Example 2: What is the pH of a solution made by combining 1.00 L each of 0.200 M sodium fluoride $\rightarrow NaF \equiv Na^+ \; F^-$ ($K_{a,\,HF}$ = 6.6x10^{-4}) and 0.0100 M hydrochloric acid? $\rightarrow HCl \equiv H^+ + Cl^-$

STEP (1) NEUTRALIZE STRONG ACID

new total volume

$1.00\,L \times 0.200\,M = 0.200\,mol / 2\,L = 0.100\,M$ NaF ($= [Na^+] = [F^-]$)

$1.00\,L \times 0.0100\,M = 0.0100\,mol / 2\,L = 0.00500\,M$ HCl ($= [H^+] = [Cl^-]$)

H^+	+ F^-	$\rightarrow HF$
0.00500M	0.100M	0
−0.00500M	−0.00500	+0.00500M
0	0.095M	0.00500M

* use all H^+ if possible → basically a limiting reagent problem since neutralization goes to completion

STEP (2) Regain equilibrium

HF	+ H_2O	$\rightleftharpoons F^-$	+ H_3O^+	
0.00500M	—	0.095M	0	I
−x	−x	+x	+x	C
(0.0500 −x)M	—	(0.095+x)M	x	E

↑ This should work with either K_a or K_b expression, as long as ICE table is set up & you use the right K.

$$K_a = \frac{[H_3O^+][F^-]}{[HF]}$$

$$6.6\times10^{-4} = \frac{x\,(0.095+x)}{(.00500-x)}$$

$$3.3\times10^{-6} - 6.6\times10^{-4}x = 0.095x + x^2$$

$$x^2 + 0.09566x - 3.3\times10^{-6} = 0$$

Solve with quadratic formula: ← show all these steps on a quiz or exam :)

$x = 3.45\times10^{-5}$

$= [H^+]$

pH = 4.46

Question: How did we get an acidic pH when there's more F^-? is this OK?

→ Think of the H-H equation:

$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$

As long as $[A^-] > [HA]$ the log will be (+) and pH > pKa (but not necessarily >7)

pKa for HF is 3.18 → so our pH is OK :)

Scenario 2: Weak + Weak

$K_a = 6.6\times10^{-4}$

A solution that contains both a weak acid (or base) and the salt of its' conjugate is dealt with by an equilibrium calculation:

e.g.: What is the pH of a solution made by combining 100 mL of a 0.1 M sodium fluoride solution with 100 mL of a 0.01 M hydrofluoric acid solution?

After mixing: $F^- = 100\text{ mL} \times 0.1\text{ M} \div 200\text{ mL} = 0.05\text{ M}$

$HF = 100\text{ mL} \times 0.01\text{ M} \div \underset{\text{total}}{200\text{ mL}} = 0.005\text{ M}$

$$HF + H_2O \rightleftharpoons H_3O^+ + F^-$$

	HF	H_2O	H_3O^+	F^-
I	0.005		0	0.05
C	$-x$		$+x$	$+x$
E	$0.005-x$		x	$0.05+x$

can't use small-x ☹

$$6.6\times10^{-4} = \frac{[H_3O^+][F^-]}{[HF]}$$

$$6.6\times10^{-4} = \frac{(x)(.05+x)}{(0.005-x)}$$

$$3.3\times10^{-6} - 6.6\times10^{-4}x = .05x + x^2$$

$$x^2 \underbrace{+0.05066x}_{b} \underbrace{-3.3\times10^{-6}}_{c} = 0$$

$$\frac{-0.05066 \pm \sqrt{0.05066^2 - 4(1)(-3.3\times10^{-6})}}{2} = 6.5\times10^{-5} = [H_3O^+]$$

$\boxed{pH = 4.18}$

Revisit the last calculation: What is the pH of a solution made by combining 100 mL of a 0.1 M sodium fluoride solution with 100 mL of a 0.01 M hydrofluoric acid solution?

0.05 M F^- 0.005 M HF

$$pH = pKa + \log \frac{[F^-]}{[HF]}$$

$$= -\log(6.6\times10^{-4}) + \log\left(\frac{(0.05\,M)}{(0.005\,M)}\right)$$

$$= 4.18$$

with the correct math on the other slide, now these agree :)