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Some Problems

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A Problem in 3 parts

Nitrous oxide gas (NO) can be made from nitrogen and oxygen gas at 640 K. The K_p for this reaction is 1.24×10^{-2}. In a 2 L flask at 640 K, there is 2.0 g nitrogen, 1.0 g oxygen and 0.53 g NO.

Is the reaction at equilibrium?

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$N_{2\,(g)} + O_{2\,(g)} \leftrightarrow 2\,NO_{(g)}$

$$K_p = \frac{P^2_{NO}}{P_{N2}P_{O2}}$$

$$2.0\text{ g } N_2 \times \frac{1\text{ mol } N_2}{28.02\text{ g}} = 0.0714\text{ mol } N_2$$

$$1.0\text{ g } O_2 \times \frac{1\text{ mol } O_2}{32.0\text{ g}} = 0.0313\text{ mol } O_2$$

$$0.53\text{ g NO} \times \frac{1\text{ mol NO}}{30.01\text{ g}} = 0.0177\text{ mol NO}$$

Moles is good, atm is better – at least if K_p is what you care about!

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P = nRT/V

$P_{N2} = (0.0714 \text{ mol } N_2)(0.082056 \text{ Latm/mol K})(640 \text{ K})/2 \text{ L}$
$P_{N2} = 1.87 \text{ atm}$
$P_{O2} = (0.0313 \text{ mol } O_2)(0.082056 \text{ Latm/mol K})(640 \text{ K})/2 \text{ L}$
$P_{O2} = 0.822 \text{ atm}$
$P_{NO} = (0.0177 \text{ mol } N_2)(0.082056 \text{ Latm/mol K})(640 \text{ K})/2 \text{ L}$
$P_{NO} = 0.465 \text{ atm}$

Does this satisfy K?

$$K_p = \frac{P^2_{NO}}{P_{N2}P_{O2}}$$

$$K_p = 1.24\text{x}10^{-2} = \frac{(0.465 \text{ atm})^2}{(1.87 \text{ atm})(0.822 \text{ atm})}$$
$1.24\text{x}10^{-2} = 0.141$

Obviously, this is NOT true – we must NOT be at equilibrium!!

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To get to equilibrium, should the reaction proceed to the right (products) or to the left (reactants)?

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INTRODUCING…

Q - Q is K when you're not at equilibrium!

$$K_p = 1.24\text{x}10^{-2} = \frac{(0.465 \text{ atm})^2}{(1.87 \text{ atm})(0.822 \text{ atm})}$$
$1.24\text{x}10^{-2} = 0.141$
This is actually a silly thing to write. So, instead of calling it K, we call it Q!

- Not at equlibrium $Q = \frac{P^2_{NO}}{P_{N2}P_{O2}}$
- AT equilibrium $K_p = \frac{P^2_{NO}}{P_{N2}P_{O2}}$

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Calculate Q, Compare to K

$$Q = \frac{P^2_{NO}}{P_{N2}P_{O2}}$$

$$Q = \frac{(0.465\ atm)^2}{(1.87\ atm)\ (0.822\ atm)}$$

Q = 0.141

$K_p = 1.24x10^{-2}$

Compare Q to K

If Q = K – we must have been at equilibrium all along
If Q<K – the numerator is too small, not enough product, reaction goes right!
If Q>K – the numerator is too big, too much product, reaction goes left!

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What should the concentration of NO be at equilibrium for this reaction mixture?

A. 0.16 atm
B. 0.40 atm
C. 0.253 atm
D. -0.177 atm
E. 0.53 atm

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	$N_{2\ (g)}$ +	$O_{2\ (g)}$ $\rightleftharpoons$	2 $NO_{(g)}$
I	1.87 atm	0.822 atm	0.465 atm
C	-x	-x	+2x
E	1.87 – x	0.822 – x	0.465 + 2x

$$K_p = 1.24x10^{-2} = \frac{(0.465\ atm + 2x)^2}{(1.87\ atm - x)\ (0.822 - x\ atm)}$$

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$K_p = 1.24\times10^{-2} = \frac{(0.465 \text{ atm} + 2x)^2}{(1.87 \text{ atm} - x)(0.822 - x \text{ atm})}$

Shortcut won't work here (try it if you like), so…

$1.24\times10^{-2} = \frac{(0.2162 + 1.86\,x + 4x^2)}{(1.537 - 2.692\,x + x^2)}$

$0.01906 - 0.0334\,x + 1.24\times10^{-2}\,x^2 = 0.2162 + 1.86\,x + 4x^2$

$3.988\,x^2 + 1.8934\,x + 0.1971 = 0$

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$3.988\,x^2 + 1.8934\,x + 0.1971 = 0$

$X = \frac{-b \pm \text{SQRT}(b^2 - 4ac)}{2a}$

$X = \frac{-1.8934 \pm \text{SQRT}(1.8934^2 - 4(3.988)(0.1971))}{2(3.988)}$

$X = \frac{-1.8934 \pm \text{SQRT}(1.8934^2 - 4(3.988)(0.1971))}{2(3.988)}$

$X = \frac{-1.8934 \pm 0.6639}{2(3.988)}$

$X = \frac{-1.8934 \pm 0.6639}{2(3.988)}$

X = -0.1541 or -0.3206

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X = -0.1541 or -0.3206

If you use the 2nd root (-0.3206)

	$N_{2\,(g)}$ +	$O_{2\,(g)}$ ↔	$2\,NO_{(g)}$
I	1.87 atm	0.822 atm	0.465 atm
C	-(-0.3206)	-(-0.3206)	+2(-0.3206)
E	2.191 atm	1.143 atm	-0.177 atm

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$X = -0.1541$ or -0.321

$N_{2\,(g)} + O_{2\,(g)} \leftrightarrow 2\,NO_{(g)}$

I	1.87 atm	0.822 atm	0.465 atm
C	-(-0.1541)	-(-0.1541)	+2(-0.1541)
E	2.02 atm	0.976 atm	0.157 atm

Check

$K_p = \frac{0.157^2}{2.02 * 0.976} = .0125$

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Variation on the problem

Ammonia gas (NH_3) can be made from nitrogen and hydrogen gas. Into a 2 L flask at 400 K, I put 1.0 g of nitrogen and 1.0 g of hydrogen. At equilibrium, the pressure in the flask is 8.5 atm. What is the equilibrium constant (K_p) for the reaction at 400 K?

A. $1.2x10^{-2}$
B. $2.3x10^{-4}$
C. $3.4x10^{-2}$
D. $2.6x10^{-3}$
E. $4.2\ x10^{-4}$

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$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightarrow 2\,NH_{3\,(g)}$

I	???	???	0 atm
C	-x	-3x	+2x
E	??? – x	??? – 3x	0 + 2x

$K_p = \frac{P^2_{NH3}}{P_{N2}P^3_{H2}}$

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$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightarrow 2\,NH_{3\,(g)}$

1.0 g N_2 * $\frac{1 \text{ mol } N_2}{28.02 \text{ g}}$ = 0.0357 mol N_2

1.0 g H_2 * $\frac{1 \text{ mol } H_2}{2.016 \text{ g}}$ = 0.496 mol H_2

Moles is good, atm is better – at least if K_p is what you care about!

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P = nRT/V

P_{N2} = (0.0357 mol N_2)(0.082056 Latm/mol K)(400 K)/2 L
P_{N2} = 0.586atm

P_{H2} = (0.496 mol O_2)(0.082056 Latm/mol K)(400 K)/2 L
P_{H2} = 8.14 atm

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	$N_{2\,(g)}$	+ 3 $H_{2\,(g)}$	↔ 2 $NH_{3\,(g)}$
I	0.586 atm	8.14 atm	0 atm
C	-x	-3x	+2x
E	0.586 – x	8.14 – 3x	0 + 2x

$K_p = \frac{(2x)^2}{(0.586-x)\,(8.14-3x)^3}$

I need x, but I know one more thing

P_{final} = 8.5 atm

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$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightarrow 2\,NH_{3\,(g)}$

I 0.586 atm 8.14 atm 0 atm

C -x -3x +2x

E 0.586 – x 8.14 – 3x 0 + 2x

P_{final} = 8.5 atm = 2x + (8.14-3x) + (0.586-x)

8.5 = -2x + 8.726

X = 0.113

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$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightarrow 2\,NH_{3\,(g)}$

I	0.586 atm	8.14 atm	0 atm
C	-0.113	-3(0.113)	+2(0.113)
E	0.473	7.801	0.226

$$K_p = \frac{(0.226)^2}{(0.473)\,(7.801)^3}$$

$K_p = 2.27\text{x}10^{-4}$