ANALITIČKA KEMIJA - SEMINAR

- osnove statistike
- kemija vodenih otopina
- gravimetrijske metode analize
- taložne titracije
- **neutralizacijske titracije**

nositelj: izv. prof. dr. sc. Tomislav Jednačak
akademska godina: 2026./27.

1. Kolika je koncentracija otopine natrijeve lužine, ako je prilikom titracije 50,00 cm^3 otopine NaOH reagiralo s 45,60 cm^3 otopine klorovodične kiseline, koncentracije 0,0998 mol dm^{-3}?

$$V(\mathrm{NaOH}) = 50{,}00\ \mathrm{cm}^3 = 50{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$$

$$V(\mathrm{HCl}) = 45{,}60\ \mathrm{cm}^3 = 45{,}60 \cdot 10^{-3}\ \mathrm{dm}^3 \qquad c(\mathrm{HCl}) = 0{,}0998\ \mathrm{mol\,dm}^{-3}$$

$$\mathrm{HCl} + \mathrm{NaOH} \rightleftharpoons \mathrm{NaCl} + \mathrm{H_2O}$$

$$n(\mathrm{HCl}) = c(\mathrm{HCl})\, V(\mathrm{HCl}) = 0{,}0046\ \mathrm{mol}$$

$$n(\mathrm{NaOH}) = n(\mathrm{HCl})$$

$$c(\mathrm{NaOH}) = \frac{n(\mathrm{NaOH})}{V(\mathrm{NaOH})} = 0{,}0910\ \mathrm{mol\,dm}^{-3}$$

2. Prilikom standardiziranja otopine kloridne kiseline 46,80 mL kiseline reagiralo je s 247,6 mg Na_2CO_3. Kolika je koncentracija otopine HCl?

$$V(\mathrm{HCl}) = 46{,}80\ \mathrm{mL} = 46{,}80 \cdot 10^{-3}\ \mathrm{L} \qquad m(\mathrm{Na_2CO_3}) = 247{,}6\ \mathrm{mg} = 0{,}2476\ \mathrm{g}$$

$$2\,\mathrm{HCl} + \mathrm{Na_2CO_3} \rightleftharpoons 2\,\mathrm{NaCl} + \mathrm{CO_2} + \mathrm{H_2O}$$

$$n(\mathrm{Na_2CO_3}) = \frac{m(\mathrm{Na_2CO_3})}{M(\mathrm{Na_2CO_3})} = 0{,}0023\ \mathrm{mol}$$

$$n(\mathrm{HCl}) : n(\mathrm{Na_2CO_3}) = 2:1$$

$$n(\mathrm{HCl}) = 2\,n(\mathrm{Na_2CO_3}) = 0{,}0046\ \mathrm{mol}$$

$$c(\mathrm{HCl}) = \frac{n(\mathrm{HCl})}{V(\mathrm{HCl})} = 0{,}0998\ \mathrm{mol\,dm^{-3}}$$

3. Čisti kalijev hidrogenftalat ($KHC_8H_4O_4$), čija je masa 0,6248 g, otopljen je u vodi i titriran otopinom natrijevog hidroksida. Utrošeno je 38,20 mL NaOH. Kolika je koncentracija otopine NaOH?

$$m(KHC_8H_4O_4) = 0{,}6248\ \text{g} \qquad V(\text{NaOH}) = 38{,}20\ \text{mL} = 38{,}20 \cdot 10^{-3}\ \text{L}$$

$$HC_8H_4O_4^- + OH^- \rightleftharpoons C_8H_4O_4^{2-} + H_2O$$

$$n(KHC_8H_4O_4) = \frac{m(KHC_8H_4O_4)}{M(KHC_8H_4O_4)} = 0{,}0031\ \text{mol}$$

$$n(\text{NaOH}) = n(OH^-) = n(HC_8H_4O_4^-) = n(KHC_8H_4O_4)$$

$$c(\text{NaOH}) = \frac{n(\text{NaOH})}{V(\text{NaOH})} = 0{,}0801\ \text{mol dm}^{-3}$$

4. Koliki je omjer koncentracija baznog i kiselog oblika indikatora metil crveno (pK_{ind} = 5,0) kad je u otopini a) pH = 6; b) pH = 4?

$$HIn + H_2O \rightleftharpoons H_3O^+ + In^- \qquad K_{ind} = \frac{[H_3O^+][In^-]}{[HIn]}$$

$$pH = pK_{ind} + \log\frac{[In^-]}{[HIn]}$$

a) $pH = 6{,}0$ $\qquad pK_{ind} = 5{,}0$

$$\log\frac{[In^-]}{[HIn]} = pH - pK_{ind} = 6{,}0 - 5{,}0 = 1{,}0$$

$$\frac{[In^-]}{[HIn]} = \text{antilog}1{,}0 = 10$$

b) $\mathrm{pH} = 4{,}0$ $\qquad\qquad$ $\mathrm{p}K_{\mathrm{ind}} = 5{,}0$

$$\log \frac{[\mathrm{In}^-]}{[\mathrm{HIn}]} = \mathrm{pH} - \mathrm{p}K_{\mathrm{ind}} = 4{,}0 - 5{,}0 = -1{,}0$$

$$\frac{[\mathrm{In}^-]}{[\mathrm{HIn}]} = \mathrm{antilog}(-1{,}0) = \frac{1}{10} = 0{,}1$$

5. Izračunajte pH vrijednost otopine koja sadrži indikator metil crveno ($\mathrm{p}K_{\mathrm{ind}}$ = 5,0), kad je 25% indikatora u lužnatom obliku.

$[\mathrm{In}^-] = 25\%\ c_{\mathrm{ind}}$ $\qquad\qquad$ $[\mathrm{HIn}] = 100\%\ c_{\mathrm{ind}} - 25\%\ c_{\mathrm{ind}} = 75\%\ c_{\mathrm{ind}}$

$$\mathrm{pH} = \mathrm{p}K_{\mathrm{ind}} + \log \frac{[\mathrm{In}^-]}{[\mathrm{HIn}]} = 5{,}0 + \log \frac{25}{75} = 4{,}5$$

6. Kolika je pH vrijednost u vodenoj otopini KCN, ako je koncentracija kalijevog cijanida 0,0100 mol dm^{-3} ($K_a = 6{,}30 \cdot 10^{-10}$ mol dm^{-3})?

$c(\mathrm{KCN}) = 0{,}0100\,\mathrm{mol\,dm^{-3}}$ $\qquad$ $K_a = 6{,}30 \cdot 10^{-10}\,\mathrm{mol\,dm^{-3}}$

$$\mathrm{KCN} \xrightleftharpoons{\mathrm{H_2O}} \mathrm{K^+} + \mathrm{CN^-}$$

$$\begin{array}{ccccccc} & a\text{-}x & & & & x & x \\ & \mathrm{CN^-} & + & \mathrm{H_2O} & \rightleftharpoons & \mathrm{HCN} & + & \mathrm{OH^-} \end{array}$$

$$K_b = \frac{K_w}{K_a} = \frac{1{,}00 \cdot 10^{-14}\,\mathrm{mol^2\,dm^{-6}}}{6{,}30 \cdot 10^{-10}\,\mathrm{mol\,dm^{-3}}} = 1{,}58 \cdot 10^{-5}\,\mathrm{mol\,dm^{-3}}$$

$$K_b = \frac{[\mathrm{HCN}][\mathrm{OH^-}]}{[\mathrm{CN^-}]} = \frac{x^2}{a - x} \approx \frac{x^2}{a}$$

$$x = [\mathrm{OH^-}] = \sqrt{a\ K_\mathrm{b}} = \sqrt{c(\mathrm{KCN})\ K_\mathrm{b}} = 3{,}98 \cdot 10^{-4}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pOH} = -\log\left(\frac{[\mathrm{OH^-}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{3{,}98 \cdot 10^{-4}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 3{,}40$$

$$\mathrm{pH} = \mathrm{p}K_\mathrm{w} - \mathrm{pOH} = 14{,}00 - 3{,}40 = 10{,}60$$

7. Kolika je pH vrijednost vodene otopine amonijevog klorida, koncentracije 0,2000 mol $\mathrm{L^{-1}}$ ($K_\mathrm{b} = 1{,}82 \cdot 10^{-5}$ mol $\mathrm{L^{-1}}$)?

$c(\mathrm{NH_4Cl}) = 0{,}2000\ \mathrm{mol\,L^{-1}}$ $\qquad$ $K_\mathrm{b} = 1{,}82 \cdot 10^{-5}\ \mathrm{mol\,L^{-1}}$

$$\mathrm{NH_4Cl} \xrightleftharpoons{\mathrm{H_2O}} \mathrm{NH_4^+} + \mathrm{Cl^-}$$

$$\underset{a\text{-}x}{\mathrm{NH_4^+}} + \mathrm{H_2O} \rightleftharpoons \underset{x}{\mathrm{H_3O^+}} + \underset{x}{\mathrm{NH_3}}$$

$$K_\mathrm{a} = \frac{K_\mathrm{w}}{K_\mathrm{b}} = \frac{1{,}00 \cdot 10^{-14}\ \mathrm{mol^2\ L^{-2}}}{1{,}82 \cdot 10^{-5}\ \mathrm{mol\,L^{-1}}} = 5{,}49 \cdot 10^{-10}\ \mathrm{mol\,L^{-1}}$$

$$K_\mathrm{a} = \frac{[\mathrm{H_3O^+}][\mathrm{NH_3}]}{[\mathrm{NH_4^+}]} = \frac{x^2}{a - x} \approx \frac{x^2}{a}$$

$$x = [\mathrm{H_3O^+}] = \sqrt{a\ K_\mathrm{a}} = \sqrt{c(\mathrm{NH_4Cl})\ K_\mathrm{a}} = 1{,}05 \cdot 10^{-5}\ \mathrm{mol\,L^{-1}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,L^{-1}}}\right) = -\log\left(\frac{1{,}05 \cdot 10^{-5}\ \mathrm{mol\,L^{-1}}}{\mathrm{mol\,L^{-1}}}\right) = 4{,}98$$

8. Koliki je pH otopine koja sadrži octenu kiselinu koncentracije 0,1000 mol dm^{-3} i 5,00 g natrijevog acetata u 1 dm^3 ($K_a = 1{,}82 \cdot 10^{-5}$ mol dm^{-3})?

$$c(CH_3COOH) = 0{,}1000\,\text{mol}\,\text{dm}^{-3} \qquad K_a = 1{,}82 \cdot 10^{-5}\,\text{mol}\,\text{dm}^{-3}$$

$$\gamma(CH_3COONa) = 5{,}00\,\text{g}\,\text{dm}^{-3}$$

$$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^- \qquad K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$$

$$CH_3COONa \overset{H_2O}{\rightleftharpoons} Na^+ + CH_3COO^-$$

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^- \qquad K_b = \frac{[CH_3COOH][OH^-]}{[CH_3COO^-]}$$

$$c(CH_3COONa) = \frac{\gamma(CH_3COONa)}{M(CH_3COONa)} = 0{,}0610\,\text{mol}\,\text{dm}^{-3}$$

$$[\mathrm{CH_3COOH}] = c(\mathrm{CH_3COOH}) - [\mathrm{H_3O^+}] + [\mathrm{OH^-}] \approx c(\mathrm{CH_3COOH})$$

$$[\mathrm{CH_3COO^-}] = c(\mathrm{CH_3COONa}) + [\mathrm{H_3O^+}] - [\mathrm{OH^-}] \approx c(\mathrm{CH_3COONa})$$

$$[\mathrm{H_3O^+}] = K_\mathrm{a} \frac{c(\mathrm{CH_3COOH})}{c(\mathrm{CH_3COONa})} = 2{,}99 \cdot 10^{-5}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{2{,}99 \cdot 10^{-5}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 4{,}52$$

9. Koliki je pH otopine koja sadrži amonijak koncentracije 0,3000 mol dm^{-3} i 3,00 g amonijevog klorida u 1 dm^3 ($K_b = 1{,}82 \cdot 10^{-5}$ mol dm^{-3})?

$$c(NH_3) = 0{,}3000\,\text{mol}\,\text{dm}^{-3} \qquad K_b = 1{,}82 \cdot 10^{-5}\,\text{mol}\,\text{dm}^{-3}$$

$$\gamma(NH_4Cl) = 3{,}00\,\text{g}\,\text{dm}^{-3}$$

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^- \qquad K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

$$NH_4Cl \overset{H_2O}{\rightleftharpoons} NH_4^+ + Cl^-$$

$$NH_4^+ + H_2O \rightleftharpoons H_3O^+ + NH_3 \qquad K_a = \frac{[H_3O^+][NH_3]}{[NH_4^+]}$$

$$c(NH_4Cl) = \frac{\gamma(NH_4Cl)}{M(NH_4Cl)} = 0{,}0561\,\text{mol}\,\text{dm}^{-3}$$

$$[\mathrm{NH_3}] = c(\mathrm{NH_3}) - [\mathrm{OH^-}] + [\mathrm{H_3O^+}] \approx c(\mathrm{NH_3})$$

$$[\mathrm{NH_4^+}] = c(\mathrm{NH_4Cl}) + [\mathrm{OH^-}] - [\mathrm{H_3O^+}] \approx c(\mathrm{NH_4Cl})$$

$$[\mathrm{OH^-}] = K_\mathrm{b} \frac{c(\mathrm{NH_3})}{c(\mathrm{NH_4Cl})} = 9{,}74 \cdot 10^{-5}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pOH} = -\log\left(\frac{[\mathrm{OH^-}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{9{,}74 \cdot 10^{-5}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 4{,}01$$

$$\mathrm{pH} = \mathrm{p}K_\mathrm{w} - \mathrm{pOH} = 14{,}00 - 4{,}01 = 9{,}99$$

10. Izračunajte množinsku koncentraciju H_3O^+ i pH vrijednost pri titraciji 40,00 cm^3 otopine HNO_3, koncentracije 0,0100 mol dm^{-3}, otopinom NaOH, koncentracije 0,0200 mol dm^{-3}, nakon dodatka: a) 0,00; b) 5,00; c) 20,00 i d) 30,00 cm^3 NaOH.

$V(\mathrm{HNO_3}) = 40{,}00\ \mathrm{cm^3} = 40{,}00 \cdot 10^{-3}\ \mathrm{dm^3}$ $\quad$ $c(\mathrm{HNO_3}) = 0{,}0100\ \mathrm{mol\,dm^{-3}}$

$c(\mathrm{NaOH}) = 0{,}0200\ \mathrm{mol\,dm^{-3}}$

$$\mathrm{HNO_3} + \mathrm{NaOH} \rightleftharpoons \mathrm{NaNO_3} + \mathrm{H_2O}$$

a) $V(\mathrm{NaOH}) = 0{,}00\ \mathrm{cm^3}$

$$[\mathrm{H_3O^+}] = c(\mathrm{HNO_3}) = 0{,}0100\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{0{,}0100\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 2{,}00$$

b) $V(\mathrm{NaOH}) = 5{,}00\ \mathrm{cm}^3 = 5{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$

$$n_\mathrm{o}(\mathrm{HNO_3}) = c(\mathrm{HNO_3})\, V(\mathrm{HNO_3}) = 4{,}0 \cdot 10^{-4}\ \mathrm{mol}$$

$$n(\mathrm{NaOH})_\mathrm{dodano} = c(\mathrm{NaOH})\, V(\mathrm{NaOH}) = 1{,}0 \cdot 10^{-4}\ \mathrm{mol}$$

$$n(\mathrm{HNO_3}) = n_\mathrm{o}(\mathrm{HNO_3}) - n(\mathrm{NaOH}) = 3{,}0 \cdot 10^{-4}\ \mathrm{mol}$$

$$[\mathrm{H_3O^+}] = \frac{n(\mathrm{HNO_3})}{V(\mathrm{HNO_3}) + V(\mathrm{NaOH})} = 0{,}0067\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{0{,}0067\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 2{,}18$$

c) $V(\mathrm{NaOH}) = 20{,}00\ \mathrm{cm}^3 = 20{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$

$n_\mathrm{o}(\mathrm{HNO_3}) = c(\mathrm{HNO_3})\, V(\mathrm{HNO_3}) = 4{,}0 \cdot 10^{-4}\ \mathrm{mol}$

$n(\mathrm{NaOH})_\mathrm{dodano} = c(\mathrm{NaOH})\, V(\mathrm{NaOH}) = 4{,}0 \cdot 10^{-4}\ \mathrm{mol}$

} točka ekvivalencije

$$[\mathrm{H_3O^+}] = [\mathrm{OH^-}] = \sqrt{K_\mathrm{w}} = 1{,}00 \cdot 10^{-7}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{1{,}00 \cdot 10^{-7}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 7{,}00$$

d) $V(\mathrm{NaOH}) = 30{,}00\ \mathrm{cm}^3 = 30{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$

$$n_{\mathrm{o}}(\mathrm{HNO_3}) = c(\mathrm{HNO_3})\, V(\mathrm{HNO_3}) = 4{,}0 \cdot 10^{-4}\ \mathrm{mol}$$

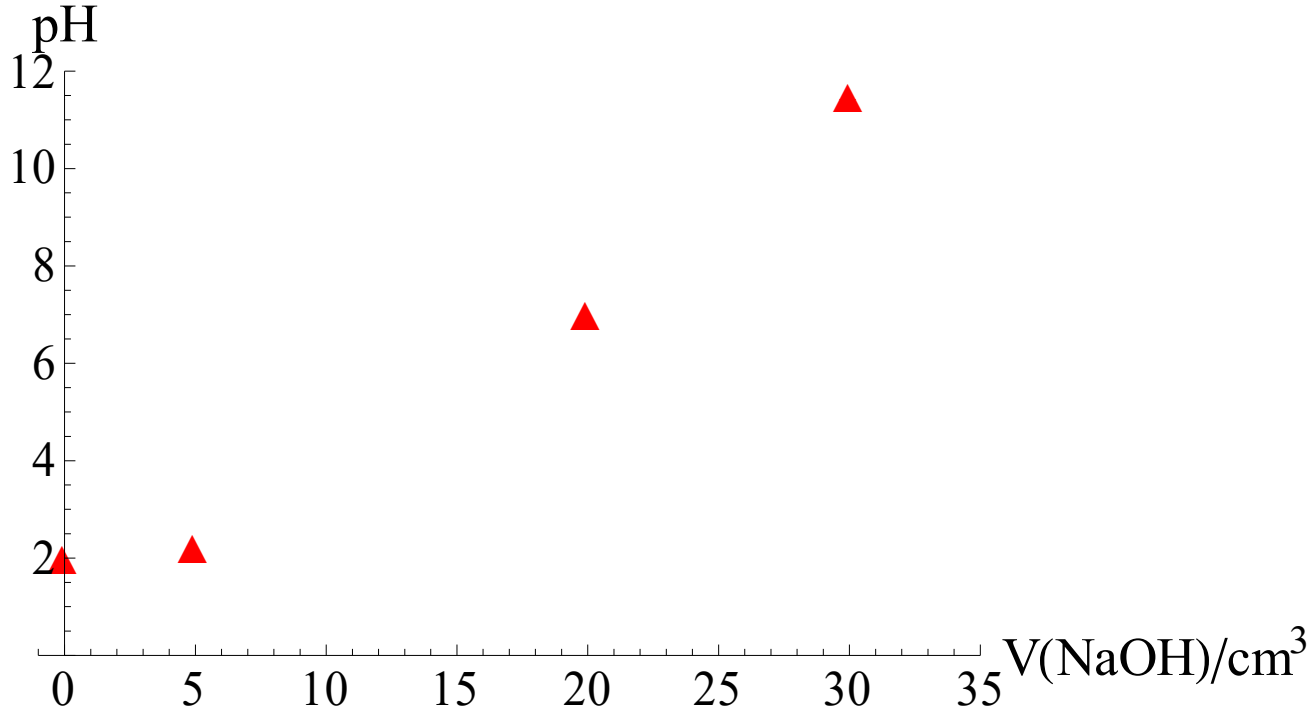
$$n(\mathrm{NaOH})_{\mathrm{dodano}} = c(\mathrm{NaOH})\, V(\mathrm{NaOH}) = 6{,}0 \cdot 10^{-4}\ \mathrm{mol}$$

$$n(\mathrm{NaOH}) = n(\mathrm{NaOH})_{\mathrm{dodano}} - n_{\mathrm{o}}(\mathrm{HNO_3}) = 2{,}0 \cdot 10^{-4}\ \mathrm{mol}$$

$$[\mathrm{OH^-}] = \frac{n(\mathrm{NaOH})}{V(\mathrm{HNO_3}) + V(\mathrm{NaOH})} = 0{,}0029\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pOH} = -\log\left(\frac{[\mathrm{OH}^-]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{0{,}0029\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 2{,}54$$

$$\mathrm{pH} = \mathrm{p}K_\mathrm{w} - \mathrm{pOH} = 14{,}00 - 2{,}54 = 11{,}46$$



Ovisnost pH o volumenu NaOH

11. Neka monoprotonska kiselina ima konstantu disocijacije $2{,}0 \cdot 10^{-4}$ mol dm^{-3}. Ako je 0,010 mol ove kiseline otopljen u 200,0 cm^3 otopine i titriran s NaOH, množinske koncentracije 0,250 mol dm^{-3}, izračunajte pH vrijednost u sljedećim točkama: a) u početnoj otopini; b) kad je jedna petina početne količine kiseline neutralizirana; c) u točki ekvivalencije.

$n_o(\mathrm{HA}) = 0{,}010\ \mathrm{mol}$ $\qquad$ $V(\mathrm{HA}) = 200{,}0\ \mathrm{cm}^{-3} = 0{,}2000\ \mathrm{dm}^{-3}$

$c(\mathrm{NaOH}) = 0{,}250\ \mathrm{mol\ dm}^{-3}$ $\qquad$ $K_a = 2{,}0 \cdot 10^{-4}\ \mathrm{mol\ dm}^{-3}$

$$\mathrm{HA} + \mathrm{NaOH} \rightleftharpoons \mathrm{NaA} + \mathrm{H_2O}$$

$$c(\mathrm{HA}) = \frac{n_o(\mathrm{HA})}{V(\mathrm{HA})} = 0{,}050\ \mathrm{mol\ dm}^{-3}$$

a)

$$\underset{a\text{-}x}{\mathrm{HA}} + \mathrm{H_2O} \rightleftharpoons \underset{x}{\mathrm{H_3O^+}} + \underset{x}{\mathrm{A^-}}$$

$$K_\mathrm{a} = \frac{[\mathrm{H_3O^+}][\mathrm{A^-}]}{[\mathrm{HA}]} = \frac{x^2}{a-x} \approx \frac{x^2}{a}$$

$$x = [\mathrm{H_3O^+}] = \sqrt{a\,K_\mathrm{a}} = \sqrt{c(\mathrm{HA})\,K_\mathrm{a}} = 3{,}16 \cdot 10^{-3}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{3{,}16 \cdot 10^{-3}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 2{,}50$$

b)

$$n_{\mathrm{o}}(\mathrm{HA}) = 0{,}010\ \mathrm{mol}$$

$$n(\mathrm{NaOH})_{\mathrm{dodano}} = n(\mathrm{NaA}) = \frac{n_{\mathrm{o}}(\mathrm{HA})}{5} = 0{,}002\ \mathrm{mol}$$

$$V(\mathrm{NaOH})_{\mathrm{dodano}} = \frac{n(\mathrm{NaOH})_{\mathrm{dodano}}}{c(\mathrm{NaOH})} = \frac{0{,}002\ \mathrm{mol}}{0{,}250\ \mathrm{mol\,dm^{-3}}} = 8{,}0 \cdot 10^{-3}\ \mathrm{dm^3}$$

$$n(\mathrm{HA}) = n_{\mathrm{o}}(\mathrm{HA}) - n(\mathrm{NaOH})_{\mathrm{dodano}} = 0{,}008\ \mathrm{mol}$$

$$c_{\mathrm{HA}} = \frac{n(\mathrm{HA})}{V(\mathrm{HA}) + V(\mathrm{NaOH})} = 0{,}0385\ \mathrm{mol\,dm^{-3}} \approx [\mathrm{HA}]$$

$$c_{\mathrm{NaA}} = \frac{n(\mathrm{NaA})}{V(\mathrm{HA}) + V(\mathrm{NaOH})} = 0{,}0096\ \mathrm{mol\,dm^{-3}} \approx [\mathrm{A^-}]$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

$$[H_3O^+] = \frac{K_a[HA]}{[A^-]} = 8{,}01 \cdot 10^{-4}\ \text{mol dm}^{-3}$$

$$\text{pH} = -\log\left(\frac{[H_3O^+]}{\text{mol dm}^{-3}}\right) = -\log\left(\frac{8{,}01 \cdot 10^{-4}\ \text{mol dm}^{-3}}{\text{mol dm}^{-3}}\right) = 3{,}10$$

c) $n_o(\text{HA}) = n(\text{NaOH})_{\text{dodano}} = 0{,}010\ \text{mol}$ ⇒ točka ekvivalencije – sva kiselina je neutralizirana

$$V(\text{NaOH})_{\text{dodano}} = \frac{n(\text{NaOH})_{\text{dodano}}}{c(\text{NaOH})} = \frac{0{,}010\ \text{mol}}{0{,}250\ \text{mol dm}^{-3}} = 40{,}0 \cdot 10^{-3}\ \text{dm}^3$$

$$n(\mathrm{NaA}) = 0{,}010\ \mathrm{mol}$$

$$c(\mathrm{NaA}) = \frac{n(\mathrm{NaA})}{V(\mathrm{HA}) + V(\mathrm{NaOH})_{\mathrm{dodano}}} = 0{,}0417\ \mathrm{mol\,dm^{-3}}$$

$$\underset{a\text{-}x}{\mathrm{A^-}} + \mathrm{H_2O} \rightleftharpoons \underset{x}{\mathrm{HA}} + \underset{x}{\mathrm{OH^-}}$$

$$K_\mathrm{b} = \frac{K_\mathrm{w}}{K_\mathrm{a}} = \frac{1{,}0 \cdot 10^{-14}\ \mathrm{mol^2\ dm^{-6}}}{2{,}0 \cdot 10^{-4}\ \mathrm{mol\,dm^{-3}}} = 5{,}0 \cdot 10^{-11}\ \mathrm{mol\,dm^{-3}}$$

$$K_\mathrm{b} = \frac{[\mathrm{HA}][\mathrm{OH^-}]}{[\mathrm{A^-}]} = \frac{x^2}{a - x} \approx \frac{x^2}{a}$$

$$x = [\mathrm{OH^-}] = \sqrt{a\ K_\mathrm{b}} = \sqrt{c(\mathrm{NaA})\ K_\mathrm{b}} = 1{,}44 \cdot 10^{-6}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pOH} = -\log\left(\frac{[\mathrm{OH}^-]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{1{,}44\cdot10^{-6}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 5{,}84$$

$$\mathrm{pH} = \mathrm{p}K_\mathrm{w} - \mathrm{pOH} = 14{,}00 - 5{,}84 = 8{,}16$$

12. 40,00 $\mathrm{cm^3}$ otopine $\mathrm{NH_3}$, koncentracije 0,1500 mol $\mathrm{dm^{-3}}$ i konstante disocijacije $1{,}82\cdot10^{-5}$ mol $\mathrm{dm^{-3}}$ titrirano je s HCl, koncentracije 0,1200 mol $\mathrm{dm^{-3}}$. Izračunajte pH vrijednosti otopine kad su dodani sljedeći volumeni kloridne kiseline: a) 0,00; b) 24,00; c) 50,00 i d) 52,00 $\mathrm{cm^3}$.

$c(\mathrm{NH_3}) = 0{,}1500\ \mathrm{mol\,dm^{-3}}$ $\qquad$ $V(\mathrm{NH_3}) = 40{,}0\ \mathrm{cm^{-3}} = 40{,}0\cdot10^{-3}\ \mathrm{dm^{-3}}$

$c(\mathrm{HCl}) = 0{,}1200\ \mathrm{mol\,dm^{-3}}$ $\qquad$ $K_\mathrm{b} = 1{,}82\cdot10^{-5}\ \mathrm{mol\,dm^{-3}}$

$$\mathrm{NH_3} + \mathrm{HCl} \rightleftharpoons \mathrm{NH_4Cl}$$

a) $V(\mathrm{HCl}) = 0{,}00\ \mathrm{cm}^3$

$$\underset{a\text{-}x}{\mathrm{NH_3}} + \mathrm{H_2O} \rightleftharpoons \underset{x}{\mathrm{NH_4^+}} + \underset{x}{\mathrm{OH^-}}$$

$$K_\mathrm{b} = \frac{[\mathrm{NH_4^+}][\mathrm{OH^-}]}{[\mathrm{NH_3}]} = \frac{x^2}{a-x} \approx \frac{x^2}{a}$$

$$x = [\mathrm{OH^-}] = \sqrt{a\ K_\mathrm{b}} = \sqrt{c(\mathrm{NH_3})\ K_\mathrm{b}} = 1{,}65 \cdot 10^{-3}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pOH} = -\log\left(\frac{[\mathrm{OH^-}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{1{,}65 \cdot 10^{-3}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 2{,}78$$

$$\mathrm{pH} = \mathrm{p}K_\mathrm{w} - \mathrm{pOH} = 14{,}00 - 2{,}78 = 11{,}22$$

b) $V(\mathrm{HCl}) = 24{,}00\ \mathrm{cm}^3 = 24{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$

$$\mathrm{NH_4^+} + \mathrm{H_2O} \rightleftharpoons \mathrm{H_3O^+} + \mathrm{NH_3}$$

$$K_\mathrm{a} = \frac{K_\mathrm{w}}{K_\mathrm{b}} = \frac{1{,}00 \cdot 10^{-14}\ \mathrm{mol^2\ dm^{-6}}}{1{,}82 \cdot 10^{-5}\ \mathrm{mol\ dm^{-3}}} = 5{,}49 \cdot 10^{-10}\ \mathrm{mol\ dm^{-3}}$$

$$n_\mathrm{o}(\mathrm{NH_3}) = c(\mathrm{NH_3})\, V(\mathrm{NH_3}) = 6{,}0 \cdot 10^{-3}\ \mathrm{mol}$$

$$n(\mathrm{NH_4Cl}) = n(\mathrm{HCl})_\mathrm{dodano} = c(\mathrm{HCl})\, V(\mathrm{HCl}) = 2{,}9 \cdot 10^{-3}\ \mathrm{mol}$$

$$c(\mathrm{NH_4Cl}) = \frac{n(\mathrm{NH_4Cl})}{V(\mathrm{NH_3}) + V(\mathrm{HCl})} = 0{,}0453\ \mathrm{mol\ dm^{-3}} \approx [\mathrm{NH_4^+}]$$

$$n(\mathrm{NH_3}) = n_\mathrm{o}(\mathrm{NH_3}) - n(\mathrm{HCl})_\mathrm{dodano} = 3{,}1 \cdot 10^{-3}\ \mathrm{mol}$$

$$c(\mathrm{NH_3}) = \frac{n(\mathrm{NH_3})}{V(\mathrm{NH_3}) + V(\mathrm{HCl})} = 0{,}0484\ \mathrm{mol\,dm^{-3}} \approx [\mathrm{NH_3}]$$

$$\mathrm{NH_4^+} \quad + \quad \mathrm{H_2O} \quad \rightleftharpoons \quad \mathrm{H_3O^+} \quad + \quad \mathrm{NH_3}$$

$$K_\mathrm{a} = \frac{[\mathrm{NH_3}][\mathrm{H_3O^+}]}{[\mathrm{NH_4^+}]}$$

$$[\mathrm{H_3O^+}] = \frac{[\mathrm{NH_4^+}]K_\mathrm{a}}{[\mathrm{NH_3}]} = 5{,}13 \cdot 10^{-10}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{5{,}13 \cdot 10^{-10}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 9{,}29$$

c) $V(\mathrm{HCl}) = 50{,}00\ \mathrm{cm}^3 = 50{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$

$$n_\mathrm{o}(\mathrm{NH_3}) = c(\mathrm{NH_3})\, V(\mathrm{NH_3}) = 6{,}0 \cdot 10^{-3}\ \mathrm{mol}$$

$$n(\mathrm{HCl})_\mathrm{dodano} = c(\mathrm{HCl})\, V(\mathrm{HCl}) = 6{,}0 \cdot 10^{-3}\ \mathrm{mol}$$

} točka ekvivalencije

$$n(\mathrm{NH_4Cl}) = 6{,}0 \cdot 10^{-3}\ \mathrm{mol}$$

$$c(\mathrm{NH_4Cl}) = \frac{n(\mathrm{NH_4Cl})}{V(\mathrm{NH_3}) + V(\mathrm{HCl})} = 0{,}0667\ \mathrm{mol\,dm^{-3}}$$

$$\underset{a\text{-}x}{\mathrm{NH_4^+}} + \mathrm{H_2O} \rightleftharpoons \underset{x}{\mathrm{H_3O^+}} + \underset{x}{\mathrm{NH_3}}$$

$$K_\mathrm{a} = \frac{K_\mathrm{w}}{K_\mathrm{b}} = \frac{1{,}00 \cdot 10^{-14}\ \mathrm{mol^2\ dm^{-6}}}{1{,}82 \cdot 10^{-5}\ \mathrm{mol\,dm^{-3}}} = 5{,}49 \cdot 10^{-10}\ \mathrm{mol\,dm^{-3}}$$

$$K_\mathrm{a} = \frac{[\mathrm{H_3O^+}][\mathrm{NH_3}]}{[\mathrm{NH_4^+}]} = \frac{x^2}{a - x} \approx \frac{x^2}{a}$$

$$x = [\mathrm{H_3O^+}] = \sqrt{a\ K_\mathrm{a}} = \sqrt{c(\mathrm{NH_4Cl})\ K_\mathrm{a}} = 6{,}05 \cdot 10^{-6}\ \mathrm{mol\,dm^{-3}}$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{6{,}05 \cdot 10^{-6}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 5{,}22$$

d) $V(\mathrm{HCl}) = 52{,}00\ \mathrm{cm}^3 = 52{,}00 \cdot 10^{-3}\ \mathrm{dm}^3$

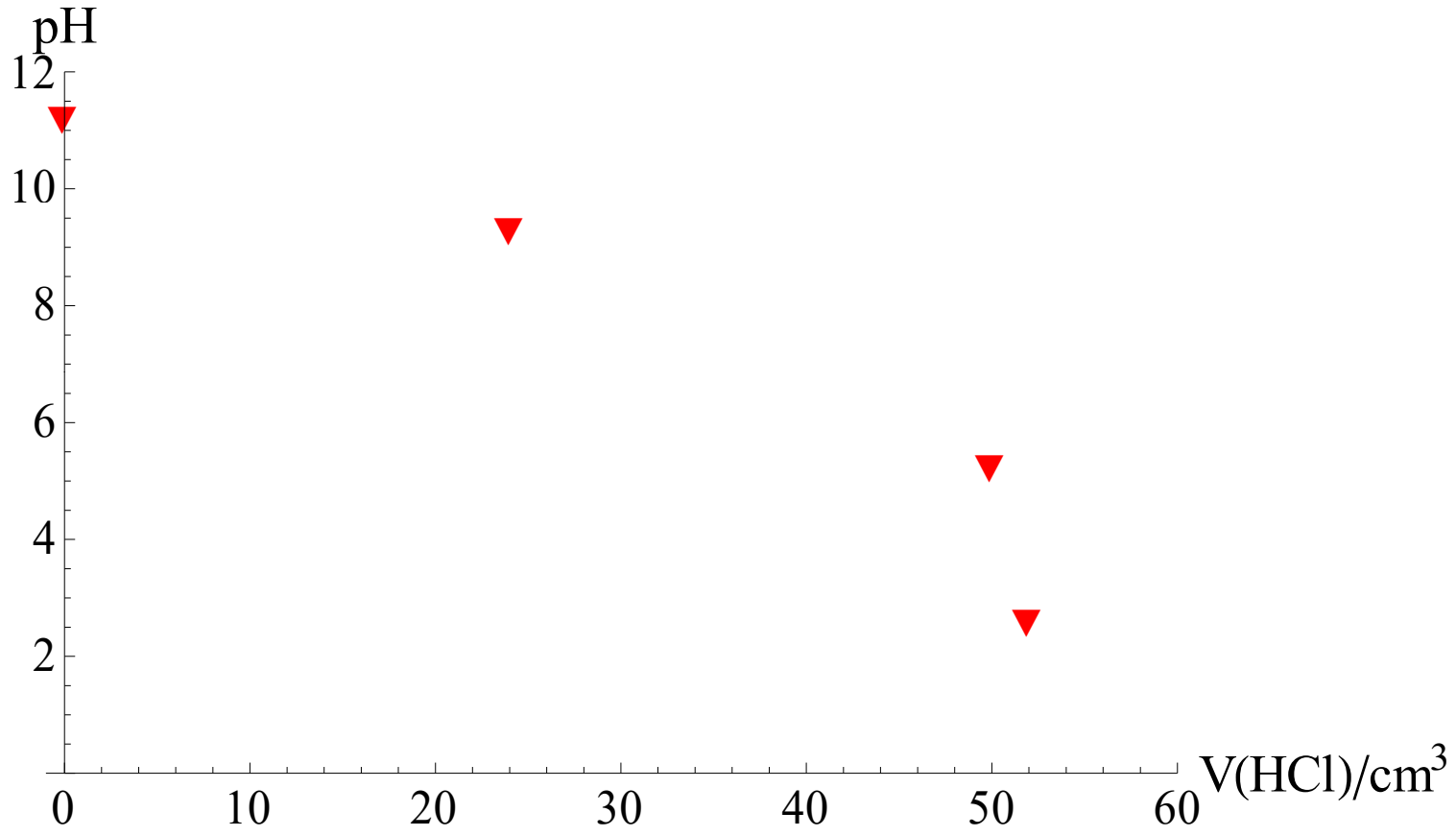
$$n_\mathrm{o}(\mathrm{NH_3}) = c(\mathrm{NH_3})\, V(\mathrm{NH_3}) = 6{,}0 \cdot 10^{-3}\ \mathrm{mol}$$

$$n(\mathrm{HCl})_\mathrm{dodano} = c(\mathrm{HCl})\, V(\mathrm{HCl}) = 6{,}24 \cdot 10^{-3}\ \mathrm{mol}$$

$$n(\mathrm{HCl}) = n(\mathrm{HCl})_\mathrm{dodano} - n_\mathrm{o}(\mathrm{NH_3}) = 2{,}4 \cdot 10^{-4}\ \mathrm{mol}$$

$$c(\mathrm{HCl}) = \frac{n(\mathrm{HCl})}{V(\mathrm{NH_3}) + V(\mathrm{HCl})} = 2{,}6 \cdot 10^{-3}\ \mathrm{mol\,dm^{-3}} \approx [\mathrm{H_3O^+}]$$

$$\mathrm{pH} = -\log\left(\frac{[\mathrm{H_3O^+}]}{\mathrm{mol\,dm^{-3}}}\right) = -\log\left(\frac{2{,}6 \cdot 10^{-3}\ \mathrm{mol\,dm^{-3}}}{\mathrm{mol\,dm^{-3}}}\right) = 2{,}58$$



Ovisnost pH o volumenu HCl