Using Initial Rates to Determine Order

Name____________________Per___

For the generic reaction: A + B → C

trial	$[A]_0$ (mol/L)	$[B]_0$ (mol/L)	Initial Rate (mole/L hour)
1	4	6	20
2	4	3	10
3	2	6	5

$$\frac{rate = k[A]_o^x[B]_o^y}{rate = k[A]_o^x[B]_o^y}$$

$$\frac{rate1}{rate2} = \left(\frac{A}{A}\right)^x\left(\frac{B}{B}\right)^y \qquad \frac{20}{10} = \frac{k}{k}\left(\frac{4}{4}\right)^x\left(\frac{6}{3}\right)^y \qquad 2 = [2]^y \quad y = 1$$

$$\frac{rate1}{rate3} = \left(\frac{A}{A}\right)^x\left(\frac{B}{B}\right)^y \qquad \frac{20}{5} = \frac{k}{k}\left(\frac{4}{2}\right)^x\left(\frac{6}{6}\right)^1 \qquad 4 = [2]^x \quad x = 2$$

$$rate = k[A]^2[B]$$

We would say the reaction is second order with respect to A, and first order with respect to B, resulting in third order overall.

Once the rate law has been established, substitute any one set of data to calculate the rate constant, k.

$rate = k[A]^2[B] \qquad 20 = k[4]^2[6] \qquad k = 0.21$ Regardless of which trial you substitute into, the constant will be the same value. You will also be asked to determine the units on the rate constant. Those units will vary depending on the overall order of the reaction. The units on rate must always be concentration (M) per time (hour). The unit on [A] and [B] is concentration (M), but since the reaction is third order, this results in M^3. To end up with the units of M/hour on rate, the units on the rate constant must be $1/M^2hour^2$ or $M^{-2}hour^{-2}$ or L^2/mol^2hour

Alternatively, for the same generic reaction: A + B → C

Instead of showing the math ratios as demonstrated, you could explain the logic with words. As long as you do it clearly, the following explanations will be acceptable:

trial	$[A]_0$ (mol/L)	$[B]_0$ (mol/L)	Initial Rate (mole/L hour)
1	4	6	20
2	× 2 4	3 × 2	× 4 10 × 2
3	2	6	5

Comparing trial 2 to 1, the concentration of A is constant and the concentration of B is doubled, causing rate of the reaction to be doubled, thus the reaction is first order with respect to B.

Comparing trial 3 to 1, the concentration of B is held constant and the concentration of A is doubled, causing the rate of the reaction to be quadrupled thus the reaction is second order with respect to A.

Thus the rate law is: Rate = k $[A]^2$ [B]

1. The reaction below was studied at 25ºC and the following data was obtained.

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O_{(L)}$$

	$[NH_4^+]_0$ (mol/L)	$[NO_2^-]_0$ (mol/L)	Initial Rate (mole/L sec)
1	0.100	0.005	1.35×10^{-7}
2	0.100	0.010	2.70×10^{-7}
3	0.200	0.010	5.40×10^{-7}

   a. What is the rate law?
   b. What is the rate constant? Be sure and include units.

2. The reaction below was studied at −10ºC and the following data was obtained.

$$2NO_{(g)} + Cl_{2(g)} \rightarrow 2NOCl_{(g)}$$

	$[NO]_0$ (mol/L)	$[Cl_2]_0$ (mol/L)	Initial Rate (mole/L min)
1	0.10	0.10	0.18
2	0.10	0.20	0.35
3	0.20	0.20	1.45

   a. What is the rate law?
   b. What is the rate constant? Be sure and include units.

 Using Initial Rates to Determine Order

3. The reaction below was studied and the following data were obtained.

$$2ClO_2 + 2OH^- \rightarrow ClO_3^- + ClO_2^- + H_2O$$

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

	$[ClO_2]_0$ (mol/L)	$[OH^-]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.050	0.100	0.057
2	0.100	0.100	0.23
3	0.100	0.050	0.115

4. The reaction below was studied and the following data were obtained.

$$BrO_3^- + 5\,Br^- + 6\,H^+ \rightarrow 3\,Br_2 + 3\,H_2O$$

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

	$[BrO_3^-]_0$ (mol/L)	$[Br^-]_0$ (mol/L)	$[H^+]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.100	0.100	0.100	8.0×10^{-4}
2	0.200	0.100	0.100	1.6×10^{-3}
3	0.200	0.200	0.100	3.2×10^{-3}
4	0.100	0.100	0.200	3.2×10^{-3}

5. The reaction below was studied and the following data were obtained.

$$I^- + OCl^- \rightarrow IO^- + Cl^-$$

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

	$[I^-]_0$ (mol/L)	$[OCl^-]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.12	0.18	7.91×10^{-2}
2	0.06	0.18	3.95×10^{-2}
3	0.03	0.09	9.88×10^{-3}
4	0.24	0.09	7.91×10^{-2}

6. The reaction below was studied at 25ºC and the following data was obtained.

$$2\,NO + 2\,H_2 \rightarrow N_2 + 2H_2O$$

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

	$[NO]_0$ (mol/L)	$[H_2]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.100	0.100	1.23×10^{-3}
2	0.100	0.200	2.46×10^{-3}
3	0.200	0.300	1.48×10^{-2}

 Using Initial Rates to Determine Order ***ANSWERS***

For the generic reaction: A + B → C

$$\frac{rate = k[A]_o^x[B]_o^y}{rate = k[A]_o^x[B]_o^y}$$

$$\frac{rate1}{rate2} = \left(\frac{A}{A}\right)^x\left(\frac{B}{B}\right)^y \qquad \frac{20}{10} = \frac{k}{k}\left(\frac{4}{4}\right)^x\left(\frac{6}{3}\right)^y \qquad 2 = [2]^y \quad y = 1$$

$$\frac{rate1}{rate3} = \left(\frac{A}{A}\right)^x\left(\frac{B}{B}\right)^y \qquad \frac{20}{5} = \frac{k}{k}\left(\frac{4}{2}\right)^x\left(\frac{6}{6}\right)^1 \qquad 4 = [2]^x \quad x = 2$$

trial	$[A]_0$ (mol/L)	$[B]_0$ (mol/L)	Initial Rate (mole/L hour)
1	4	6	20
2	4	3	10
3	2	6	5

$$rate = k[A]^2[B]$$

We would say the reaction is second order with respect to A, and first order with respect to B, resulting in third order overall.

Once the rate law has been established, substitute any one set of data to calculate the rate constant, k.

$rate = k[A]^2[B] \quad 20 = k[4]^2[6] \quad k = 0.21$ Regardless of which trial you substitute into, the constant will be the same value. You will also be asked to determine the units on the rate constant. Those units will vary depending on the overall order of the reaction. The units on rate must always be concentration (M) per time (hour). The unit on [A] and [B] is concentration (M), but since the reaction is third order, this results in M^3. To end up with the units of M/hour on rate, the units on the rate constant must be $1/M^2hour^2$ or $M^{-2}hour^{-2}$ or L^2/mol^2hour

Alternatively, for the same generic reaction: A + B → C

Instead of showing the math ratios as demonstrated, you could explain the logic with words. As long as you do it clearly, the following explanations will be acceptable:

trial	$[A]_0$ (mol/L)	$[B]_0$ (mol/L)	Initial Rate (mole/L hour)
1	4	6	20
2	× 2 4	3 × 2	× 4 10 × 2
3	2	6	5

Comparing trial 2 to 1, the concentration of A is constant and the concentration of B is doubled, causing rate of the reaction to be doubled, thus the reaction is first order with respect to B.

Comparing trial 3 to 1, the concentration of B is held constant and the concentration of A is doubled, causing the rate of the reaction to be quadrupled thus the reaction is second order with respect to A.

Thus the rate law is: Rate = k $[A]^2$ [B]

1. The reaction below was studied at 25ºC and the following data was obtained.

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O_{(L)}$$

	$[NH_4^+]_0$ (mol/L)	$[NO_2^-]_0$ (mol/L)	Initial Rate (mole/L sec)
1	0.100	0.005	1.35×10^{-7}
2	0.100	0.010	2.70×10^{-7}
3	0.200	0.010	5.40×10^{-7}

a. What is the rate law?

b. What is the rate constant? Be sure and include units.

$$\frac{rate2}{rate1} = \left(\frac{NH_4^+}{NH_4^+}\right)^x\left(\frac{NO_2^-}{NO_2^-}\right)^y \qquad \frac{2.7}{1.35} = \frac{k}{k}\left(\frac{1}{1}\right)^x\left(\frac{0.01}{0.005}\right)^y \qquad 2 = [2]^y \quad y = 1$$

$$\frac{rate3}{rate2} = \left(\frac{NH_4^+}{NH_4^+}\right)^x\left(\frac{NO_2^-}{NO_2^-}\right)^y \qquad \frac{2.7}{1.35} = \frac{k}{k}\left(\frac{0.2}{0.1}\right)^x\left(\frac{0.01}{0.01}\right)^y \qquad 2 = [2]^x \quad x = 1$$

$$rate = k\left[NH_4^+\right]\left[NO_2^-\right]$$

$$1.35\times10^{-7} = k[0.1][0.005]$$

$$k = 2.7\times10^{-4}\,Lmol^{-1}\sec^{-1}$$

2. The reaction below was studied at −10ºC and the following data was obtained.

$$2NO_{(g)} + Cl_{2(g)} \rightarrow 2NOCl_{(g)}$$

	$[NO]_0$ (mol/L)	$[Cl_2]_0$ (mol/L)	Initial Rate (mole/L min)
1	0.10	0.10	0.18
2	0.10	0.20	0.35
3	0.20	0.20	1.45

a. What is the rate law?

b. What is the rate constant? Be sure and include units.

$$\frac{rate2}{rate1} = \left(\frac{NO}{NO}\right)^x\left(\frac{Cl_2}{Cl_2}\right)^y \qquad \frac{0.35}{0.18} = \frac{k}{k}\left(\frac{0.1}{0.1}\right)^x\left(\frac{0.02}{0.01}\right)^y \qquad 1.94 = [2]^y \quad y = 1$$

$$\frac{rate3}{rate2} = \left(\frac{NO}{NO}\right)^x\left(\frac{Cl_2}{Cl_2}\right)^y \qquad \frac{1.45}{0.35} = \frac{k}{k}\left(\frac{0.2}{0.1}\right)^x\left(\frac{0.2}{0.2}\right)^y \qquad 4.1 = [2]^x \quad x = 2$$

$$rate = k[NO]^2[Cl_2]$$

$$0.18 = k[0.1]^2[0.1]$$

$$k = 180\,L^2mol^{-2}\sec^{-1}$$

 Using Initial Rates to Determine Order

3. The reaction below was studied and the following data were obtained.

$$2ClO_2 + 2OH^- \rightarrow ClO_3^- + ClO_2^- + H_2O$$

	$[ClO_2]_0$ (mol/L)	$[OH^-]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.050	0.100	0.057
2	0.100	0.100	0.23
3	0.100	0.050	0.115

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

$$\frac{rate2}{rate1} = \left(\frac{ClO_2}{ClO_2}\right)^x \left(\frac{OH^-}{OH^-}\right)^y \quad \frac{0.23}{0.057} = \frac{k}{k}\left(\frac{0.1}{0.05}\right)^x \left(\frac{0.1}{0.1}\right)^y \quad 4 = [2]^x \quad x = 2$$

$$\frac{rate2}{rate3} = \left(\frac{ClO_2}{ClO_2}\right)^x \left(\frac{OH^-}{OH^-}\right)^y \quad \frac{0.23}{0.115} = \frac{k}{k}\left(\frac{0.1}{0.1}\right)^x \left(\frac{0.1}{0.05}\right)^y \quad 2 = [2]^y \quad y = 1$$

$$rate = k\left[ClO_2\right]^2\left[OH^-\right]$$
$$0.057 = k\left[0.05\right]^2\left[0.1\right]$$
$$k = 230 M^{-2}\sec^{-1}$$

4. The reaction below was studied and the following data were obtained.

$$BrO_3^- + 5\,Br^- + 6\,H^+ \rightarrow 3\,Br_2 + 3\,H_2O$$

	A	B	C	
	$[BrO_3^-]_0$ (mol/L)	$[Br^-]_0$ (mol/L)	$[H^+]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.100	0.100	0.100	8.0×10^{-4}
2	0.200	0.100	0.100	1.6×10^{-3}
3	0.200	0.200	0.100	3.2×10^{-3}
4	0.100	0.100	0.200	3.2×10^{-3}

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

$$\frac{rate2}{rate1} = \left(\frac{A}{A}\right)^x \left(\frac{B}{B}\right)^y \left(\frac{C}{C}\right)^z \quad \frac{0.0016}{0.0008} = \frac{k}{k}\left(\frac{.2}{.1}\right)^x \left(\frac{.1}{.1}\right)^y \left(\frac{.1}{.1}\right)^z \quad 2 = [2]^x \quad x = 1$$

$$\frac{rate3}{rate2} = \left(\frac{A}{A}\right)^1 \left(\frac{B}{B}\right)^y \left(\frac{C}{C}\right)^z \quad \frac{0.0032}{0.0016} = \frac{k}{k}\left(\frac{.2}{.2}\right)^1 \left(\frac{.2}{.1}\right)^y \left(\frac{.1}{.1}\right)^z \quad 2 = [2]^y \quad y = 1$$

$$\frac{rate4}{rate2} = \left(\frac{A}{A}\right)^1 \left(\frac{B}{B}\right)^1 \left(\frac{C}{C}\right)^z \quad \frac{0.0032}{0.0008} = \frac{k}{k}\left(\frac{.1}{.1}\right)^1 \left(\frac{.1}{.1}\right)^1 \left(\frac{.2}{.1}\right)^z \quad 4 = [2]^z \quad z = 2$$

$$rate = k[A][B][C]^2$$
$$8\times10^{-4} = k[0.1][0.1][0.1]^2$$
$$k = 8.0 L^3 mol^{-3}\sec^{-1}$$

5. The reaction below was studied and the following data were obtained.

$$I^- + OCl^- \rightarrow IO^- + Cl^-$$

	$[I^-]_0$ (mol/L)	$[OCl^-]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.12	0.18	7.91×10^{-2}
2	0.06	0.18	3.95×10^{-2}
3	0.03	0.09	9.88×10^{-3}
4	0.24	0.09	7.91×10^{-2}

$$\frac{rate1}{rate2} = \left(\frac{I^-}{I^-}\right)^x \left(\frac{OCl^-}{OCl^-}\right)^y \quad \frac{7.91}{3.95} = \frac{k}{k}\left(\frac{0.12}{0.06}\right)^x \left(\frac{0.18}{0.18}\right)^y \quad 2 = [2]^x \quad x = 1$$

$$\frac{rate2}{rate3} = \left(\frac{I^-}{I^-}\right)^x \left(\frac{OCl^-}{OCl^-}\right)^y \quad \frac{3.95\times10^{-2}}{9.88\times10^{-3}} = \frac{k}{k}\left(\frac{0.06}{0.03}\right)^1 \left(\frac{0.18}{0.09}\right)^y \quad 4 = [2]^1[2]^x \quad x = 1$$

$$rate = k\left[I^-\right]\left[OCl^-\right]$$
$$7.91\times10^{-2} = k\left[0.12\right]\left[0.18\right]$$
$$k = 3.66 M^{-1}\sec^{-1}$$

6. The reaction below was studied at 25ºC and the following data was obtained.

$$2\,NO + 2\,H_2 \rightarrow N_2 + 2H_2O$$

	$[NO]_0$ (mol/L)	$[H_2]_0$ (mol/L)	Initial Rate (mol/L s)
1	0.100	0.100	1.23×10^{-3}
2	0.100	0.200	2.46×10^{-3}
3	0.200	0.300	1.48×10^{-2}

a. What is the rate law?
b. What is the rate constant? Be sure and include units.

$$\frac{rate2}{rate1} = \left(\frac{NO}{NO}\right)^x \left(\frac{H_2}{H_2}\right)^y \quad \frac{2.46}{1.23} = \frac{k}{k}\left(\frac{0.1}{0.1}\right)^x \left(\frac{0.2}{0.1}\right)^y \quad 2 = [2]^y \quad y = 1$$

$$\frac{rate3}{rate2} = \left(\frac{NO}{NO}\right)^x \left(\frac{H_2}{H_2}\right)^y \quad \frac{1.48\times10^{-2}}{2.46\times10^{-3}} = \frac{k}{k}\left(\frac{0.2}{0.1}\right)^x \left(\frac{0.3}{0.2}\right)^1 \quad 4 = [2]^x \quad x = 2$$

$$rate = k\left[NO\right]\left[H_2\right]$$
$$1.23\times10^{-3} = k\left[0.1\right]^2\left[0.1\right]$$
$$k = 1.23 L^2 mol^{-2}\sec^{-1}$$

 Using Initial Rates to Determine Order **.....Extra for those who want a challenge!**

While it is most likely that any rate laws on the AP exam will only be first or second order, it is possible that other orders are indeed possible. When the order is not 1 or 2 and thus not so obvious, it is useful to know this handy log rule:

$$When\ Q = R^x \quad then\ \log Q = x \log R$$

$$RateRatio = [ConcRatio]^x \quad \text{thus; } \log[RateRatio] = x \log[ConcRatio] \quad \text{and so; } \frac{\log[RateRatio]}{\log[ConcRatio]} = x$$

7. Given the hypothetical data below, determine the order of the reaction A + B + C → D + E

Trial	[A] (M)	[B] (M)	[C] (M)	Rate (M/sec)
1	1.0	1.0	1.0	0.0076
2	2.0	1.0	1.0	0.0304
3	1.0	1.0	2.0	0.0107
4	1.0	2.0	1.0	0.0152

8. Given the hypothetical data below, determine the order of the reaction P + Q + R → S + T

Trial	[P] (M)	[Q] (M)	[R] (M)	Rate (M/sec)
1	1.0	1.0	1.0	0.0365
2	1.0	6.35	1.0	1.47
3	1.0	1.0	0.75	0.0274
4	1.9	1.0	0.75	0.0274

9. Given the hypothetical data below, determine the order of the reaction H + I + J → K

Trial	[H] (M)	[I] (M)	[J] (M)	Rate (M/sec)
1	1.0	1.0	1.0	1.7
2	2.3	1.0	1.0	3.91
3	1.0	1.0	4.0	2.7
4	1.0	1.8	2.0	6.94

10. Given the hypothetical data below, determine the order of the reaction V + W + X → Y + Z

Trial	[V] (M)	[W] (M)	[X] (M)	Rate (M/sec)
1	0.01	0.01	0.01	2.80×10^{-6}
2	0.01	0.04	0.01	4.48×10^{-5}
3	0.01	0.02	0.06	6.72×10^{-5}
4	0.05	0.025	0.036	1.41×10^{-4}

 Using Initial Rates to Determine Order ***ANSWERS***

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$$When\ Rr = Cr^x \quad then\ \log Rr = x \log Cr$$

$$RateRatio = [ConcRatio]^x \quad \text{thus; } \log[RateRatio] = x\log[ConcRatio] \quad \text{and so; } \frac{\log[RateRatio]}{\log[ConcRatio]} = x$$

11. Given the hypothetical data below, determine the order of the reaction A + B + C → D + E

Trial	[A] (M)	[B] (M)	[C] (M)	Rate (M/sec)
1	1.0	1.0	1.0	0.0076
2	2.0	1.0	1.0	0.0304
3	1.0	1.0	2.0	0.0107
4	1.0	2.0	1.0	0.0152

Trial 2:1 as A doubles (B, C constant), rate is quadrupled. $[A]^2$

Trial 4:1 as B doubles (A,C constant), rate is doubled. $[B]^1$

$$\frac{rate3}{rate1} = \frac{0.0107}{0.0076} = \left(\frac{1}{1}\right)^2\left(\frac{1}{1}\right)^1\left(\frac{2}{1}\right)^x \qquad x = \frac{\log 1.4}{\log 2} \qquad x = 0.5 \quad [C]^{½}$$

12. Given the hypothetical data below, determine the order of the reaction P + Q + R → S + T

Trial	[P] (M)	[Q] (M)	[R] (M)	Rate (M/sec)
1	1.0	1.0	1.0	0.0365
2	1.0	6.35	1.0	1.47
3	1.0	1.0	0.75	0.0274
4	1.9	1.0	0.75	0.0274

Trial 4:1 as P is 1.9× (Q, R constant), rate stays same. $[P]^0$

$$\frac{rate2}{rate1} = \frac{1.47}{0.0365} = \left(\frac{1}{1}\right)^0\left(\frac{6.35}{1}\right)^x\left(\frac{1}{1}\right)^y \qquad x = \frac{\log 40.3}{\log 6.35} \qquad x = 2 \quad [Q]^2$$

Trial 1:3 as R 1.33× (P, Q constant), rate is 1.33× $[R]^1$

13. Given the hypothetical data below, determine the order of the reaction H + I + J → K

Trial	[H] (M)	[I] (M)	[J] (M)	Rate (M/sec)
1	1.0	1.0	1.0	1.7
2	2.3	1.0	1.0	3.91
3	1.0	1.0	4.0	2.7
4	1.0	1.8	2.0	6.94

Trial 2:1 as H is 2.3× (I, J constant), rate is 2.3×. $[H]^1$

$$\frac{rate3}{rate1} = \frac{2.7}{1.7} = \left(\frac{1}{1}\right)^1\left(\frac{1}{1}\right)^x\left(\frac{4}{1}\right)^y \qquad y = \frac{\log 1.6}{\log 4} \qquad y = 0.34 \quad [J]^{⅓}$$

$$\frac{rate4}{rate1} = \frac{6.94}{1.7} = \left(\frac{1}{1}\right)^1\left(\frac{1.8}{1}\right)^x\left(\frac{2}{1}\right)^{1/3} \qquad \frac{4.1}{\sqrt[3]{2}} = \left(\frac{1.8}{1}\right)^x \qquad x = \frac{\log 3.24}{\log 1.8} \qquad x = 2 \quad [I]^2$$

14. Given the hypothetical data below, determine the order of the reaction V + W + X → Y + Z

Trial	[V] (M)	[W] (M)	[X] (M)	Rate (M/sec)
1	0.01	0.01	0.01	2.80×10^{-6}
2	0.01	0.04	0.01	4.48×10^{-5}
3	0.01	0.02	0.06	6.72×10^{-5}
4	0.05	0.025	0.036	1.41×10^{-4}

Trial 2:1 as W is 4× (V, X constant), rate is 16× $[W]^2$

$$\frac{rate3}{rate1} = \frac{6.72\times10^{-5}}{2.8\times10^{-6}} = \left(\frac{0.01}{0.01}\right)^x\left(\frac{2}{1}\right)^2\left(\frac{0.06}{0.01}\right)^y \qquad \frac{24}{2^2} = [6]^y \quad 6 = [6]^y \quad y = 1 \qquad [X]^1$$

$$\frac{rate4}{rate3} = \frac{1.41\times10^{-4}}{6.72\times10^{-5}} = \left(\frac{0.05}{0.01}\right)^x\left(\frac{0.025}{0.02}\right)^2\left(\frac{0.036}{0.06}\right)^1 \qquad \frac{2.1}{(1.25)^2\times0.6} = [5]^x \quad 2.24 = [5]^x \quad x = \frac{\log 2.24}{\log 5} \qquad x = 0.5 \quad [V]^{½}$$