

| Acid-base titration | | | pK's | | | | | | | | | | | |
|---------------------|---------|----------|-------|-------|-------|----------------------------|-------|-----|--------|------|------|---------|--|--|
| | Ka1= | 1.00E-03 | 3 | Ca= | 0.1 | Initial acid concentration | | | | | | | | |
| | Ka2= | 1.00E-07 | 7 | Cb= | 0.1 | Initial base concentration | | | | | | | | |
| | Ka3= | 1.00E-09 | 9 | Va= | 10 | Volume of acid to titrate | | | | | | | | |
| pH | [H+] | [OH-] | aH3A | aH2A- | aHA-- | A3- | phi | pH | Vb(mL) | Av | pH | dVb/dpH | | |
| 1 | 0.1 | 1E-13 | 0.99 | 0.01 | 1E-08 | 9.9E-17 | -0.5 | 1 | | | | | | |
| 1.1 | 0.07943 | 1.26E-13 | 0.988 | 0.012 | 2E-08 | 1.97E-16 | -0.44 | 1.1 | | | | | | |
| 1.2 | 0.0631 | 1.58E-13 | 0.984 | 0.016 | 2E-08 | 3.92E-16 | -0.38 | 1.2 | | | | | | |
| 1.3 | 0.05012 | 2E-13 | 0.98 | 0.02 | 4E-08 | 7.79E-16 | -0.32 | 1.3 | | | | | | |
| 1.4 | 0.03981 | 2.51E-13 | 0.975 | 0.025 | 6E-08 | 1.55E-15 | -0.27 | 1.4 | | | | | | |
| 1.5 | 0.03162 | 3.16E-13 | 0.969 | 0.031 | 1E-07 | 3.07E-15 | -0.22 | 1.5 | | | | | | |
| 1.6 | 0.02512 | 3.98E-13 | 0.962 | 0.038 | 2E-07 | 6.07E-15 | -0.17 | 1.6 | -1.7 | | | | | |
| 1.7 | 0.01995 | 5.01E-13 | 0.952 | 0.048 | 2E-07 | 1.2E-14 | -0.13 | 1.7 | -1.27 | 1.65 | 4.36 | | | |
| 1.8 | 0.01585 | 6.31E-13 | 0.941 | 0.059 | 4E-07 | 2.36E-14 | -0.09 | 1.8 | -0.86 | 1.75 | 4.1 | | | |
| 1.9 | 0.01259 | 7.94E-13 | 0.926 | 0.074 | 6E-07 | 4.64E-14 | -0.05 | 1.9 | -0.46 | 1.85 | 3.91 | | | |
| 2 | 0.01 | 1E-12 | 0.909 | 0.091 | 9E-07 | 9.09E-14 | -0.01 | 2 | -0.08 | 1.95 | 3.82 | | | |
| 2.1 | 0.00794 | 1.26E-12 | 0.888 | 0.112 | 1E-06 | 1.77E-13 | 0.03 | 2.1 | 0.3 | 2.05 | 3.83 | | | |
| 2.2 | 0.00631 | 1.58E-12 | 0.863 | 0.137 | 2E-06 | 3.44E-13 | 0.069 | 2.2 | 0.69 | 2.15 | 3.93 | | | |
| 2.3 | 0.00501 | 2E-12 | 0.834 | 0.166 | 3E-06 | 6.62E-13 | 0.111 | 2.3 | 1.11 | 2.25 | 4.13 | | | |
| 2.4 | 0.00398 | 2.51E-12 | 0.799 | 0.201 | 5E-06 | 1.27E-12 | 0.155 | 2.4 | 1.55 | 2.35 | 4.41 | | | |
| 2.5 | 0.00316 | 3.16E-12 | 0.76 | 0.24 | 8E-06 | 2.4E-12 | 0.202 | 2.5 | 2.02 | 2.45 | 4.75 | | | |
| 2.6 | 0.00251 | 3.98E-12 | 0.715 | 0.285 | 1E-05 | 4.51E-12 | 0.253 | 2.6 | 2.53 | 2.55 | 5.1 | | | |
| 2.7 | 0.002 | 5.01E-12 | 0.666 | 0.334 | 2E-05 | 8.39E-12 | 0.308 | 2.7 | 3.08 | 2.65 | 5.45 | | | |
| 2.8 | 0.00158 | 6.31E-12 | 0.613 | 0.387 | 2E-05 | 1.54E-11 | 0.365 | 2.8 | 3.65 | 2.75 | 5.75 | | | |
| 2.9 | 0.00126 | 7.94E-12 | 0.557 | 0.443 | 4E-05 | 2.79E-11 | 0.425 | 2.9 | 4.25 | 2.85 | 5.95 | | | |
| 3 | 0.001 | 1E-11 | 0.5 | 0.5 | 5E-05 | 5E-11 | 0.485 | 3 | 4.85 | 2.95 | 6.04 | | | |
| 3.1 | 0.00079 | 1.26E-11 | 0.443 | 0.557 | 7E-05 | 8.83E-11 | 0.545 | 3.1 | 5.45 | 3.05 | 5.99 | | | |
| 3.2 | 0.00063 | 1.58E-11 | 0.387 | 0.613 | 1E-04 | 1.54E-10 | 0.603 | 3.2 | 6.03 | 3.15 | 5.8 | | | |
| 3.3 | 0.0005 | 2E-11 | 0.334 | 0.666 | 1E-04 | 2.65E-10 | 0.658 | 3.3 | 6.58 | 3.25 | 5.49 | | | |
| 3.4 | 0.0004 | 2.51E-11 | 0.285 | 0.715 | 2E-04 | 4.51E-10 | 0.709 | 3.4 | 7.09 | 3.35 | 5.07 | | | |
| 3.5 | 0.00032 | 3.16E-11 | 0.24 | 0.76 | 2E-04 | 7.6E-10 | 0.754 | 3.5 | 7.54 | 3.45 | 4.58 | | | |
| 3.6 | 0.00025 | 3.98E-11 | 0.201 | 0.799 | 3E-04 | 1.27E-09 | 0.795 | 3.6 | 7.95 | 3.55 | 4.06 | | | |
| 3.7 | 0.0002 | 5.01E-11 | 0.166 | 0.833 | 4E-04 | 2.09E-09 | 0.83 | 3.7 | 8.3 | 3.65 | 3.54 | | | |
| 3.8 | 0.00016 | 6.31E-11 | 0.137 | 0.863 | 5E-04 | 3.43E-09 | 0.861 | 3.8 | 8.61 | 3.75 | 3.04 | | | |
| 3.9 | 0.00013 | 7.94E-11 | 0.112 | 0.888 | 7E-04 | 5.6E-09 | 0.887 | 3.9 | 8.87 | 3.85 | 2.57 | | | |
| 4 | 1E-04 | 1E-10 | 0.091 | 0.908 | 9E-04 | 9.08E-09 | 0.908 | 4 | 9.08 | 3.95 | 2.16 | | | |
| 4.1 | 7.9E-05 | 1.26E-10 | 0.074 | 0.925 | 0.001 | 1.47E-08 | 0.926 | 4.1 | 9.26 | 4.05 | 1.8 | | | |
| 4.2 | 6.3E-05 | 1.58E-10 | 0.059 | 0.939 | 0.001 | 2.36E-08 | 0.941 | 4.2 | 9.41 | 4.15 | 1.49 | | | |
| 4.3 | 5E-05 | 2E-10 | 0.048 | 0.95 | 0.002 | 3.78E-08 | 0.953 | 4.3 | 9.53 | 4.25 | 1.23 | | | |
| 4.4 | 4E-05 | 2.51E-10 | 0.038 | 0.959 | 0.002 | 6.05E-08 | 0.963 | 4.4 | 9.63 | 4.35 | 1.02 | | | |
| 4.5 | 3.2E-05 | 3.16E-10 | 0.031 | 0.966 | 0.003 | 9.66E-08 | 0.972 | 4.5 | 9.72 | 4.45 | 0.84 | | | |
| 4.6 | 2.5E-05 | 3.98E-10 | 0.024 | 0.972 | 0.004 | 1.54E-07 | 0.979 | 4.6 | 9.79 | 4.55 | 0.71 | | | |
| 4.7 | 2E-05 | 5.01E-10 | 0.019 | 0.976 | 0.005 | 2.45E-07 | 0.985 | 4.7 | 9.85 | 4.65 | 0.61 | | | |
| 4.8 | 1.6E-05 | 6.31E-10 | 0.016 | 0.978 | 0.006 | 3.89E-07 | 0.99 | 4.8 | 9.9 | 4.75 | 0.53 | | | |
| 4.9 | 1.3E-05 | 7.94E-10 | 0.012 | 0.98 | 0.008 | 6.18E-07 | 0.995 | 4.9 | 9.95 | 4.85 | 0.48 | | | |
| 5 | 0.00001 | 1E-09 | 0.01 | 0.98 | 0.01 | 9.8E-07 | 1 | 5 | 10 | 4.95 | 0.46 | | | |
| 5.1 | 7.9E-06 | 1.26E-09 | 0.008 | 0.98 | 0.012 | 1.55E-06 | 1.004 | 5.1 | 10 | 5.05 | 0.46 | | | |
| 5.2 | 6.3E-06 | 1.58E-09 | 0.006 | 0.978 | 0.016 | 2.46E-06 | 1.009 | 5.2 | 10.1 | 5.15 | 0.48 | | | |
| 5.3 | 5E-06 | 2E-09 | 0.005 | 0.976 | 0.019 | 3.88E-06 | 1.014 | 5.3 | 10.1 | 5.25 | 0.53 | | | |
| 5.4 | 4E-06 | 2.51E-09 | 0.004 | 0.972 | 0.024 | 6.13E-06 | 1.02 | 5.4 | 10.2 | 5.35 | 0.6 | | | |
| 5.5 | 3.2E-06 | 3.16E-09 | 0.003 | 0.966 | 0.031 | 9.66E-06 | 1.027 | 5.5 | 10.3 | 5.45 | 0.7 | | | |

| | | | | | | | | | | | | |
|------|---------|----------|-------|-------|-------|----------|-------|-----|------|------|------|--|
| 5.6 | 2.5E-06 | 3.98E-09 | 0.002 | 0.959 | 0.038 | 1.52E-05 | 1.036 | 5.6 | 10.4 | 5.55 | 0.83 | |
| 5.7 | 2E-06 | 5.01E-09 | 0.002 | 0.95 | 0.048 | 2.39E-05 | 1.046 | 5.7 | 10.5 | 5.65 | 1 | |
| 5.8 | 1.6E-06 | 6.31E-09 | 0.001 | 0.939 | 0.059 | 3.74E-05 | 1.058 | 5.8 | 10.6 | 5.75 | 1.21 | |
| 5.9 | 1.3E-06 | 7.94E-09 | 0.001 | 0.925 | 0.073 | 5.84E-05 | 1.072 | 5.9 | 10.7 | 5.85 | 1.46 | |
| 6 | 1E-06 | 1E-08 | 9E-04 | 0.908 | 0.091 | 9.08E-05 | 1.09 | 6 | 10.9 | 5.95 | 1.76 | |
| 6.1 | 7.9E-07 | 1.26E-08 | 7E-04 | 0.887 | 0.112 | 0.000141 | 1.111 | 6.1 | 11.1 | 6.05 | 2.12 | |
| 6.2 | 6.3E-07 | 1.58E-08 | 5E-04 | 0.863 | 0.137 | 0.000217 | 1.137 | 6.2 | 11.4 | 6.15 | 2.53 | |
| 6.3 | 5E-07 | 2E-08 | 4E-04 | 0.833 | 0.166 | 0.000332 | 1.166 | 6.3 | 11.7 | 6.25 | 2.99 | |
| 6.4 | 4E-07 | 2.51E-08 | 3E-04 | 0.799 | 0.201 | 0.000504 | 1.201 | 6.4 | 12 | 6.35 | 3.48 | |
| 6.5 | 3.2E-07 | 3.16E-08 | 2E-04 | 0.759 | 0.24 | 0.000759 | 1.241 | 6.5 | 12.4 | 6.45 | 4 | |
| 6.6 | 2.5E-07 | 3.98E-08 | 2E-04 | 0.714 | 0.284 | 0.001132 | 1.286 | 6.6 | 12.9 | 6.55 | 4.52 | |
| 6.7 | 2E-07 | 5.01E-08 | 1E-04 | 0.665 | 0.333 | 0.00167 | 1.336 | 6.7 | 13.4 | 6.65 | 5 | |
| 6.8 | 1.6E-07 | 6.31E-08 | 1E-04 | 0.612 | 0.386 | 0.002435 | 1.391 | 6.8 | 13.9 | 6.75 | 5.42 | |
| 6.9 | 1.3E-07 | 7.94E-08 | 7E-05 | 0.555 | 0.441 | 0.003504 | 1.448 | 6.9 | 14.5 | 6.85 | 5.74 | |
| 7 | 1E-07 | 1E-07 | 5E-05 | 0.497 | 0.497 | 0.004975 | 1.507 | 7 | 15.1 | 6.95 | 5.93 | |
| 7.1 | 7.9E-08 | 1.26E-07 | 3E-05 | 0.44 | 0.553 | 0.006967 | 1.567 | 7.1 | 15.7 | 7.05 | 5.99 | |
| 7.2 | 6.3E-08 | 1.58E-07 | 2E-05 | 0.383 | 0.607 | 0.009624 | 1.626 | 7.2 | 16.3 | 7.15 | 5.91 | |
| 7.3 | 5E-08 | 2E-07 | 2E-05 | 0.329 | 0.657 | 0.013117 | 1.684 | 7.3 | 16.8 | 7.25 | 5.72 | |
| 7.4 | 4E-08 | 2.51E-07 | 1E-05 | 0.28 | 0.703 | 0.017649 | 1.738 | 7.4 | 17.4 | 7.35 | 5.43 | |
| 7.5 | 3.2E-08 | 3.16E-07 | 7E-06 | 0.235 | 0.742 | 0.023461 | 1.789 | 7.5 | 17.9 | 7.45 | 5.09 | |
| 7.6 | 2.5E-08 | 3.98E-07 | 5E-06 | 0.195 | 0.775 | 0.030837 | 1.836 | 7.6 | 18.4 | 7.55 | 4.74 | |
| 7.7 | 2E-08 | 5.01E-07 | 3E-06 | 0.16 | 0.8 | 0.040106 | 1.88 | 7.7 | 18.8 | 7.65 | 4.42 | |
| 7.8 | 1.6E-08 | 6.31E-07 | 2E-06 | 0.13 | 0.819 | 0.051651 | 1.922 | 7.8 | 19.2 | 7.75 | 4.15 | |
| 7.9 | 1.3E-08 | 7.94E-07 | 1E-06 | 0.104 | 0.83 | 0.065901 | 1.961 | 7.9 | 19.6 | 7.85 | 3.96 | |
| 8 | 1E-08 | 1E-06 | 8E-07 | 0.083 | 0.833 | 0.083333 | 2 | 8 | 20 | 7.95 | 3.86 | |
| 8.1 | 7.9E-09 | 1.26E-06 | 5E-07 | 0.066 | 0.83 | 0.104447 | 2.039 | 8.1 | 20.4 | 8.05 | 3.86 | |
| 8.2 | 6.3E-09 | 1.58E-06 | 3E-07 | 0.052 | 0.819 | 0.129741 | 2.078 | 8.2 | 20.8 | 8.15 | 3.96 | |
| 8.3 | 5E-09 | 2E-06 | 2E-07 | 0.04 | 0.8 | 0.159666 | 2.12 | 8.3 | 21.2 | 8.25 | 4.15 | |
| 8.4 | 4E-09 | 2.51E-06 | 1E-07 | 0.031 | 0.775 | 0.194569 | 2.164 | 8.4 | 21.6 | 8.35 | 4.42 | |
| 8.5 | 3.2E-09 | 3.16E-06 | 7E-08 | 0.023 | 0.742 | 0.234616 | 2.211 | 8.5 | 22.1 | 8.45 | 4.74 | |
| 8.6 | 2.5E-09 | 3.98E-06 | 4E-08 | 0.018 | 0.703 | 0.279722 | 2.262 | 8.6 | 22.6 | 8.55 | 5.09 | |
| 8.7 | 2E-09 | 5.01E-06 | 3E-08 | 0.013 | 0.657 | 0.329481 | 2.317 | 8.7 | 23.2 | 8.65 | 5.43 | |
| 8.8 | 1.6E-09 | 6.31E-06 | 2E-08 | 0.01 | 0.607 | 0.38314 | 2.374 | 8.8 | 23.7 | 8.75 | 5.72 | |
| 8.9 | 1.3E-09 | 7.94E-06 | 9E-09 | 0.007 | 0.553 | 0.439604 | 2.433 | 8.9 | 24.3 | 8.85 | 5.92 | |
| 9 | 1E-09 | 1E-05 | 5E-09 | 0.005 | 0.498 | 0.497512 | 2.493 | 9 | 24.9 | 8.95 | 6 | |
| 9.1 | 7.9E-10 | 1.26E-05 | 3E-09 | 0.004 | 0.441 | 0.555359 | 2.552 | 9.1 | 25.5 | 9.05 | 5.94 | |
| 9.2 | 6.3E-10 | 1.58E-05 | 2E-09 | 0.002 | 0.386 | 0.611644 | 2.61 | 9.2 | 26.1 | 9.15 | 5.75 | |
| 9.3 | 5E-10 | 2E-05 | 8E-10 | 0.002 | 0.333 | 0.665027 | 2.664 | 9.3 | 26.6 | 9.25 | 5.43 | |
| 9.4 | 4E-10 | 2.51E-05 | 5E-10 | 0.001 | 0.284 | 0.714443 | 2.714 | 9.4 | 27.1 | 9.35 | 5.02 | |
| 9.5 | 3.2E-10 | 3.16E-05 | 2E-10 | 8E-04 | 0.24 | 0.75917 | 2.76 | 9.5 | 27.6 | 9.45 | 4.54 | |
| 9.6 | 2.5E-10 | 3.98E-05 | 1E-10 | 5E-04 | 0.201 | 0.798837 | 2.8 | 9.6 | 28 | 9.55 | 4.02 | |
| 9.7 | 2E-10 | 5.01E-05 | 7E-11 | 3E-04 | 0.166 | 0.833386 | 2.835 | 9.7 | 28.3 | 9.65 | 3.51 | |
| 9.8 | 1.6E-10 | 6.31E-05 | 3E-11 | 2E-04 | 0.137 | 0.863006 | 2.865 | 9.8 | 28.7 | 9.75 | 3.03 | |
| 9.9 | 1.3E-10 | 7.94E-05 | 2E-11 | 1E-04 | 0.112 | 0.888059 | 2.891 | 9.9 | 28.9 | 9.85 | 2.58 | |
| 10 | 1E-10 | 1E-04 | 9E-12 | 9E-05 | 0.091 | 0.909008 | 2.913 | 10 | 29.1 | 9.95 | 2.18 | |
| 10.1 | 7.9E-11 | 0.000126 | 5E-12 | 6E-05 | 0.074 | 0.926358 | 2.931 | 10 | 29.3 | 10.1 | 1.84 | |
| 10.2 | 6.3E-11 | 0.000158 | 2E-12 | 4E-05 | 0.059 | 0.940614 | 2.947 | 10 | 29.5 | 10.2 | 1.56 | |
| 10.3 | 5E-11 | 0.0002 | 1E-12 | 2E-05 | 0.048 | 0.952251 | 2.96 | 10 | 29.6 | 10.3 | 1.33 | |
| 10.4 | 4E-11 | 0.000251 | 6E-13 | 2E-05 | 0.038 | 0.961699 | 2.972 | 10 | 29.7 | 10.4 | 1.15 | |
| 10.5 | 3.2E-11 | 0.000316 | 3E-13 | 1E-05 | 0.031 | 0.969337 | 2.982 | 11 | 29.8 | 10.5 | 1.03 | |
| 10.6 | 2.5E-11 | 0.000398 | 2E-13 | 6E-06 | 0.025 | 0.975491 | 2.991 | 11 | 29.9 | 10.6 | 0.95 | |

Sheet1

| | | | | | | | | | | | | |
|------|---------|----------|-------|-------|-------|----------|-------|----|------|------|------|--|
| 10.7 | 2E-11 | 0.000501 | 8E-14 | 4E-06 | 0.02 | 0.980434 | 3 | 11 | 30 | 10.7 | 0.91 | |
| 10.9 | 1.3E-11 | 0.000794 | 2E-14 | 2E-06 | 0.012 | 0.987566 | 3.019 | 11 | 30.2 | 10.8 | 0.95 | |
| 11.1 | 7.9E-12 | 0.001259 | 5E-15 | 6E-07 | 0.008 | 0.992119 | 3.043 | 11 | 30.4 | 11 | 1.18 | |
| 11.3 | 5E-12 | 0.001995 | 1E-15 | 2E-07 | 0.005 | 0.995013 | 3.076 | 11 | 30.8 | 11.2 | 1.67 | |
| 11.5 | 3.2E-12 | 0.003162 | 3E-16 | 1E-07 | 0.003 | 0.996848 | 3.127 | 12 | 31.3 | 11.4 | 2.55 | |
| 11.7 | 2E-12 | 0.005012 | 8E-17 | 4E-08 | 0.002 | 0.998009 | 3.209 | 12 | 32.1 | 11.6 | 4.08 | |
| 11.9 | 1.3E-12 | 0.007943 | 2E-17 | 2E-08 | 0.001 | 0.998743 | 3.344 | 12 | 33.4 | 11.8 | 6.74 | |
| 12.1 | 7.9E-13 | 0.012589 | 5E-18 | 6E-09 | 8E-04 | 0.999206 | 3.575 | 12 | 35.8 | 12 | 11.6 | |
| 12.3 | 5E-13 | 0.019953 | 1E-18 | 3E-09 | 5E-04 | 0.999499 | 3.996 | 12 | 40 | 12.2 | 21.1 | |
| 12.5 | 3.2E-13 | 0.031623 | 3E-19 | 1E-09 | 3E-04 | 0.999684 | 4.849 | | | | | |
| 12.7 | 2E-13 | 0.050119 | 8E-20 | 4E-10 | 2E-04 | 0.999801 | 7.019 | | | | | |
| 12.9 | 1.3E-13 | 0.079433 | 2E-20 | 2E-10 | 1E-04 | 0.999874 | 18.45 | | | | | |
| 13.1 | 7.9E-14 | 0.125893 | 5E-21 | 6E-11 | 8E-05 | 0.999921 | -16.4 | | | | | |
| 13.3 | 5E-14 | 0.199526 | 1E-21 | 3E-11 | 5E-05 | 0.99995 | -5.02 | | | | | |
| 13.5 | 3.2E-14 | 0.316228 | 3E-22 | 1E-11 | 3E-05 | 0.999968 | -2.85 | | | | | |
| 13.7 | 2E-14 | 0.501187 | 8E-23 | 4E-12 | 2E-05 | 0.99998 | -2 | | | | | |
| 13.9 | 1.3E-14 | 0.794328 | 2E-23 | 2E-12 | 1E-05 | 0.999987 | -1.58 | | | | | |



