

12.2 Se valoran 100,0 mL de NaOH 0,100 M con HBr 1,00 M. Hallar el pH para los siguientes volúmenes de ácido añadido, y trazar un gráfico de pH frente a V_a : $V_a =$ a) 0, b) 1,00, c) 5,00, d) 9,00, e) 9,90, f) 10,0, g) 10,1 y h) 12,0 mL.

Respuesta/ a) 12,996
 b) 12,96
 c) 12,68
 d) 11,96
 e) 11,0
 f) 7,000
 g) 3,0
 h) 1,74

a)

$$[\text{OH}^-] = 0,100 \text{ mol/L} \Rightarrow [\text{H}^+] = 1,01 \times 10^{-13} \text{ mol/L}$$

$$\text{pH} = 12,996$$

b)

	HBr	+	NaOH	→	NaBr	+	H ₂ O
mmol _{inicial}	1,00		10,0		---		---
mmol _{final}	---		9,0		---		---

$$[\text{OH}^-] = \frac{9,0 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 0,089 \text{ mol/L}$$

$$[\text{H}^+] = 1,1 \times 10^{-13} \text{ mol/L}$$

$$\text{pH} = 12,96$$

c)

	HBr	+	NaOH	→	NaBr	+	H ₂ O
mmol _{inicial}	5,00		10,0		---		---
mmol _{final}	---		5,0		---		---

$$[\text{OH}^-] = \frac{5,0 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,048 \text{ mol/L}$$

$$[\text{H}^+] = 2,1 \times 10^{-13} \text{ mol/L}$$

$$\text{pH} = 12,68$$

d)

	HBr	+	NaOH	→	NaBr	+	H ₂ O
mmol _{inicial}	9,00		10,0		---		---
mmol _{final}	---		1,0		---		---

$$[\text{OH}^-] = \frac{1,0 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 9,2 \times 10^{-3} \text{ mol/L}$$

$$[\text{H}^+] = 1,1 \times 10^{-12} \text{ mol/L}$$

$$\text{pH} = 11,96$$

e)

	HBr	+	NaOH	→	NaBr	+	H ₂ O
mmol _{inicial}	9,90		10,0		---		---
mmol _{final}	---		0,1		---		---

$$[\text{OH}^-] = \frac{0,1 \text{ mmol}}{(100,0 + 9,90) \text{ mL}} = 9 \times 10^{-4} \text{ mol/L}$$

$$[\text{H}^+] = 1 \times 10^{-11} \text{ mol/L}$$

$$\text{pH} = 11,0$$

f)

	H ₂ O	⇌	H ⁺	+	OH ⁻
Cn _{inicial}	---		0		0
Cn _{final}	---		x		x

$$K_w = [H^+][OH^-] = (x)(x) = 1,01 \times 10^{-14}$$

$$x = 1,00 \times 10^{-7} \text{ mol/L}$$

$$\text{pH} = 7,000$$

g)

	HBr	+	NaOH	→	NaBr	+	H ₂ O
mmol _{inicial}	10,1		10,0		---		---
mmol _{final}	0,1		---		---		---

$$[H^+] = \frac{0,1 \text{ mmol}}{(100,0 + 10,1) \text{ mL}} = 9 \times 10^{-4} \text{ mol/L}$$

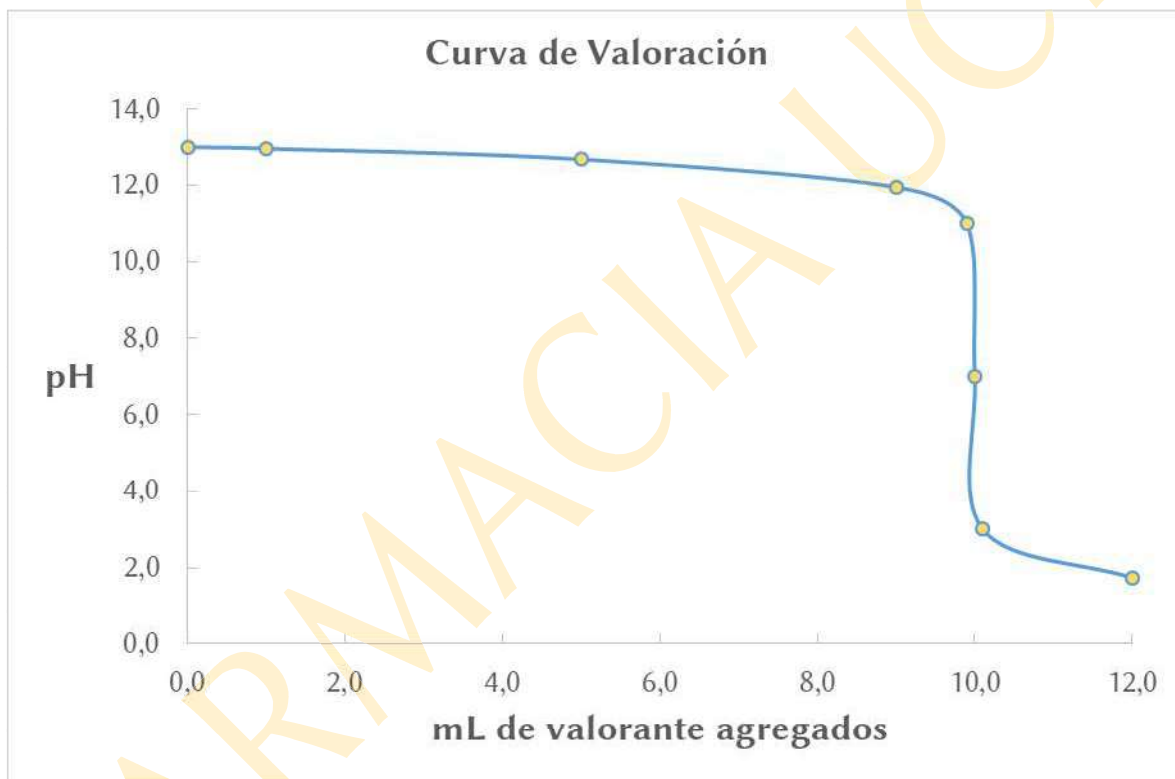
$$\text{pH} = 3,0$$

h)

	HBr	+	NaOH	→	NaBr	+	H ₂ O
mmol _{inicial}	12,0		10,0		---		---
mmol _{final}	2,0		---		---		---

$$[H^+] = \frac{2,0 \text{ mmol}}{(100,0 + 12,0) \text{ mL}} = 0,018 \text{ mol/L}$$

$$\text{pH} = 1,74$$

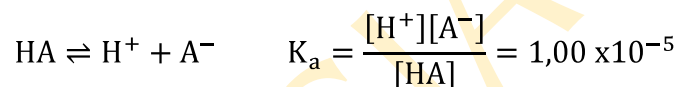


12.6 Se valora un ácido débil HA ($pK_a = 5,000$) con KOH 1,00 M. La disolución ácida tiene un volumen de 100,0 mL y una molaridad de 0,100 M. Hallar el pH para los siguientes volúmenes de base añadida, y trazar un gráfico de pH frente a V_b : $V_b =$ a) 0, b) 1,00, c) 5,00, d) 9,00, e) 9,90, f) 10,0, g) 10,1 y h) 12,0 mL.

Respuesta/ a) 3,002
 b) 4,05
 c) 5,00
 d) 5,96
 e) 7,0
 f) 8,977
 g) 11,0
 h) 12,26

a)

$$pK_a = 5,000 \Rightarrow K_a = 1,00 \times 10^{-5}$$



	HA	\rightleftharpoons	H ⁺	+	A ⁻
Cn _{inicial}	0,100		0		0
Cn _{final}	0,100 - x		x		x

$$K_a = \frac{[H^+][A^-]}{[HA]} = \frac{(x)(x)}{0,100 - x} = 1,00 \times 10^{-5}$$

$$x = 9,95 \times 10^{-4} \text{ mol/L} = [H^+]$$

$$pH = 3,002$$

b)

	HA	+	KOH	\rightarrow	KA	+	H ₂ O
mmol _{inicial}	10,0		1,00		---		---

mmol _{final}	9,0	---	1,00	---
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$$[\text{HA}] = \frac{9,0 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 0,089 \text{ mol/L}$$

$$[\text{A}^-] = \frac{1,00 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 9,90 \times 10^{-3} \text{ mol/L}$$

	HA	⇌	H ⁺	+	A ⁻
Cn _{inicial}	0,089		0		9,90 × 10 ⁻³
Cn _{final}	0,089 - x		x		9,90 × 10 ⁻³ + x

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} = \frac{(x)(9,90 \times 10^{-3} + x)}{0,089 - x} = 1,00 \times 10^{-5}$$

$$x = 8,9 \times 10^{-5} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 4,05$$

c)

	HA	+	KOH	→	KA	+	H ₂ O
mmol _{inicial}	10,0		5,00		---		---
mmol _{final}	5,0		---		5,00		---

$$[\text{HA}] = \frac{5,0 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,048 \text{ mol/L}$$

$$[\text{A}^-] = \frac{5,00 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,0476 \text{ mol/L}$$

	HA	⇌	H ⁺	+	A ⁻
Cn _{inicial}	0,048		0		0,0476
Cn _{final}	0,048 - x		x		0,0476 + x

$$K_a = \frac{[H^+][A^-]}{[HA]} = \frac{(x)(0,0476 + x)}{0,048 - x} = 1,00 \times 10^{-5}$$

$$x = 1,0 \times 10^{-5} \text{ mol/L} = [H^+]$$

$$\text{pH} = 5,00$$

d)

	HA	+	KOH	→	KA	+	H ₂ O
mmol _{inicial}	10,0		9,00		---		---
mmol _{final}	1,0		---		9,00		---

$$[HA] = \frac{1,0 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 9,2 \times 10^{-3} \text{ mol/L}$$

$$[A^-] = \frac{9,00 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 0,0826 \text{ mol/L}$$

	HA	⇌	H ⁺	+	A ⁻
Cn _{inicial}	9,2 x 10 ⁻³		0		0,0826
Cn _{final}	9,2 x 10 ⁻³ - x		x		0,0826 + x

$$K_a = \frac{[H^+][A^-]}{[HA]} = \frac{(x)(0,0826 + x)}{9,2 \times 10^{-3} - x} = 1,00 \times 10^{-5}$$

$$x = 1,1 \times 10^{-6} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 5,96$$

e)

	HA	+	KOH	→	KA	+	H ₂ O
mmol _{inicial}	10,0		9,90		---		---
mmol _{final}	0,1		---		9,90		---

$$[\text{HA}] = \frac{0,1 \text{ mmol}}{(100,0 + 9,90) \text{ mL}} = 9 \times 10^{-4} \text{ mol/L}$$

$$[\text{A}^-] = \frac{9,90 \text{ mmol}}{(100,0 + 9,90) \text{ mL}} = 0,0901 \text{ mol/L}$$

	HA	⇌	H ⁺	+	A ⁻
Cn _{inicial}	9 × 10 ⁻⁴		0		0,0901
Cn _{final}	9 × 10 ⁻⁴ - x		x		0,0901 + x

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} = \frac{(x)(0,0901 + x)}{9 \times 10^{-4} - x} = 1,00 \times 10^{-5}$$

$$x = 1 \times 10^{-7} \text{ mol/L} = [\text{H}^+]$$

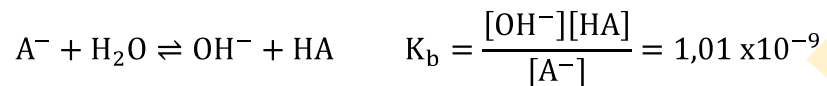
$$\text{pH} = 7,0$$

f)

	HA	+	KOH	→	KA	+	H ₂ O
mmol _{inicial}	10,0		10,0		---		---
mmol _{final}	---		---		10,0		---

$$[A^-] = \frac{10,0 \text{ mmol}}{(100,0 + 10,0) \text{ mL}} = 0,0909 \text{ mol/L}$$

$$K_a = 1,00 \times 10^{-5} \Rightarrow K_b = 1,01 \times 10^{-9}$$



	A ⁻	+ H ₂ O	⇌	OH ⁻	+	HA
Cn _{inicial}	0,0909	---		0		0
Cn _{final}	0,0909 - x	---		x		x

$$K_b = \frac{[OH^-][HA]}{[A^-]} = \frac{(x)(x)}{0,0909 - x} = 1,01 \times 10^{-9}$$

$$x = 9,58 \times 10^{-6} \text{ mol/L} = [OH^-]$$

$$pOH = 5,019 \Rightarrow pH = 8,977$$

g)

	HA	+	KOH	→	KA	+	H ₂ O
mmol _{inicial}	10,0		10,1		---		---
mmol _{final}	---		0,1		10,0		---

$$[OH^-] = \frac{0,1 \text{ mmol}}{(100,0 + 10,1) \text{ mL}} = 9 \times 10^{-4} \text{ mol/L}$$

$$[A^-] = \frac{10,0 \text{ mmol}}{(100,0 + 10,1) \text{ mL}} = 0,0908 \text{ mol/L}$$

	A^-	$+ H_2O$	\rightleftharpoons	OH^-	$+$	HA
$Cn_{inicial}$	0,0908	---		9×10^{-4}		0
Cn_{final}	$0,0908 - x$	---		$9 \times 10^{-4} + x$		x

$$K_b = \frac{[OH^-][HA]}{[A^-]} = \frac{(9 \times 10^{-4} + x)(x)}{0,0908 - x} = 1,01 \times 10^{-9}$$

$$x = 1 \times 10^{-7} \text{ mol/L}$$

$$[OH^-] = 9 \times 10^{-4} + x = 9 \times 10^{-4} \text{ mol/L} + 1 \times 10^{-7} \text{ mol/L} = 9 \times 10^{-4} \text{ mol/L}$$

$$pOH = 3,0 \Rightarrow pH = 11,0$$

h)

	HA	$+$	KOH	\rightarrow	KA	$+$	H_2O
$mmol_{inicial}$	10,0		12,0		---		---
$mmol_{final}$	---		2,0		10,0		---

$$[OH^-] = \frac{2,0 \text{ mmol}}{(100,0 + 12,0) \text{ mL}} = 0,018 \text{ mol/L}$$

$$[A^-] = \frac{10,0 \text{ mmol}}{(100,0 + 12,0) \text{ mL}} = 0,0893 \text{ mol/L}$$

	A^-	$+ H_2O$	\rightleftharpoons	OH^-	$+$	HA
$Cn_{inicial}$	0,0893	---		0,018		0
Cn_{final}	$0,0893 - x$	---		$0,018 + x$		x

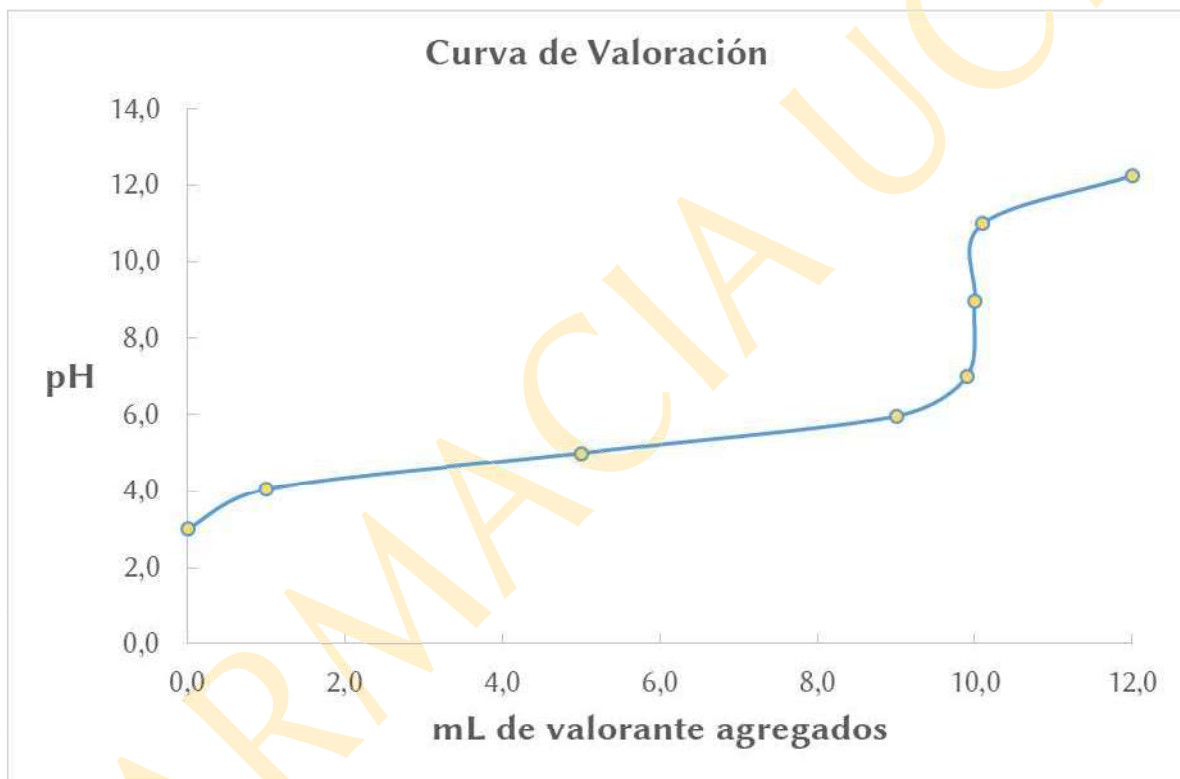
$$K_b = \frac{[\text{OH}^-][\text{HA}]}{[\text{A}^-]} = \frac{(0,018 + x)(x)}{0,0893 - x} = 1,01 \times 10^{-9}$$

$$x = 5,0 \times 10^{-9} \text{ mol/L}$$

$$[\text{OH}^-] = 0,018 + x = 0,018 \text{ mol/L} + 5,0 \times 10^{-9} \text{ mol/L} = 0,018 \text{ mol/L}$$

$$\text{pOH} = 1,74 \Rightarrow \text{pH} = 12,26$$

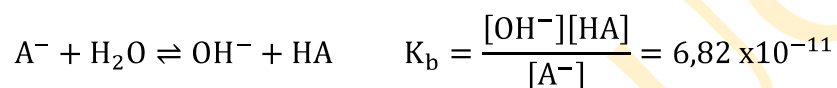
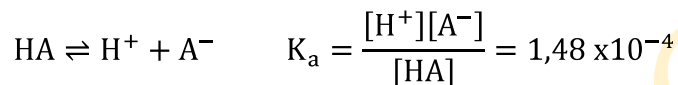
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12.8 ¿Cuál es el pH en el punto de equivalencia cuando se valora ácido hidroxiacético 0,100 M con KOH 0,0500 M?

Respuesta/ 8,175

Representamos ácido hidroxiacético como HA



Si tenemos 20,0 mL de HA

$$20,0 \text{ mL} * \frac{0,100 \text{ mmol HA}}{\text{mL}} * \frac{1 \text{ mmol KOH}}{1 \text{ mmol HA}} * \frac{\text{mL}}{0,0500 \text{ mmol KOH}} = 40,0 \text{ mL}$$

	HA	+	KOH	→	KA	+	H ₂ O
mmol _{inicial}	2,00		2,00		---		---
mmol _{final}	---		---		2,00		---

$$[\text{A}^-] = \frac{2,00 \text{ mmol}}{(20,0 + 40,0) \text{ mL}} = 0,0333 \text{ mol/L}$$

	A ⁻	+	H ₂ O	⇌	OH ⁻	+	HA
C _n _{inicial}	0,0333		---		0		0
C _n _{final}	0,0333 - x		---		x		x

$$K_b = \frac{[\text{OH}^-][\text{HA}]}{[\text{A}^-]} = \frac{(x)(x)}{0,0333 - x} = 6,82 \times 10^{-11}$$

$$x = 1,51 \times 10^{-6} \text{ mol/L} = [\text{OH}^-]$$

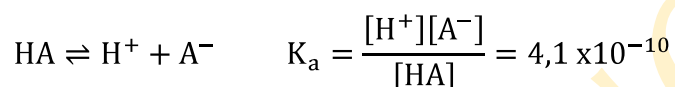
$$\text{pOH} = 5,821 \Rightarrow \text{pH} = 8,175$$

FARMACIA UCR

12.10 Cuando se añaden a 22,63 mL de disolución acuosa de NaOH 1,214 g de ácido ciclohexilaminoetanosulfónico (tabla 10.2) disueltos en 41,37 mL de agua, el pH resultante es 9,24. Calcular la molaridad del NaOH.

Respuesta/ 0,11 mol/L de NaOH

Representamos ácido ciclohexilaminoetanosulfónico como HA



$$1,214 \text{ g HA} * \frac{1000 \text{ mmol HA}}{207,29 \text{ g HA}} = 5,857 \text{ mmol HA}$$

Si tenemos "x" mmol de NaOH

	HA	+	OH ⁻	→	A ⁻	+	H ₂ O
mmol _{inicial}	5,857		x		---		---
mmol _{final}	5,857 - x		---		x		---

$$\text{pH} = \text{pK}_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

$$9,24 = 9,39 + \log \frac{x}{5,857 - x}$$

$$x = 2,4 \text{ mmol NaOH}$$

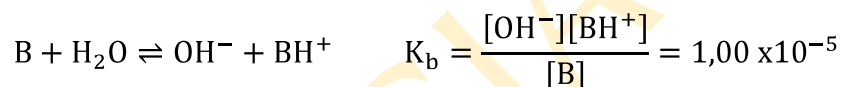
$$\frac{2,4 \text{ mmol KOH}}{22,63 \text{ mL}} = 0,11 \text{ mol/L}$$

12.14 Se valora una alícuota de 100,0 mL de una base débil B ($pK_b = 5,000$) 0,100 M con $HClO_4$ 1,00 M. Hallar el pH después de añadir los siguientes volúmenes de ácido, y representar gráficamente el pH frente al volumen añadido. $V_a =$ a) 0, b) 1,00, c) 5,00, d) 9,00, e) 9,90, f) 10,0, g) 10,1 y h) 12,0 mL.

Respuesta/ a) 10,994
 b) 9,95
 c) 9,00
 d) 8,04
 e) 7,0
 f) 5,019
 g) 3,0
 h) 1,74

a)

$$pK_b = 5,000 \Rightarrow K_b = 1,00 \times 10^{-5}$$



	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
$C_{n_{inicial}}$	0,100	---		0		0
$C_{n_{final}}$	0,100 - x	---		x		x

$$K_b = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(x)}{0,100 - x} = 1,00 \times 10^{-5}$$

$$x = 9,95 \times 10^{-4} \text{ mol/L} = [OH^-]$$

$$pOH = 3,002 \Rightarrow pH = 10,994$$

b)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
$mmol_{inicial}$	10,0		1,00		---		---

mmol _{final}	9,0	---	1,00	---
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$$[B] = \frac{9,0 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 0,089 \text{ mol/L}$$

$$[BH^+] = \frac{1,00 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 9,90 \times 10^{-3} \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,089	---		0		9,90 × 10 ⁻³
Cn _{final}	0,089 - x	---		x		9,90 × 10 ⁻³ + x

$$K_b = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(9,90 \times 10^{-3} + x)}{0,089 - x} = 1,00 \times 10^{-5}$$

$$x = 8,9 \times 10^{-5} \text{ mol/L} = [OH^-]$$

$$pOH = 4,05 \Rightarrow pH = 9,95$$

c)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
mmol _{inicial}	10,0		5,00		---		---
mmol _{final}	5,0		---		5,00		---

$$[B] = \frac{5,0 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,048 \text{ mol/L}$$

$$[BH^+] = \frac{5,00 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,0476 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,048	---		0		0,0476
Cn _{final}	0,048 - x	---		x		0,0476 + x

$$K_b = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0476 + x)}{0,048 - x} = 1,00 \times 10^{-5}$$

$$x = 1,0 \times 10^{-5} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 5,00 \Rightarrow \text{pH} = 9,00$$

d)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
mmol _{inicial}	10,0		9,00		---		---
mmol _{final}	1,0		---		9,00		---

$$[\text{B}] = \frac{1,0 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 9,2 \times 10^{-3} \text{ mol/L}$$

$$[\text{BH}^+] = \frac{9,00 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 0,0826 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	9,2 × 10 ⁻³	---		0		0,0826
Cn _{final}	9,2 × 10 ⁻³ - x	---		x		0,0826 + x

$$K_b = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0826 + x)}{9,2 \times 10^{-3} - x} = 1,00 \times 10^{-5}$$

$$x = 1,1 \times 10^{-6} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 5,96 \Rightarrow \text{pH} = 8,04$$

e)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
mmol _{inicial}	10,0		9,90		---		---
mmol _{final}	0,1		---		9,90		---

$$[\text{B}] = \frac{0,1 \text{ mmol}}{(100,0 + 9,90) \text{ mL}} = 9 \times 10^{-4} \text{ mol/L}$$

$$[\text{BH}^+] = \frac{9,90 \text{ mmol}}{(100,0 + 9,90) \text{ mL}} = 0,0901 \text{ mol/L}$$

	B	+	H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	9 × 10 ⁻⁴		---		0		0,0901
Cn _{final}	9 × 10 ⁻⁴ - x		---		x		0,0901 + x

$$K_b = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0901 + x)}{9 \times 10^{-4} - x} = 1,00 \times 10^{-5}$$

$$x = 1 \times 10^{-7} \text{ mol/L} = [\text{OH}^-]$$

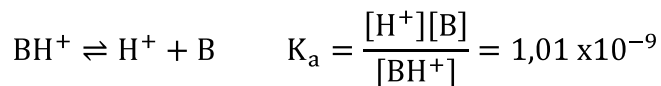
$$\text{pOH} = 7,0 \Rightarrow \text{pH} = 7,0$$

f)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
mmol _{inicial}	10,0		10,0		---		---
mmol _{final}	---		---		10,0		---

$$[\text{BH}^+] = \frac{10,0 \text{ mmol}}{(100,0 + 10,0) \text{ mL}} = 0,0909 \text{ mol/L}$$

$$K_b = 1,00 \times 10^{-5} \Rightarrow K_a = 1,01 \times 10^{-9}$$



	BH ⁺	⇌	H ⁺	+	B
Cn _{inicial}	0,0909		0		0
Cn _{final}	0,0909 - x		x		x

$$K_a = \frac{[\text{H}^+][\text{B}]}{[\text{BH}^+]} = \frac{(x)(x)}{0,0909 - x} = 1,01 \times 10^{-9}$$

$$x = 9,58 \times 10^{-6} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 5,019$$

g)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
mmol _{inicial}	10,0		10,1		---		---
mmol _{final}	---		0,1		10,0		---

$$[\text{H}^+] = \frac{0,1 \text{ mmol}}{(100,0 + 10,1) \text{ mL}} = 9 \times 10^{-4} \text{ mol/L}$$

$$[\text{BH}^+] = \frac{10,0 \text{ mmol}}{(100,0 + 10,1) \text{ mL}} = 0,0908 \text{ mol/L}$$

	BH ⁺	⇌	H ⁺	+	B
Cn _{inicial}	0,0908		9 x 10 ⁻⁴		0
Cn _{final}	0,0908 - x		9 x 10 ⁻⁴ + x		x

$$K_a = \frac{[H^+][B]}{[BH^+]} = \frac{(9 \times 10^{-4} + x)(x)}{0,0908 - x} = 1,01 \times 10^{-9}$$

$$x = 1 \times 10^{-7} \text{ mol/L}$$

$$[H^+] = 9 \times 10^{-4} + x = 9 \times 10^{-4} \text{ mol/L} + 1 \times 10^{-7} \text{ mol/L} = 9 \times 10^{-4} \text{ mol/L}$$

$$\text{pH} = 3,0$$

h)

	B	+	HClO ₄	→	BH ⁺	+	ClO ₄ ⁻
mmol _{inicial}	10,0		12,0		---		---
mmol _{final}	---		2,0		10,0		---

$$[H^+] = \frac{2,0 \text{ mmol}}{(100,0 + 12,0) \text{ mL}} = 0,018 \text{ mol/L}$$

$$[BH^+] = \frac{10,0 \text{ mmol}}{(100,0 + 12,0) \text{ mL}} = 0,0893 \text{ mol/L}$$

	BH ⁺	⇌	H ⁺	+	B
Cn _{inicial}	0,0893		0,018		0
Cn _{final}	0,0893 - x		0,018 + x		x

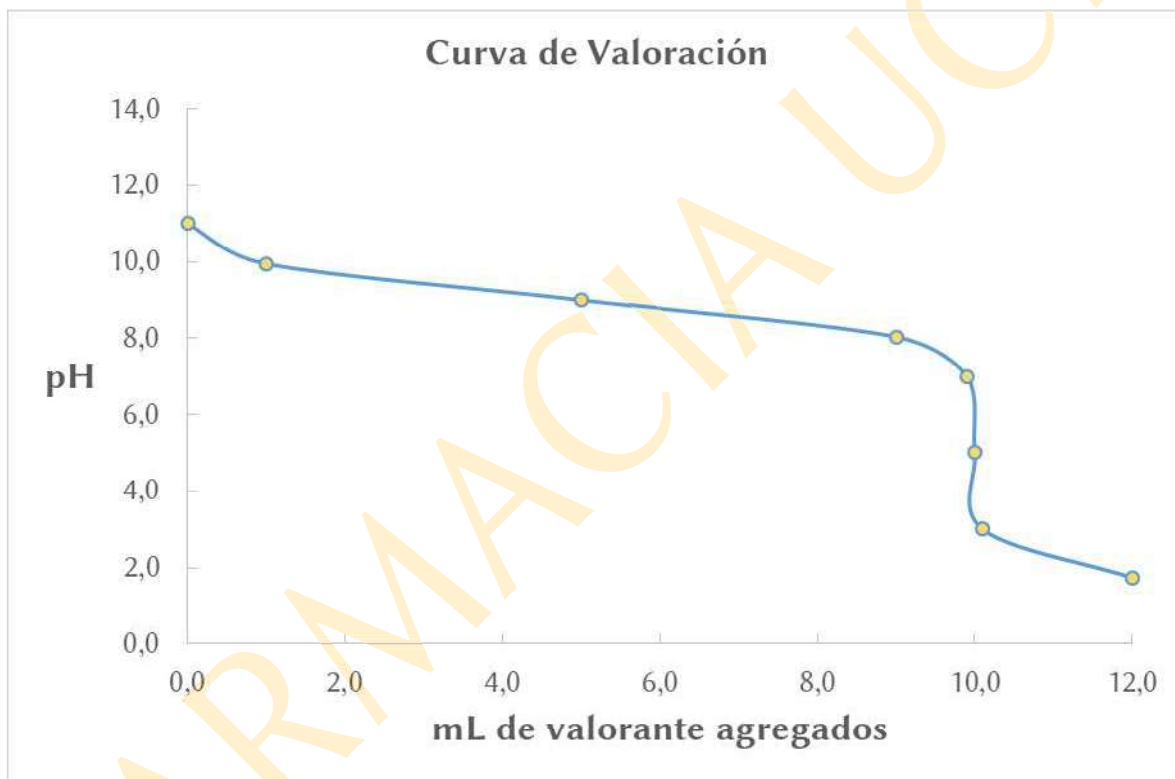
$$K_a = \frac{[H^+][B]}{[BH^+]} = \frac{(0,018 + x)(x)}{0,0893 - x} = 1,01 \times 10^{-9}$$

$$x = 5,0 \times 10^{-9} \text{ mol/L}$$

$$[H^+] = 0,018 + x = 0,018 \text{ mol/L} + 5,0 \times 10^{-9} \text{ mol/L} = 0,018 \text{ mol/L}$$

$$\text{pH} = 1,74$$

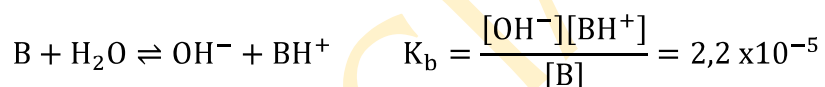
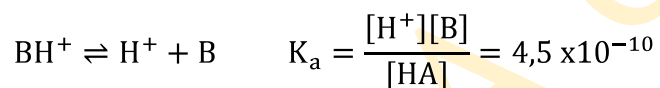
FARMACIA UCR



12.17 Se valora una disolución que contiene 50,0 mL de bencilamina 0,0319 M con HCl 0,0500 M. Calcular el pH después de añadir los siguientes volúmenes de ácido: $V_a =$ a) 0, b) 12,0, c) $\frac{1}{2} V_e$, d) 30,0, e) V_e y f) 35,0 mL.

Respuesta/ a) 10,92
 b) 9,56
 c) 9,34
 d) 8,15
 e) 5,52
 f) 2,74

Representamos bencilamina como B



a)

	B	+ H ₂ O	\rightleftharpoons	OH ⁻	+	BH ⁺
C _n inicial	0,0319	---		0		0
C _n final	0,0319 - x	---		x		x

$$K_b = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(x)}{0,0319 - x} = 2,2 \times 10^{-5}$$

$$x = 8,3 \times 10^{-4} \text{ mol/L} = [OH^-]$$

$$pOH = 3,08 \Rightarrow pH = 10,92$$

b)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	1,60		0,600		---		---
mmol _{final}	1,00		---		0,600		---

$$[B] = \frac{1,00 \text{ mmol}}{(50,0 + 12,0) \text{ mL}} = 0,0161 \text{ mol/L}$$

$$[BH^+] = \frac{0,600 \text{ mmol}}{(50,0 + 12,0) \text{ mL}} = 9,68 \times 10^{-3} \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,0161			0		9,68 × 10 ⁻³
Cn _{final}	0,0161 - x			x		9,68 × 10 ⁻³ + x

$$K_b = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(9,68 \times 10^{-3} + x)}{0,0161 - x} = 2,2 \times 10^{-5}$$

$$x = 3,6 \times 10^{-5} \text{ mol/L} = [OH^-]$$

$$pOH = 4,44 \Rightarrow pH = 9,56$$

c)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	1,60		0,800		---		---
mmol _{final}	0,80		---		0,800		---

$$[B] = \frac{0,80 \text{ mmol}}{(50,0 + 31,9/2) \text{ mL}} = 0,012 \text{ mol/L}$$

$$[\text{BH}^+] = \frac{0,800 \text{ mmol}}{(50,0 + 31,9/2) \text{ mL}} = 0,0121 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,012	---		0		0,0121
Cn _{final}	0,012 - x	---		x		0,0121 + x

$$K_b = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0121 + x)}{0,012 - x} = 2,2 \times 10^{-5}$$

$$x = 2,2 \times 10^{-5} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 4,66 \Rightarrow \text{pH} = 9,34$$

d)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	1,60		1,50		---		---
mmol _{final}	0,10		---		1,50		---

$$[\text{B}] = \frac{0,10 \text{ mmol}}{(50,0 + 30,0) \text{ mL}} = 1,2 \times 10^{-3} \text{ mol/L}$$

$$[\text{BH}^+] = \frac{1,50 \text{ mmol}}{(50,0 + 30,0) \text{ mL}} = 0,0188 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	1,2 × 10 ⁻³	---		0		0,0188
Cn _{final}	1,2 × 10 ⁻³ - x	---		x		0,0188 + x

$$K_b = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0188 + x)}{1,2 \times 10^{-3} - x} = 2,2 \times 10^{-5}$$

$$x = 1,4 \times 10^{-6} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 5,85 \Rightarrow \text{pH} = 8,15$$

e)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	1,60		1,60		---		---
mmol _{final}	---		---		1,60		---

$$[\text{BH}^+] = \frac{1,60 \text{ mmol}}{(50,0 + 31,9) \text{ mL}} = 0,0195 \text{ mol/L}$$

	BH ⁺	⇌	H ⁺	+	B
Cn _{inicial}	0,0195		0		0
Cn _{final}	0,0195 - x		x		x

$$K_a = \frac{[\text{H}^+][\text{B}]}{[\text{BH}^+]} = \frac{(x)(x)}{0,0195 - x} = 4,5 \times 10^{-10}$$

$$x = 3,0 \times 10^{-6} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 5,52$$

f)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	1,60		1,75		---		---
mmol _{final}	---		0,15		1,60		---

$$[H^+] = \frac{0,15 \text{ mmol}}{(50,0 + 35,0) \text{ mL}} = 1,8 \times 10^{-3} \text{ mol/L}$$

$$[BH^+] = \frac{1,60 \text{ mmol}}{(50,0 + 35,0) \text{ mL}} = 0,0188 \text{ mol/L}$$

	BH ⁺	⇌	H ⁺	+	B
Cn _{inicial}	0,0188		1,8 × 10 ⁻³		0
Cn _{final}	0,0188 - x		1,8 × 10 ⁻³ + x		x

$$K_a = \frac{[H^+][B]}{[BH^+]} = \frac{(1,8 \times 10^{-3} + x)(x)}{0,0188 - x} = 4,5 \times 10^{-10}$$

$$x = 4,7 \times 10^{-9} \text{ mol/L}$$

$$[H^+] = 1,8 \times 10^{-3} + x = 1,8 \times 10^{-3} \text{ mol/L} + 4,7 \times 10^{-9} \text{ mol/L} = 1,8 \times 10^{-3} \text{ mol/L}$$

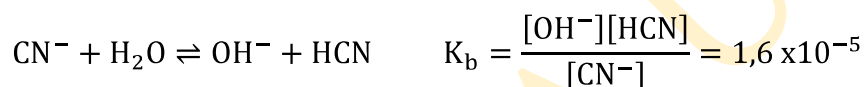
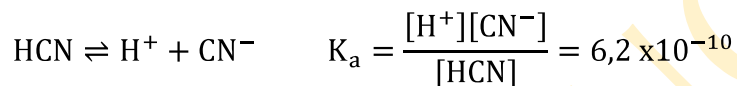
$$\text{pH} = 2,74$$

12.18 Calcular el pH de la disolución que resulta al mezclar 50,00 mL de NaCN 0,100 M con

- 4,20 mL de ácido perclórico 0,438 M.
- 11,82 mL de ácido perclórico 0,438 M.
- ¿Cuál es el pH del punto de equivalencia usando ácido perclórico 0,438 M?

Respuesta/

- 9,43
- 2,54
- 5,15



a)

	CN ⁻	+	HClO ₄	→	HCN	+	ClO ₄ ⁻
mmol _{inicial}	5,00		1,84		---		---
mmol _{final}	3,16		---		1,84		---

$$[\text{CN}^-] = \frac{3,16 \text{ mmol}}{(50,0 + 4,20) \text{ mL}} = 0,0583 \text{ mol/L}$$

$$[\text{HCN}] = \frac{1,84 \text{ mmol}}{(50,0 + 4,20) \text{ mL}} = 0,0339 \text{ mol/L}$$

	CN ⁻	+	H ₂ O	⇌	OH ⁻	+	HCN
C _n _{inicial}	0,0583		---		0		0,0339
C _n _{final}	0,0583 - x		---		x		0,0339 + x

$$K_b = \frac{[\text{OH}^-][\text{HCN}]}{[\text{CN}^-]} = \frac{(x)(0,0339 + x)}{0,0583 - x} = 1,6 \times 10^{-5}$$

$$x = 2,7 \times 10^{-5} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 4,57 \Rightarrow \text{pH} = 9,43$$

b)

	CN^-	+	HClO_4	\rightarrow	HCN	+	ClO_4^-
mmol _{inicial}	5,00		5,18		---		---
mmol _{final}	---		0,18		5,00		---

$$[\text{H}^+] = \frac{0,18 \text{ mmol}}{(50,0 + 11,82) \text{ mL}} = 2,9 \times 10^{-3} \text{ mol/L}$$

$$[\text{HCN}] = \frac{1,60 \text{ mmol}}{(50,0 + 11,82) \text{ mL}} = 0,0259 \text{ mol/L}$$

	HCN	\rightleftharpoons	H^+	+	CN^-
$C_{n_{\text{inicial}}}$	0,0259		$2,9 \times 10^{-3}$		0
$C_{n_{\text{final}}}$	$0,0259 - x$		$2,9 \times 10^{-3} + x$		x

$$K_a = \frac{[\text{H}^+][\text{CN}^-]}{[\text{HCN}]} = \frac{(2,9 \times 10^{-3} + x)(x)}{0,0259 - x} = 6,2 \times 10^{-10}$$

$$x = 5,5 \times 10^{-9} \text{ mol/L}$$

$$[\text{H}^+] = 2,9 \times 10^{-3} + x = 2,9 \times 10^{-3} \text{ mol/L} + 5,5 \times 10^{-9} \text{ mol/L} = 2,9 \times 10^{-3} \text{ mol/L}$$

$$\text{pH} = 2,54$$

c)

	CN ⁻	+	HClO ₄	→	HCN	+	ClO ₄ ⁻
mmol _{inicial}	5,00		5,00		---		---
mmol _{final}	---		---		5,00		---

$$[\text{HCN}] = \frac{5,00 \text{ mmol}}{(50,0 + 11,4) \text{ mL}} = 0,0814 \text{ mol/L}$$

	HCN	⇌	H ⁺	+	CN ⁻
Cn _{inicial}	0,0814		0		0
Cn _{final}	0,0814 - x		x		x

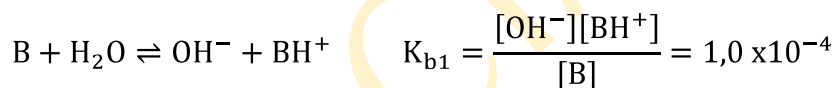
$$K_a = \frac{[\text{H}^+][\text{CN}^-]}{[\text{HCN}]} = \frac{(x)(x)}{0,0814 - x} = 6,2 \times 10^{-10}$$

$$x = 7,1 \times 10^{-6} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 5,15$$

12.23 Se valora el compuesto dibásico B ($pK_{b1} = 4,00$, $pK_{b2} = 8,00$) con HCl 1,00 M. La disolución inicial de B es 0,100 M, y tiene un volumen de 100,0 mL. Hallar el pH para los siguientes volúmenes de ácido añadido, y representar gráficamente pH frente al volumen añadido: $V_a =$ a) 0, b) 1,00, c) 5,00, d) 9,00, e) 10,0, f) 11,0, g) 15,0, h) 19,0, i) 20,0 y j) 21,0 y k) 22,0 mL.

- Respuesta/
- a) 11,49
 - b) 10,91
 - c) 10,00
 - d) 9,04
 - e) 8,00
 - f) 6,95
 - g) 6,00
 - h) 5,04
 - i) 3,54
 - j) 2,08
 - k) 1,80



a)

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
$C_{n_{inicial}}$	0,100	---		0		0
$C_{n_{final}}$	0,100- x	---		x		x

$$K_{b1} = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(x)}{0,100 - x} = 1,0 \times 10^{-4}$$

$$x = 3,1 \times 10^{-3} \text{ mol/L} = [OH^-]$$

$$pOH = 2,51 \Rightarrow pH = 11,49$$

b)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	10,0		1,00		---		---
mmol _{final}	9,0		---		1,00		---

$$[B] = \frac{9,0 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 0,089 \text{ mol/L}$$

$$[BH^+] = \frac{1,00 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 9,90 \times 10^{-3} \text{ mol/L}$$

	B	+	H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,089		---		0		9,90 × 10 ⁻³
Cn _{final}	0,089 - x		---		x		9,90 × 10 ⁻³ + x

$$K_{b1} = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(9,90 \times 10^{-3} + x)}{0,089 - x} = 1,0 \times 10^{-4}$$

$$x = 8,2 \times 10^{-4} \text{ mol/L} = [OH^-]$$

$$pOH = 3,09 \Rightarrow pH = 10,91$$

c)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	10,0		5,00		---		---
mmol _{final}	5,0		---		5,00		---

$$[B] = \frac{5,0 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,048 \text{ mol/L}$$

$$[\text{BH}^+] = \frac{5,00 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,0476 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,048	---		0		0,0476
Cn _{final}	0,048 - x	---		x		0,0476 + x

$$K_{b1} = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0476 + x)}{0,048 - x} = 1,0 \times 10^{-4}$$

$$x = 1,0 \times 10^{-4} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 4,00 \Rightarrow \text{pH} = 10,00$$

d)

	B	+ HCl	→	BH ⁺	+ Cl ⁻
mmol _{inicial}	10,0	9,00		---	---
mmol _{final}	1,0	---		9,00	---

$$[\text{B}] = \frac{1,0 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 9,2 \times 10^{-3} \text{ mol/L}$$

$$[\text{BH}^+] = \frac{9,00 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 0,0826 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	9,2 × 10 ⁻³	---		0		0,0826
Cn _{final}	9,2 × 10 ⁻³ - x	---		x		0,0826 + x

$$K_{b1} = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0826 + x)}{9,2 \times 10^{-3} - x} = 1,0 \times 10^{-4}$$

$$x = 1,1 \times 10^{-5} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 4,96 \Rightarrow \text{pH} = 9,04$$

e)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	10,0		10,0		---		---
mmol _{final}	---		---		10,0		---

$$[\text{BH}^+] = \frac{10,0 \text{ mmol}}{(100,0 + 10,0) \text{ mL}} = 0,0909 \text{ mol/L}$$

$$[\text{H}^+] = \sqrt{\frac{K_{a1}K_{a2}[\text{BH}^+] + K_{a1}K_w}{K_{a1} + [\text{BH}^+]}} \Rightarrow \sqrt{\frac{K_{a1}K_{a2}F + K_{a1}K_w}{K_{a1} + F}}$$

$$[\text{H}^+] = \sqrt{\frac{(1,0 \times 10^{-6})(1,0 \times 10^{-10})(0,0909) + (1,0 \times 10^{-6})(1,01 \times 10^{-14})}{1,0 \times 10^{-6} + 0,0909}}$$

$$[\text{H}^+] = 1,0 \times 10^{-8} \text{ mol/L}$$

$$\text{pH} = 8,00$$

f)

	BH ⁺	+	HCl	→	BH ₂ ²⁺	+	Cl ⁻
mmol _{inicial}	10,0		1,00		---		---
mmol _{final}	9,0		---		1,00		---

$$[\text{BH}^+] = \frac{9,0 \text{ mmol}}{(100,0 + 11,0) \text{ mL}} = 0,081 \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{1,00 \text{ mmol}}{(100,0 + 11,0) \text{ mL}} = 9,01 \times 10^{-3} \text{ mol/L}$$

	BH ⁺	+ H ₂ O	⇌	OH ⁻	+	BH ₂ ²⁺
Cn _{inicial}	0,081	---		0		9,01 x 10 ⁻³
Cn _{final}	0,081 - x	---		x		9,01 x 10 ⁻³ + x

$$K_{b2} = \frac{[\text{OH}^-][\text{BH}_2^{2+}]}{[\text{BH}^+]} = \frac{(x)(9,01 \times 10^{-3} + x)}{0,081 - x} = 1,0 \times 10^{-8}$$

$$x = 9,0 \times 10^{-8} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 7,05 \Rightarrow \text{pH} = 6,95$$

g)

	BH ⁺	+	HCl	→	BH ₂ ²⁺	+	Cl ⁻
mmol _{inicial}	10,0		5,00		---		---
mmol _{final}	5,0		---		5,00		---

$$[\text{BH}^+] = \frac{5,0 \text{ mmol}}{(100,0 + 15,0) \text{ mL}} = 0,043 \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{5,00 \text{ mmol}}{(100,0 + 15,0) \text{ mL}} = 0,0435 \text{ mol/L}$$

	BH ⁺	+ H ₂ O	⇌	OH ⁻	+	BH ₂ ²⁺
Cn _{inicial}	0,043	---		0		0,0435

$C_{n_{final}}$	$0,043 - x$	---	x	$0,0435 + x$
-----------------	-------------	-----	-----	--------------

$$K_{b2} = \frac{[OH^-][BH_2^{2+}]}{[BH^+]} = \frac{(x)(0,0435 + x)}{0,043 - x} = 1,0 \times 10^{-8}$$

$$x = 9,9 \times 10^{-9} \text{ mol/L} = [OH^-]$$

$$pOH = 8,00 \Rightarrow pH = 6,00$$

h)

	BH^+	+	HCl	\rightarrow	BH_2^{2+}	+	Cl^-
$mmol_{inicial}$	10,0		9,00		---		---
$mmol_{final}$	1,0		---		9,00		---

$$[BH^+] = \frac{1,0 \text{ mmol}}{(100,0 + 19,0) \text{ mL}} = 8,4 \times 10^{-3} \text{ mol/L}$$

$$[BH_2^{2+}] = \frac{9,00 \text{ mmol}}{(100,0 + 19,0) \text{ mL}} = 0,0756 \text{ mol/L}$$

	BH^+	+	H_2O	\rightleftharpoons	OH^-	+	BH_2^{2+}
$C_{n_{inicial}}$	$8,4 \times 10^{-3}$		---		0		0,0756
$C_{n_{final}}$	$8,4 \times 10^{-3} - x$		---		x		$0,0756 + x$

$$K_{b2} = \frac{[OH^-][BH_2^{2+}]}{[BH^+]} = \frac{(x)(0,0756 + x)}{8,4 \times 10^{-3} - x} = 1,0 \times 10^{-8}$$

$$x = 1,1 \times 10^{-9} \text{ mol/L} = [OH^-]$$

$$pOH = 8,96 \Rightarrow pH = 5,04$$

i)

	BH ⁺	+	HCl	→	BH ₂ ⁺	+	Cl ⁻
mmol _{inicial}	10,0		10,0		---		---
mmol _{final}	---		---		10,0		---

$$[\text{BH}_2^+] = \frac{10,0 \text{ mmol}}{(100,0 + 20,0) \text{ mL}} = 0,0833 \text{ mol/L}$$

	BH ₂ ⁺	⇌	H ⁺	+	BH ⁺
Cn _{inicial}	0,0833		0		0
Cn _{final}	0,0833 - x		x		x

$$K_{a1} = \frac{[\text{H}^+][\text{BH}^+]}{[\text{BH}_2^+]} = \frac{(x)(x)}{0,0833 - x} = 1,0 \times 10^{-6}$$

$$x = 2,9 \times 10^{-4} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 3,54$$

j)

	BH ⁺	+	HCl	→	BH ₂ ⁺	+	Cl ⁻
mmol _{inicial}	10,0		11,0		---		---
mmol _{final}	---		1,0		10,0		---

$$[\text{H}^+] = \frac{1,0 \text{ mmol}}{(100,0 + 21,0) \text{ mL}} = 8,3 \times 10^{-3} \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{10,0 \text{ mmol}}{(100,0 + 21,0) \text{ mL}} = 0,0826 \text{ mol/L}$$

	BH_2^{2+}	\rightleftharpoons	H^+	+	BH^+
$\text{Cn}_{\text{inicial}}$	0,0826		$8,3 \times 10^{-3}$		0
Cn_{final}	$0,0826 - x$		$8,3 \times 10^{-3} + x$		x

$$K_{a1} = \frac{[\text{H}^+][\text{BH}^+]}{[\text{BH}_2^{2+}]} = \frac{(8,3 \times 10^{-3} + x)(x)}{0,0826 - x} = 1,0 \times 10^{-6}$$

$$x = 9,9 \times 10^{-6} \text{ mol/L}$$

$$[\text{H}^+] = 8,3 \times 10^{-3} + x = 8,3 \times 10^{-3} \text{ mol/L} + 9,9 \times 10^{-6} \text{ mol/L} = 8,3 \times 10^{-3} \text{ mol/L}$$

$$\text{pH} = 2,08$$

k)

	BH^+	+	HCl	\rightarrow	BH_2^{2+}	+	Cl^-
$\text{mmol}_{\text{inicial}}$	10,0		12,0		---		---
$\text{mmol}_{\text{final}}$	---		2,0		10,0		---

$$[\text{H}^+] = \frac{2,0 \text{ mmol}}{(100,0 + 22,0) \text{ mL}} = 0,016 \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{10,0 \text{ mmol}}{(100,0 + 22,0) \text{ mL}} = 0,0820 \text{ mol/L}$$

	BH_2^{2+}	\rightleftharpoons	H^+	+	BH^+
$\text{Cn}_{\text{inicial}}$	0,0820		0,016		0
Cn_{final}	$0,0820 - x$		$0,016 + x$		x

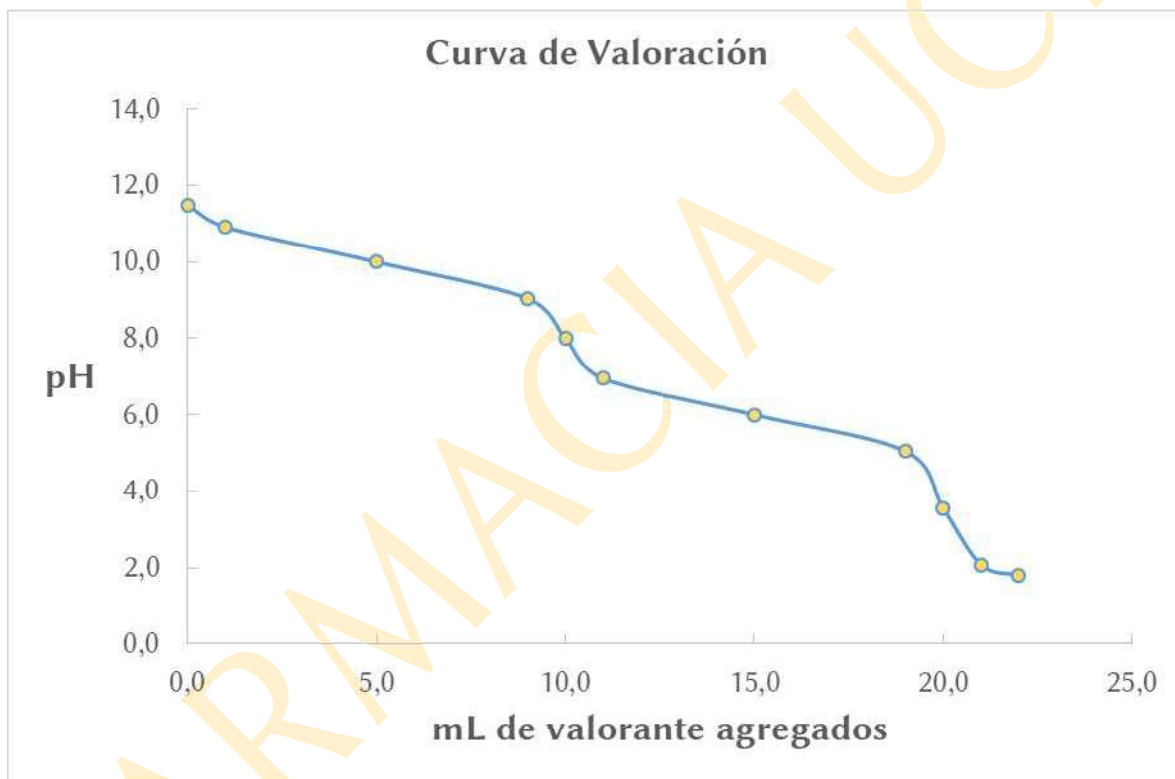
$$K_{a1} = \frac{[H^+][BH^+]}{[BH_2^+]} = \frac{(0,016 + x)(x)}{0,0820 - x} = 1,0 \times 10^{-6}$$

$$x = 5,1 \times 10^{-6} \text{ mol/L}$$

$$[H^+] = 0,016 + x = 0,016 \text{ mol/L} + 5,1 \times 10^{-6} \text{ mol/L} = 0,016 \text{ mol/L}$$

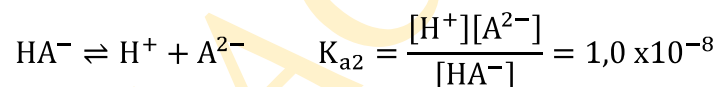
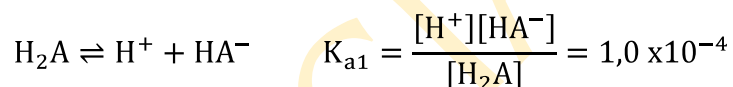
$$\text{pH} = 1,80$$

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12.24 Se valora una alícuota de 100,0 mL del ácido diprótico H_2A 0,100 M ($pK_{a1} = 4,00$, $pK_{a2} = 8,00$) con NaOH 1,00 M. Hallar el pH para los siguientes volúmenes añadidos de base, y representar gráficamente pH frente a $V_b = a) 0, b) 1,00, c) 5,00, d) 9,00, e) 10,0, f) 11,0, g) 15,0, h) 19,0, i) 20,0$ y j) 21,0 y k) 22,0 mL.

- Respuesta/
- a) 2,51
 - b) 3,09
 - c) 4,00
 - d) 4,96
 - e) 6,00
 - f) 7,05
 - g) 8,00
 - h) 8,96
 - i) 10,46
 - j) 11,92
 - k) 12,20



a)

	H_2A	\rightleftharpoons	H^+	+	HA^-
Cn _{inicial}	0,100		0		0
Cn _{final}	0,100 - x		x		x

$$K_{a1} = \frac{[H^+][HA^-]}{[H_2A]} = \frac{(x)(x)}{0,100 - x} = 1,0 \times 10^{-4}$$

$$x = 3,1 \times 10^{-3} \text{ mol/L} = [H^+]$$

$$pH = 2,51$$

b)

	H ₂ A	+	NaOH	→	NaHA	+	H ₂ O
mmol _{inicial}	10,0		1,00		---		---
mmol _{final}	9,0		---		1,00		---

$$[\text{H}_2\text{A}] = \frac{9,0 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 0,089 \text{ mol/L}$$

$$[\text{HA}^-] = \frac{1,00 \text{ mmol}}{(100,0 + 1,00) \text{ mL}} = 9,90 \times 10^{-3} \text{ mol/L}$$

	H ₂ A	⇌	H ⁺	+	HA ⁻
Cn _{inicial}	0,089		0		9,90 × 10 ⁻³
Cn _{final}	0,089 - x		x		9,90 × 10 ⁻³ + x

$$K_{a1} = \frac{[\text{H}^+][\text{HA}^-]}{[\text{H}_2\text{A}]} = \frac{(x)(9,90 \times 10^{-3} + x)}{0,089 - x} = 1,0 \times 10^{-4}$$

$$x = 8,2 \times 10^{-4} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 3,09$$

c)

	H ₂ A	+	NaOH	→	NaHA	+	H ₂ O
mmol _{inicial}	10,0		5,00		---		---
mmol _{final}	5,0		---		5,00		---

$$[\text{H}_2\text{A}] = \frac{5,0 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,048 \text{ mol/L}$$

$$[\text{HA}^-] = \frac{5,00 \text{ mmol}}{(100,0 + 5,00) \text{ mL}} = 0,0476 \text{ mol/L}$$

	H_2A	\rightleftharpoons	H^+	+	HA^-
$\text{Cn}_{\text{inicial}}$	0,048		0		0,0476
Cn_{final}	$0,048 - x$		x		$0,0476 + x$

$$K_{a1} = \frac{[\text{H}^+][\text{HA}^-]}{[\text{H}_2\text{A}]} = \frac{(x)(0,0476 + x)}{0,048 - x} = 1,0 \times 10^{-4}$$

$$x = 1,0 \times 10^{-4} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 4,00$$

d)

	H_2A	+	NaOH	\rightarrow	NaHA	+	H_2O
$\text{mmol}_{\text{inicial}}$	10,0		9,00		---		---
$\text{mmol}_{\text{final}}$	1,0		---		9,00		---

$$[\text{H}_2\text{A}] = \frac{1,0 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 9,2 \times 10^{-3} \text{ mol/L}$$

$$[\text{HA}^-] = \frac{9,00 \text{ mmol}}{(100,0 + 9,00) \text{ mL}} = 0,0826 \text{ mol/L}$$

	H_2A	\rightleftharpoons	H^+	+	HA^-
$\text{Cn}_{\text{inicial}}$	$9,2 \times 10^{-3}$		0		0,0826
Cn_{final}	$9,2 \times 10^{-3} - x$		x		$0,0826 + x$

$$K_{a1} = \frac{[H^+][HA^-]}{[H_2A]} = \frac{(x)(0,0826 + x)}{9,2 \times 10^{-3} - x} = 1,0 \times 10^{-4}$$

$$x = 1,1 \times 10^{-5} \text{ mol/L} = [H^+]$$

$$\text{pH} = 4,96$$

e)

	H ₂ A	+	NaOH	→	NaHA	+	H ₂ O
mmol _{inicial}	10,0		10,0		---		---
mmol _{final}	---		---		10,0		---

$$[HA^-] = \frac{10,0 \text{ mmol}}{(100,0 + 10,0) \text{ mL}} = 0,0909 \text{ mol/L}$$

$$[H^+] = \sqrt{\frac{K_{a1}K_{a2}[HA^-] + K_{a1}K_w}{K_{a1} + [HA^-]}} \Rightarrow \sqrt{\frac{K_{a1}K_{a2}F + K_{a1}K_w}{K_{a1} + F}}$$

$$[H^+] = \sqrt{\frac{(1,0 \times 10^{-4})(1,0 \times 10^{-8})(0,0909) + (1,0 \times 10^{-4})(1,01 \times 10^{-14})}{1,0 \times 10^{-4} + 0,0909}}$$

$$[H^+] = 1,0 \times 10^{-6} \text{ mol/L}$$

$$\text{pH} = 6,00$$

f)

	NaHA	+	NaOH	→	Na ₂ A	+	H ₂ O
mmol _{inicial}	10,0		1,00		---		---
mmol _{final}	9,0		---		1,00		---

$$[\text{HA}^-] = \frac{9,0 \text{ mmol}}{(100,0 + 11,0) \text{ mL}} = 0,081 \text{ mol/L}$$

$$[\text{A}^{2-}] = \frac{1,00 \text{ mmol}}{(100,0 + 11,0) \text{ mL}} = 9,01 \times 10^{-3} \text{ mol/L}$$

	HA^-	\rightleftharpoons	H^+	+	A^{2-}
$C_{n_{\text{inicial}}}$	0,081		0		$9,01 \times 10^{-3}$
$C_{n_{\text{final}}}$	$0,081 - x$		x		$9,01 \times 10^{-3} + x$

$$K_{a2} = \frac{[\text{H}^+][\text{A}^{2-}]}{[\text{HA}^-]} = \frac{(x)(9,01 \times 10^{-3} + x)}{0,081 - x} = 1,0 \times 10^{-8}$$

$$x = 9,0 \times 10^{-8} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 7,05$$

g)

	NaHA	+	NaOH	\rightarrow	Na_2A	+	H_2O
$\text{mmol}_{\text{inicial}}$	10,0		5,00		---		---
$\text{mmol}_{\text{final}}$	5,0		---		5,00		---

$$[\text{HA}^-] = \frac{5,0 \text{ mmol}}{(100,0 + 15,0) \text{ mL}} = 0,043 \text{ mol/L}$$

$$[\text{A}^{2-}] = \frac{5,00 \text{ mmol}}{(100,0 + 15,0) \text{ mL}} = 0,0435 \text{ mol/L}$$

	HA^-	\rightleftharpoons	H^+	+	A^{2-}
$C_{n_{\text{inicial}}}$	0,043		0		0,0435

$C_{n_{final}}$	$0,043 - x$	x	$0,0435 + x$
-----------------	-------------	-----	--------------

$$K_{a2} = \frac{[H^+][A^{2-}]}{[HA^-]} = \frac{(x)(0,0435 + x)}{0,043 - x} = 1,0 \times 10^{-8}$$

$$x = 9,9 \times 10^{-9} \text{ mol/L} = [H^+]$$

$$\text{pH} = 8,00$$

h)

	NaHA	+	NaOH	→	Na ₂ A	+	H ₂ O
mmol _{inicial}	10,0		9,00		---		---
mmol _{final}	1,0		---		9,00		---

$$[HA^-] = \frac{1,0 \text{ mmol}}{(100,0 + 19,0) \text{ mL}} = 8,4 \times 10^{-3} \text{ mol/L}$$

$$[A^{2-}] = \frac{9,00 \text{ mmol}}{(100,0 + 19,0) \text{ mL}} = 0,0756 \text{ mol/L}$$

	HA ⁻	⇌	H ⁺	+	A ²⁻
$C_{n_{inicial}}$	$8,4 \times 10^{-3}$		0		0,0756
$C_{n_{final}}$	$8,4 \times 10^{-3} - x$		x		$0,0756 + x$

$$K_{a2} = \frac{[H^+][A^{2-}]}{[HA^-]} = \frac{(x)(0,0756 + x)}{8,4 \times 10^{-3} - x} = 1,0 \times 10^{-8}$$

$$x = 1,1 \times 10^{-9} \text{ mol/L} = [H^+]$$

$$\text{pH} = 8,96$$

i)

	NaHA	+	NaOH	→	Na ₂ A	+	H ₂ O
mmol _{inicial}	10,0		10,0		---		---
mmol _{final}	---		---		10,0		---

$$[A^{2-}] = \frac{10,0 \text{ mmol}}{(100,0 + 20,0) \text{ mL}} = 0,0833 \text{ mol/L}$$

	A ²⁻	+ H ₂ O	⇌	OH ⁻	+	HA ⁻
Cn _{inicial}	0,0833	---		0		0
Cn _{final}	0,0833 - x	---		x		x

$$K_{b1} = \frac{[OH^-][HA^-]}{[A^{2-}]} = \frac{(x)(x)}{0,0833 - x} = 1,0 \times 10^{-6}$$

$$x = 2,9 \times 10^{-4} \text{ mol/L} = [OH^-]$$

$$pOH = 3,54 \Rightarrow pH = 10,46$$

j)

	NaHA	+	NaOH	→	Na ₂ A	+	H ₂ O
mmol _{inicial}	10,0		11,0		---		---
mmol _{final}	---		1,0		10,0		---

$$[OH^-] = \frac{1,0 \text{ mmol}}{(100,0 + 21,0) \text{ mL}} = 8,3 \times 10^{-3} \text{ mol/L}$$

$$[A^{2-}] = \frac{10,0 \text{ mmol}}{(100,0 + 21,0) \text{ mL}} = 0,0826 \text{ mol/L}$$

	A^{2-}	+ H_2O	\rightleftharpoons	OH^-	+	HA^-
$Cn_{inicial}$	0,0826	---		$8,3 \times 10^{-3}$		0
Cn_{final}	$0,0826 - x$	---		$8,3 \times 10^{-3} + x$		x

$$K_{b1} = \frac{[OH^-][HA^-]}{[A^{2-}]} = \frac{(8,3 \times 10^{-3} + x)(x)}{0,0826 - x} = 1,0 \times 10^{-6}$$

$$x = 9,9 \times 10^{-6} \text{ mol/L}$$

$$[OH^-] = 8,3 \times 10^{-3} + x = 8,3 \times 10^{-3} \text{ mol/L} + 9,9 \times 10^{-6} \text{ mol/L} = 8,3 \times 10^{-3} \text{ mol/L}$$

$$pOH = 2,08 \Rightarrow pH = 11,92$$

k)

	NaHA	+	NaOH	\rightarrow	Na_2A	+	H_2O
$mmol_{inicial}$	10,0		12,0		---		---
$mmol_{final}$	---		2,0		10,0		---

$$[OH^-] = \frac{2,0 \text{ mmol}}{(100,0 + 22,0) \text{ mL}} = 0,016 \text{ mol/L}$$

$$[A^{2-}] = \frac{10,0 \text{ mmol}}{(100,0 + 22,0) \text{ mL}} = 0,0820 \text{ mol/L}$$

	A^{2-}	+ H_2O	\rightleftharpoons	OH^-	+	HA^-
$Cn_{inicial}$	0,0820	---		0,016		0
Cn_{final}	$0,0820 - x$	---		$0,016 + x$		x

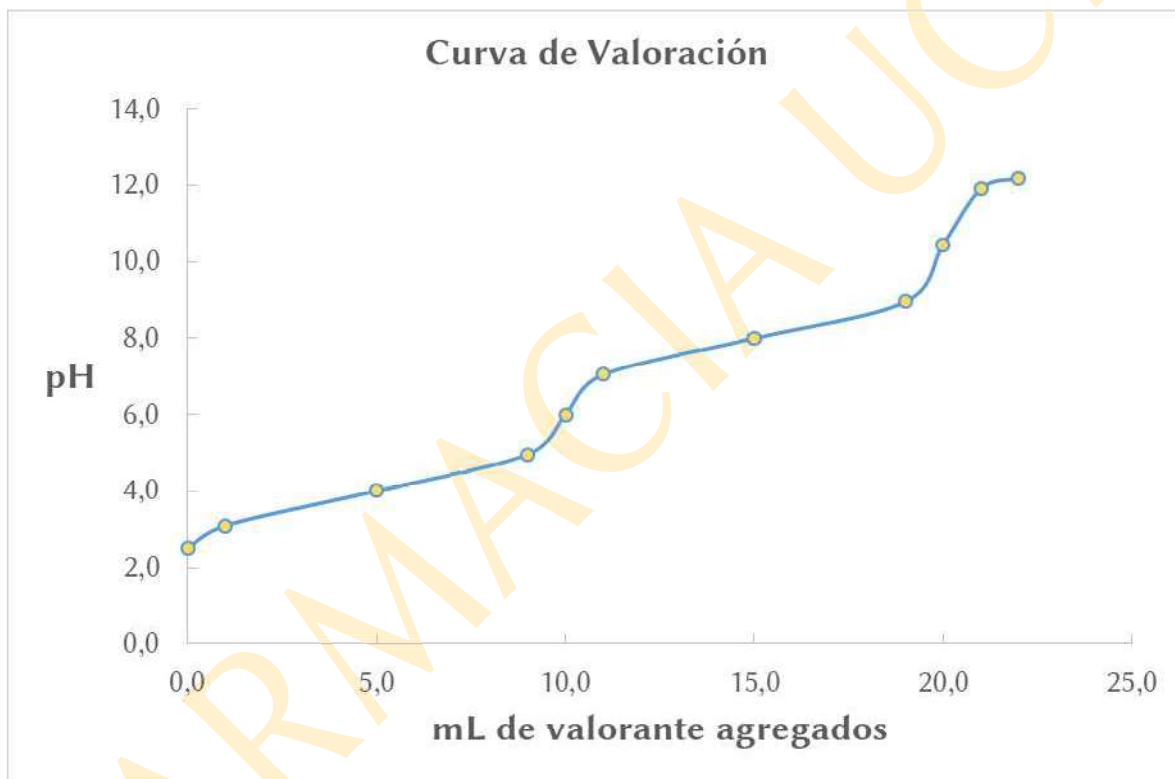
$$K_{b1} = \frac{[\text{OH}^-][\text{HA}^-]}{[\text{A}^{2-}]} = \frac{(0,016 + x)(x)}{0,0820 - x} = 1,0 \times 10^{-6}$$

$$x = 5,1 \times 10^{-6} \text{ mol/L}$$

$$[\text{OH}^-] = 0,016 + x = 0,016 \text{ mol/L} + 5,1 \times 10^{-6} \text{ mol/L} = 0,016 \text{ mol/L}$$

$$\text{pOH} = 1,80 \Rightarrow \text{pH} = 12,20$$

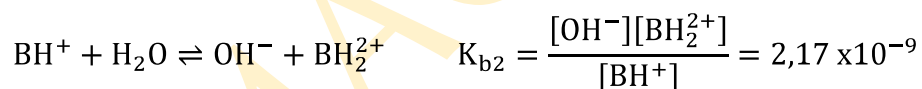
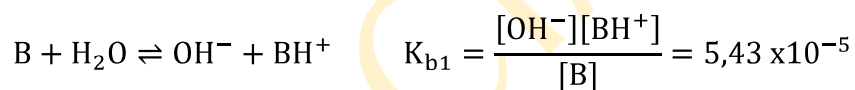
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12.25 Calcular el pH a intervalos de 10,0 mL (desde 0 hasta 100,0 mL) al valorar 40,0 mL de piperacina 0,100 M con HCl 0,100 M. Representar pH frente a V_a .

- Respuesta/
- a) 11,358
 - b) 10,203
 - c) 9,729
 - d) 9,254
 - e) 7,532
 - f) 5,810
 - g) 5,332
 - h) 4,855
 - i) 3,408
 - j) 2,113
 - k) 1,845

Representamos piperacina como B



a)

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,100	---		0		0
Cn _{final}	0,100- x	---		x		x

$$K_{b1} = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(x)}{0,100 - x} = 5,43 \times 10^{-5}$$

$$x = 2,30 \times 10^{-3} \text{ mol/L} = [OH^-]$$

$$pOH = 2,638 \Rightarrow pH = 11,358$$

b)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	4,00		1,00		---		---
mmol _{final}	3,00		---		1,00		---

$$[B] = \frac{3,00 \text{ mmol}}{(40,0 + 10,0) \text{ mL}} = 0,0600 \text{ mol/L}$$

$$[BH^+] = \frac{1,00 \text{ mmol}}{(40,0 + 10,0) \text{ mL}} = 0,0200 \text{ mol/L}$$

	B	+	H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,0600		---		0		0,0200
Cn _{final}	0,0600 - x		---		x		0,0200 + x

$$K_{b1} = \frac{[OH^-][BH^+]}{[B]} = \frac{(x)(0,0200 + x)}{0,0600 - x} = 5,43 \times 10^{-5}$$

$$x = 1,61 \times 10^{-4} \text{ mol/L} = [OH^-]$$

$$pOH = 3,793 \Rightarrow pH = 10,203$$

c)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	4,00		2,00		---		---
mmol _{final}	2,00		---		2,00		---

$$[B] = \frac{2,00 \text{ mmol}}{(40,0 + 20,0) \text{ mL}} = 0,0333 \text{ mol/L}$$

$$[\text{BH}^+] = \frac{2,00 \text{ mmol}}{(40,0 + 20,0) \text{ mL}} = 0,0333 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,0333	---		0		0,0333
Cn _{final}	0,0333 - x	---		x		0,0333 + x

$$K_{b1} = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0333 + x)}{0,0333 - x} = 5,43 \times 10^{-5}$$

$$x = 5,41 \times 10^{-5} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 4,267 \Rightarrow \text{pH} = 9,729$$

d)

	B	+ HCl	→	BH ⁺	+ Cl ⁻
mmol _{inicial}	4,00	3,00		---	---
mmol _{final}	1,00	---		3,00	---

$$[\text{B}] = \frac{1,00 \text{ mmol}}{(40,0 + 30,0) \text{ mL}} = 0,0143 \text{ mol/L}$$

$$[\text{BH}^+] = \frac{3,00 \text{ mmol}}{(40,0 + 30,0) \text{ mL}} = 0,0429 \text{ mol/L}$$

	B	+ H ₂ O	⇌	OH ⁻	+	BH ⁺
Cn _{inicial}	0,0143	---		0		0,0429
Cn _{final}	0,0143 - x	---		x		0,0429 + x

$$K_{b1} = \frac{[\text{OH}^-][\text{BH}^+]}{[\text{B}]} = \frac{(x)(0,0429 + x)}{0,0143 - x} = 5,43 \times 10^{-5}$$

$$x = 1,81 \times 10^{-5} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 4,742 \Rightarrow \text{pH} = 9,254$$

e)

	B	+	HCl	→	BH ⁺	+	Cl ⁻
mmol _{inicial}	4,00		4,00		---		---
mmol _{final}	---		---		4,00		---

$$[\text{BH}^+] = \frac{4,00 \text{ mmol}}{(40,0 + 40,0) \text{ mL}} = 0,0500 \text{ mol/L}$$

$$[\text{H}^+] = \sqrt{\frac{K_{a1}K_{a2}[\text{BH}^+] + K_{a1}K_w}{K_{a1} + [\text{BH}^+]}} \Rightarrow \sqrt{\frac{K_{a1}K_{a2}F + K_{a1}K_w}{K_{a1} + F}}$$

$$[\text{H}^+] = \sqrt{\frac{(4,65 \times 10^{-6})(1,86 \times 10^{-10})(0,0500) + (4,65 \times 10^{-6})(1,01 \times 10^{-14})}{4,65 \times 10^{-6} + 0,0500}}$$

$$[\text{H}^+] = 2,94 \times 10^{-8} \text{ mol/L}$$

$$\text{pH} = 7,532$$

f)

	BH ⁺	+	HCl	→	BH ₂ ⁺	+	Cl ⁻
mmol _{inicial}	4,00		1,00		---		---
mmol _{final}	3,00		---		1,00		---

$$[\text{BH}^+] = \frac{3,00 \text{ mmol}}{(40,0 + 50,0) \text{ mL}} = 0,0333 \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{1,00 \text{ mmol}}{(40,0 + 50,0) \text{ mL}} = 0,0111 \text{ mol/L}$$

	BH ⁺	+ H ₂ O	⇌	OH ⁻	+	BH ₂ ²⁺
Cn _{inicial}	0,0333	---		0		0,0111
Cn _{final}	0,0333 - x	---		x		0,0111 + x

$$K_{b2} = \frac{[\text{OH}^-][\text{BH}_2^{2+}]}{[\text{BH}^+]} = \frac{(x)(0,0111 + x)}{0,0333 - x} = 2,17 \times 10^{-9}$$

$$x = 6,51 \times 10^{-9} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 8,186 \Rightarrow \text{pH} = 5,810$$

g)

	BH ⁺	+	HCl	→	BH ₂ ²⁺	+	Cl ⁻
mmol _{inicial}	4,00		2,00		---		---
mmol _{final}	2,00		---		2,00		---

$$[\text{BH}^+] = \frac{2,00 \text{ mmol}}{(40,0 + 60,0) \text{ mL}} = 0,0200 \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{2,00 \text{ mmol}}{(40,0 + 60,0) \text{ mL}} = 0,0200 \text{ mol/L}$$

	BH ⁺	+ H ₂ O	⇌	OH ⁻	+	BH ₂ ²⁺
Cn _{inicial}	0,0200	---		0		0,0200

$C_{n_{\text{final}}}$	$0,0200 - x$	---	x	$0,0200 + x$
------------------------	--------------	-----	-----	--------------

$$K_{b2} = \frac{[\text{OH}^-][\text{BH}_2^{2+}]}{[\text{BH}^+]} = \frac{(x)(0,0200 + x)}{0,0200 - x} = 2,17 \times 10^{-9}$$

$$x = 2,17 \times 10^{-9} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 8,664 \Rightarrow \text{pH} = 5,332$$

h)

	BH^+	+	HCl	\rightarrow	BH_2^{2+}	+	Cl^-
$\text{mmol}_{\text{inicial}}$	4,00		3,00		---		---
$\text{mmol}_{\text{final}}$	1,00		---		3,00		---

$$[\text{BH}^+] = \frac{1,00 \text{ mmol}}{(40,0 + 70,0) \text{ mL}} = 9,09 \times 10^{-3} \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{3,00 \text{ mmol}}{(40,0 + 70,0) \text{ mL}} = 0,0273 \text{ mol/L}$$

	BH^+	+	H_2O	\rightleftharpoons	OH^-	+	BH_2^{2+}
$C_{n_{\text{inicial}}}$	$9,09 \times 10^{-3}$		---		0		0,0273
$C_{n_{\text{final}}}$	$9,09 \times 10^{-3} - x$		---		x		$0,0273 + x$

$$K_{b2} = \frac{[\text{OH}^-][\text{BH}_2^{2+}]}{[\text{BH}^+]} = \frac{(x)(0,0273 + x)}{9,09 \times 10^{-3} - x} = 2,17 \times 10^{-9}$$

$$x = 7,23 \times 10^{-10} \text{ mol/L} = [\text{OH}^-]$$

$$\text{pOH} = 9,141 \Rightarrow \text{pH} = 4,855$$

i)

	BH ⁺	+	HCl	→	BH ₂ ⁺	+	Cl ⁻
mmol _{inicial}	4,00		4,00		---		---
mmol _{final}	---		---		4,00		---

$$[\text{BH}_2^+] = \frac{4,00 \text{ mmol}}{(40,0 + 80,0) \text{ mL}} = 0,0333 \text{ mol/L}$$

	BH ₂ ⁺	⇌	H ⁺	+	BH ⁺
C _n _{inicial}	0,0333		0		0
C _n _{final}	0,0333 - x		x		x

$$K_{a1} = \frac{[\text{H}^+][\text{BH}^+]}{[\text{BH}_2^+]} = \frac{(x)(x)}{0,0333 - x} = 4,65 \times 10^{-6}$$

$$x = 3,91 \times 10^{-4} \text{ mol/L} = [\text{H}^+]$$

$$\text{pH} = 3,408$$

j)

	BH ⁺	+	HCl	→	BH ₂ ⁺	+	Cl ⁻
mmol _{inicial}	4,00		5,00		---		---
mmol _{final}	---		1,00		4,00		---

$$[\text{H}^+] = \frac{1,00 \text{ mmol}}{(40,0 + 90,0) \text{ mL}} = 7,69 \times 10^{-3} \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{4,00 \text{ mmol}}{(40,0 + 90,0) \text{ mL}} = 0,0308 \text{ mol/L}$$

	BH_2^{2+}	\rightleftharpoons	H^+	+	BH^+
$\text{Cn}_{\text{inicial}}$	0,0308		$7,69 \times 10^{-3}$		0
Cn_{final}	$0,0308 - x$		$7,69 \times 10^{-3} + x$		x

$$K_{a1} = \frac{[\text{H}^+][\text{BH}^+]}{[\text{BH}_2^{2+}]} = \frac{(7,69 \times 10^{-3} + x)(x)}{0,0308 - x} = 4,65 \times 10^{-6}$$

$$x = 1,86 \times 10^{-5} \text{ mol/L}$$

$$[\text{H}^+] = 7,69 \times 10^{-3} + x = 7,69 \times 10^{-3} \text{ mol/L} + 1,86 \times 10^{-5} \text{ mol/L} = 7,71 \times 10^{-3} \text{ mol/L}$$

$$\text{pH} = 2,113$$

k)

	BH^+	+	HCl	\rightarrow	BH_2^{2+}	+	Cl^-
$\text{mmol}_{\text{inicial}}$	4,00		6,00		---		---
$\text{mmol}_{\text{final}}$	---		2,00		4,00		---

$$[\text{H}^+] = \frac{2,00 \text{ mmol}}{(40,0 + 100,0) \text{ mL}} = 0,0143 \text{ mol/L}$$

$$[\text{BH}_2^{2+}] = \frac{4,00 \text{ mmol}}{(40,0 + 100,0) \text{ mL}} = 0,0286 \text{ mol/L}$$

	BH_2^{2+}	\rightleftharpoons	H^+	+	BH^+
$\text{Cn}_{\text{inicial}}$	0,0286		0,0143		0
Cn_{final}	$0,286 - x$		$0,0143 + x$		x

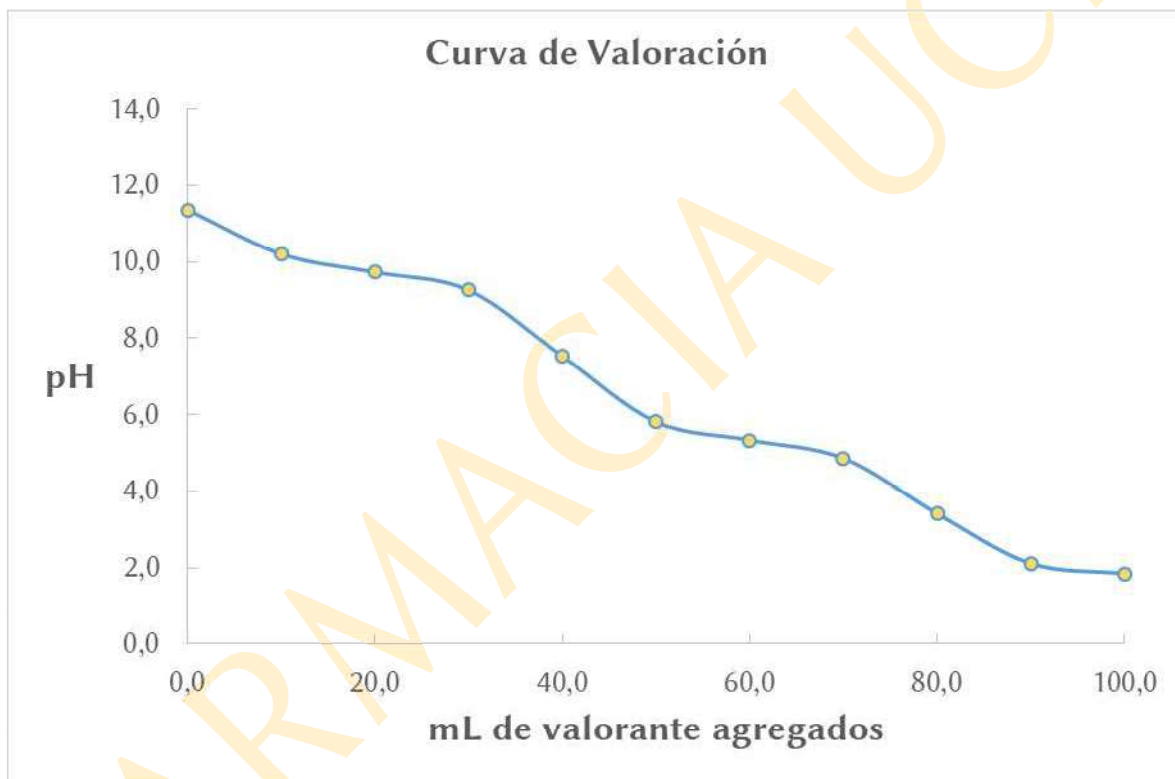
$$K_{a1} = \frac{[H^+][BH^+]}{[BH_2^{2+}]} = \frac{(0,0143 + x)(x)}{0,0286 - x} = 4,65 \times 10^{-6}$$

$$x = 9,29 \times 10^{-6} \text{ mol/L}$$

$$[H^+] = 0,0143 + x = 0,0143 \text{ mol/L} + 9,29 \times 10^{-6} \text{ mol/L} = 0,0143 \text{ mol/L}$$

$$\text{pH} = 1,845$$

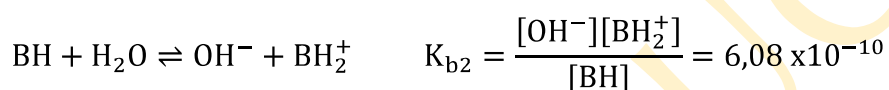
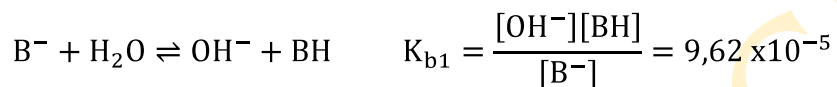
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12.26 Calcular el pH cuando se valoran 25,0 mL de 2-aminofenol 0,0200 M con 10,9 mL mL de HClO₄ 0,0150 M.

Respuesta/ 5,093

Representamos 2 – aminofenol como BH



	BH	+	HClO ₄	→	BH ₂ ⁺	+	ClO ₄ ⁻
mmol _{inicial}	0,500		0,164		---		---
mmol _{final}	0,336		---		0,164		---

$$[BH] = \frac{0,336 \text{ mmol}}{(25,0 + 10,9) \text{ mL}} = 9,36 \times 10^{-3} \text{ mol/L}$$

$$[BH_2^+] = \frac{0,164 \text{ mmol}}{(25,0 + 10,9) \text{ mL}} = 4,57 \times 10^{-3} \text{ mol/L}$$

	BH	+	H ₂ O	⇌	OH ⁻	+	BH ₂ ⁺
C _n _{inicial}	9,36 × 10 ⁻³		---		0		4,57 × 10 ⁻³
C _n _{final}	9,36 × 10 ⁻³ - x		---		x		4,57 × 10 ⁻³ + x

$$K_{b2} = \frac{[OH^-][BH_2^+]}{[BH]} = \frac{(x)(4,57 \times 10^{-3} + x)}{9,36 \times 10^{-3} - x} = 6,08 \times 10^{-10}$$

$$x = 1,25 \times 10^{-9} \text{ mol/L} = [\text{OH}^-]$$

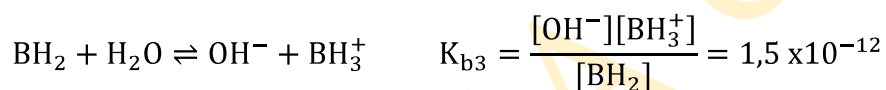
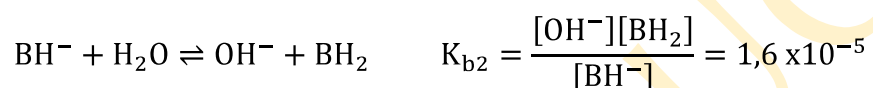
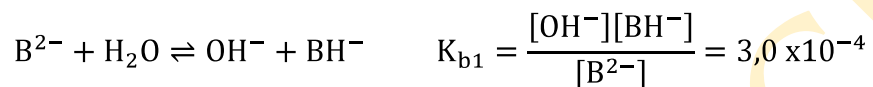
$$\text{pOH} = 8,903 \Rightarrow \text{pH} = 5,093$$

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12.29 Hallar el pH del punto de equivalencia cuando se valora una disolución de tirosina 0,0100 M con HClO₄ 0,00400 M.

Respuesta/ 2,66

Representamos tirosina como BH₂



Si tenemos 10,0 mL de BH₂

$$10,0 \text{ mL} * \frac{0,0100 \text{ mmol BH}_2}{\text{mL}} * \frac{1 \text{ mmol HClO}_4}{1 \text{ mmol BH}_2} * \frac{\text{mL}}{0,00400 \text{ mmol HClO}_4} = 25,0 \text{ mL}$$

	BH ₂	+	HClO ₄	→	BH ₃ ⁺	+	ClO ₄ ⁻
mmol _{inicial}	0,100		0,100		---		---
mmol _{final}	---		---		0,100		---

$$[BH_3^+] = \frac{0,100 \text{ mmol}}{(10,0 + 25,0) \text{ mL}} = 2,86 \times 10^{-3} \text{ mol/L}$$

	BH ₃ ⁺	⇌	H ⁺	+	BH ₂
Cn _{inicial}	2,86 × 10 ⁻³		0		0

$C_{n_{\text{final}}}$

$2,86 \times 10^{-3} - x$

x

x

$$K_{a1} = \frac{[H^+][BH^+]}{[BH_2^{2+}]} = \frac{(x)(x)}{2,86 \times 10^{-3} - x} = 6,8 \times 10^{-3}$$

$$x = 2,2 \times 10^{-3} \text{ mol/L} = [H^+]$$

$$\text{pH} = 2,66$$

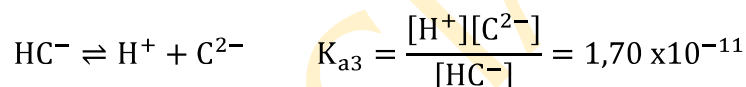
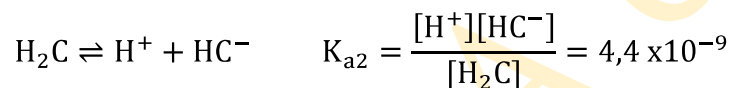
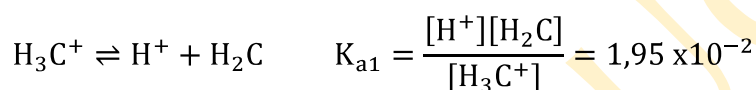
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12.30 Este problema se refiere al aminoácido cisteína que representaremos abreviadamente por H_2C .

a) Se prepara una disolución 0,0300 M disolviendo cisteína de potasio, K_2C , en agua. Se valoran 40,0 mL de esta disolución con $HClO_4$ 0,0600 M. Calcular el pH del primer punto de equivalencia.

b) Calcular el cociente $[C^{2-}]/[HC^-]$ en una disolución de bromuro de cisteinico 0,0500 M (la sal es $H_3C^+Br^-$).

Respuesta/ a) 9,55
 b) $7,39 \times 10^{-10}$



a)

$$40,0 \text{ mL} * \frac{0,0300 \text{ mmol } C^{2-}}{\text{mL}} * \frac{1 \text{ mmol } HClO_4}{1 \text{ mmol } C^{2-}} * \frac{\text{mL}}{0,0600 \text{ mmol } HClO_4} = 20,0 \text{ mL}$$

	C^{2-}	+	$HClO_4$	→	HC^-	+	ClO_4^-
mmol _{inicial}	1,20		1,20		---		---
mmol _{final}	---		---		1,20		---

$$[HC^-] = \frac{1,20 \text{ mmol}}{(40,0 + 20,0) \text{ mL}} = 0,0200 \text{ mol/L}$$

$$[H^+] = \sqrt{\frac{K_{a2}K_{a3}[HC^-] + K_{a2}K_w}{K_{a2} + [HC^-]}} \Rightarrow \sqrt{\frac{K_{a2}K_{a3}F + K_{a2}K_w}{K_{a2} + F}}$$

$$[H^+] = \sqrt{\frac{(4,4 \times 10^{-9})(1,70 \times 10^{-11})(0,0200) + (4,4 \times 10^{-9})(1,01 \times 10^{-14})}{4,4 \times 10^{-9} + 0,0200}}$$

$$[H^+] = 2,8 \times 10^{-10} \text{ mol/L}$$

$$\text{pH} = 9,55$$

b)

	H_3C^+	\rightleftharpoons	H^+	+	H_2C
$C_{n_{\text{inicial}}}$	0,0500		0		0
$C_{n_{\text{final}}}$	$0,0500 - x$		x		x

$$K_{a1} = \frac{[H^+][H_2C]}{[H_3C^+]} = \frac{(x)(x)}{0,0500 - x} = 1,95 \times 10^{-2}$$

$$x = 0,0230 \text{ mol/L} = [H^+]$$

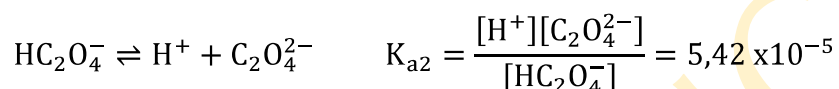
$$K_{a3} = \frac{[H^+][C^{2-}]}{[HC^-]} = \frac{(0,0230)[C^{2-}]}{[HC^-]} = 1,70 \times 10^{-11}$$

$$\frac{[C^{2-}]}{[HC^-]} = 7,39 \times 10^{-10}$$

12.31 ¿Cuántos gramos de oxalato de dipotasio (166,21 g/mol) se tienen que añadir a 20,0 mL de HClO₄ 0,800 M para dar un pH de 4,400, cuando la disolución se diluye a 500 mL?

Respuesta/ 6,28 g de K₂C₂O₄

$$20,0 \text{ mL} * \frac{0,800 \text{ mmol HClO}_4}{\text{mL}} = 16,0 \text{ mmol HClO}_4$$



Si tenemos "x" mmol de K₂C₂O₄

	HClO ₄	+	K ₂ C ₂ O ₄	→	KHC ₂ O ₄	+	KClO ₄
mmol _{inicial}	16,0		x		---		---
mmol _{final}	---		x - 16,0		16,0		---

$$\text{pH} = \text{p}K_{a2} + \log \frac{[\text{C}_2\text{O}_4^{2-}]}{[\text{HC}_2\text{O}_4^-]}$$

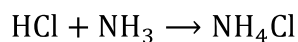
$$4,400 = 4,266 + \log \frac{x - 16,0}{16,0}$$

$$x = 37,8 \text{ mmol K}_2\text{C}_2\text{O}_4$$

$$37,8 \text{ mmol K}_2\text{C}_2\text{O}_4 * \frac{166,21 \text{ g K}_2\text{C}_2\text{O}_4}{1000 \text{ mmol K}_2\text{C}_2\text{O}_4} = 6,28 \text{ g K}_2\text{C}_2\text{O}_4$$

12.47 Una muestra de 10,231 g de un limpia cristales que contiene amoniaco se diluye con 39,466 g de agua. A continuación, se valoran 4,373 g de la disolución con 14,22 mL de HCl 0,1063 M hasta alcanzar el punto final del verde de bromocresol. Hallar el porcentaje m/m de amoniaco (17,03 g/mol) en el limpia cristales.

Respuesta/ 2,859 % m/m de NH₃



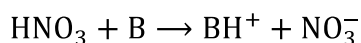
$$14,22 \text{ mL} * \frac{0,1063 \text{ mol HCl}}{1000 \text{ mL}} * \frac{1 \text{ mol NH}_3}{1 \text{ mol HCl}} * \frac{17,03 \text{ g NH}_3}{\text{mol NH}_3} = 0,02574 \text{ g NH}_3$$

$$0,02574 \text{ g NH}_3 * \frac{(10,231 + 39,466) \text{ g totales}}{4,373 \text{ g alícuota}} * \frac{100}{10,231 \text{ g muestra}} = 2,859 \% \text{ m/m}$$

12.51 Se prepara una disolución con 1,023 g de patrón primario TRIS (tabla 12.5) y 99,367 g de agua. Se valoran 4,963 g de esta disolución con 5,262 g de $\text{HNO}_3(\text{ac})$ hasta alcanzar el punto final del rojo de metilo. Calcular la concentración del HNO_3 (expresada en mol HNO_3/kg de disolución).

Respuesta/ 0,07934 mol/kg disolución de HNO_3

Representamos TRIS como B

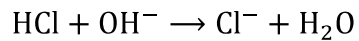
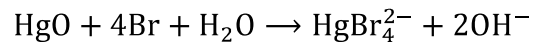


$$1,023 \text{ g B} * \frac{4,963 \text{ g alícuota}}{(1,023 + 99,367) \text{ g totales}} * \frac{\text{mol B}}{121,14 \text{ g B}} * \frac{1 \text{ mol HNO}_3}{1 \text{ mol B}}$$
$$= 4,175 \times 10^{-4} \text{ mol HNO}_3$$

$$\frac{4,175 \times 10^{-4} \text{ mol HNO}_3}{5,262 \text{ g disolución}} * \frac{1000 \text{ g disolución}}{\text{kg disolución}} = 0,07934 \text{ mol HNO}_3/\text{kg disolución}$$

12.53 Se prepara una disolución disolviendo 0,1947 g de HgO (tabla 12.5) en 20,0 mL de agua que contienen 4 g de KBr. La valoración de HCl precisa 17,98 mL para alcanzar el punto final utilizando fenolftaleína. Calcular la molaridad del HCl.

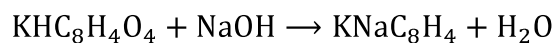
Respuesta/ 0,09999 mol/L de HCl



$$\begin{aligned} &0,1947 \text{ g HgO} * \frac{1000 \text{ mmol HgO}}{216,59 \text{ g HgO}} * \frac{2 \text{ mmol OH}^-}{1 \text{ mmol HgO}} * \frac{1 \text{ mmol HCl}}{1 \text{ mmol OH}^-} \div 17,98 \text{ mL} \\ &= 0,09999 \text{ mmol HCl/mL} \Rightarrow \text{mol/L} \end{aligned}$$

12.54 ¿Cuántos gramos de hidrogenoftalato potásico hay que pesar para estandarizar una disolución de NaOH 0,0500 M, si se desean gastar 30,0 mL de base en su valoración?

Respuesta/ 0,306 g de $\text{KHC}_8\text{H}_4\text{O}_4$



$$30,0 \text{ mL} * \frac{0,0500 \text{ mol NaOH}}{1000 \text{ mL}} * \frac{1 \text{ mol KHC}_8\text{H}_4\text{O}_4}{1 \text{ mol NaO}} * \frac{204,22 \text{ g KHC}_8\text{H}_4\text{O}_4}{\text{mol KHC}_8\text{H}_4\text{O}_4}$$
$$= 0,306 \text{ g KHC}_8\text{H}_4\text{O}_4$$

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