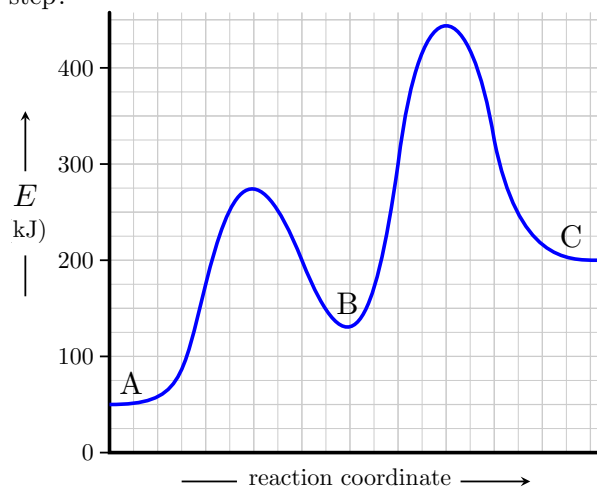


The activation energy is  $1.0 \times 10^5 \text{ J/mol}$  and the value of  $k$  at  $30^\circ\text{C}$  is  $7.3 \times 10^{-5} \text{ s}^{-1}$ . What is the value of  $k$  at  $40^\circ\text{C}$ ?

- a.  $2.0 \times 10^{-6} \text{ s}^{-1}$
- b.  $2.6 \times 10^{-4} \text{ s}^{-1}$
- c.  $8.4 \times 10^{-13} \text{ s}^{-1}$
- d.  $2.0 \times 10^{-5} \text{ s}^{-1}$
- e.  $9.3 \times 10^{-5} \text{ s}^{-1}$

**Explanation:** As temperature increases, the rate constant increases. Use the Arrhenius equation to calculate the new rate constant.

21. The potential energy diagram shown below is for a specific reaction scheme. How many steps are in the reaction mechanism and which step is the rate limiting step?



- a. 2 steps , 1st step limiting
- b. 2 steps , 2nd step limiting
- c. 3 steps , 3rd step limiting
- d. 3 steps , 2nd step limiting
- e. 3 steps , 1st step limiting
- f. 1 step , 1st step limiting

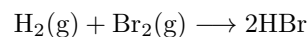
**Explanation:** There are 2 maxima and that means 2 steps. The 2nd step (2nd peak) has the largest rise from base to peak ( about 315 kJ vs 225 kJ for the first one) and therefore is the rate limiting step.

22. The half-life of U-235 is 700 million years. After 2.8 billion years \_\_\_\_\_ of the original amount of U-235 remains.

- a.  $\frac{1}{16}$
- b.  $\frac{1}{2}$
- c.  $\frac{1}{32}$
- d.  $\frac{1}{8}$
- e.  $\frac{1}{4}$

**Explanation:** 2.8 billion years is four half-lives. After the first half-life, one half remains. After the second half-life, half of that, or overall one fourth remains, and so on.

23. The reaction



is first order in hydrogen concentration and second order in bromine concentration. What are the units for the rate constant?

- a.  $\text{M}^{-1}$
- b.  $\text{M s}^{-1}$
- c.  $\text{M}^{-2} \text{ s}^{-1}$
- d.  $\text{M}^{-1} \text{ s}^{-1}$
- e.  $\text{s}^{-1}$

**Explanation:** The reaction is third order overall.  $\text{rate} = k[\text{H}_2][\text{Br}_2]^2$  In order to get the desired M/s units for rate,  $k$  must have units of  $\text{M}^{-2} \text{ s}^{-1}$ .

24. The decomposition of azomethane ( $\text{C}_2\text{H}_6\text{N}_2$ ) follows first order kinetics with a rate constant of  $25 \text{ min}^{-1}$ . If you start with a concentration of  $0.30 \text{ M}$   $\text{C}_2\text{H}_6\text{N}_2$ , what is the **rate** of the decomposition at a time of exactly 6 seconds into the reaction?

- a.  $4.0 \text{ M min}^{-1}$
- b.  $3.7 \times 10^{-3} \text{ M min}^{-1}$
- c.  $4.5 \times 10^2 \text{ M min}^{-1}$
- d.  $0.10 \text{ M min}^{-1}$
- e.  $0.62 \text{ M min}^{-1}$

**Explanation:** the rate =  $k[\text{C}_2\text{H}_6\text{N}_2]$ . The  $[\text{C}_2\text{H}_6\text{N}_2] = [\text{C}_2\text{H}_6\text{N}_2]_0 \times e^{-kt}$ .  $[\text{C}_2\text{H}_6\text{N}_2] = (0.3) \times e^{-2.5} = 2.46 \times 10^{-2} \text{ M}$ . The rate =  $k[\text{C}_2\text{H}_6\text{N}_2] = (25 \text{ min}^{-1})(2.46 \times 10^{-2} \text{ M}) = 0.62 \text{ M min}^{-1}$

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25. Which of the following is false regarding activation energy?

- a. It can be negative
- b. It can be positive
- c. It is independent of temperature
- d. It determines how fast a reaction will go
- e. It can be lowered by adding in a catalyst

**Explanation:** Activation energy can only ever assume a positive value. It can be lowered with the addition of a catalyst, and can get very close to zero with the proper catalyst. Activation energy is usually independent in temperature, cases where it varies with temperature can be ascribed to a change in mechanism. Activation energy directly determines how fast a reaction will go (see Arrhenius equation).

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After you are finished and have all your answers circled, go to the front of the room and then use the QR code show below to pull up the virtual answer page for your exam. Enter the appropriate info plus all your answers - click the SUBMIT button. Double check your choices on the next page. Once you are sure, click the submit button on that page to enter your answers. Make sure you get the confirmation screen (different background color!) and show it to the TA or proctor. After that, turn in your exam and scratch paper. You're free to leave after that.



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