INFORMATION IN THE TABLE BELOW AND IN THE TABLES ON PAGES 4-6 MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

**DO NOT DETACH FROM BOOK.**

# PERIODIC TABLE OF THE ELEMENTS

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 **H** 1.008 | | | | | | | | | | | | | | | | | 2 **He** 4.00 |
| 3 **Li** 6.94 | 4 **Be** 9.01 | | | | | | | | | | | 5 **B** 10.81 | 6 **C** 12.01 | 7 **N** 14.01 | 8 **O** 16.00 | 9 **F** 19.00 | 10 **Ne** 20.18 |
| 11 **Na** 22.99 | 12 **Mg** 24.30 | | | | | | | | | | | 13 **Al** 26.98 | 14 **Si** 28.09 | 15 **P** 30.97 | 16 **S** 32.06 | 17 **Cl** 35.45 | 18 **Ar** 39.95 |
| 19 **K** 39.10 | 20 **Ca** 40.08 | 21 **Sc** 44.96 | 22 **Ti** 47.90 | 23 **V** 50.94 | 24 **Cr** 52.00 | 25 **Mn** 54.94 | 26 **Fe** 55.85 | 27 **Co** 58.93 | 28 **Ni** 58.69 | 29 **Cu** 63.55 | 30 **Zn** 65.39 | 31 **Ga** 69.72 | 32 **Ge** 72.59 | 33 **As** 74.92 | 34 **Se** 78.96 | 35 **Br** 79.90 | 36 **Kr** 83.80 |
| 37 **Rb** 85.47 | 38 **Sr** 87.62 | 39 **Y** 88.91 | 40 **Zr** 91.22 | 41 **Nb** 92.91 | 42 **Mo** 95.94 | 43 **Tc** (98) | 44 **Ru** 101.1 | 45 **Rh** 102.91 | 46 **Pd** 106.42 | 47 **Ag** 107.87 | 48 **Cd** 112.41 | 49 **In** 114.82 | 50 **Sn** 118.71 | 51 **Sb** 121.75 | 52 **Te** 127.60 | 53 **I** 126.91 | 54 **Xe** 131.29 |
| 55 **Cs** 132.91 | 56 **Ba** 137.33 | 57 ***La** 138.91 | 72 **Hf** 178.49 | 73 **Ta** 180.95 | 74 **W** 183.85 | 75 **Re** 186.21 | 76 **Os** 190.2 | 77 **Ir** 192.2 | 78 **Pt** 195.08 | 79 **Au** 196.97 | 80 **Hg** 200.59 | 81 **Tl** 204.38 | 82 **Pb** 207.2 | 83 **Bi** 208.98 | 84 **Po** (209) | 85 **At** (210) | 86 **Rn** (222) |
| 87 **Fr** (223) | 88 **Ra** 226.02 | 89 **†Ac** 227.03 | 104 **Rf** (261) | 105 **Db** (262) | 106 **Sg** (266) | 107 **Bh** (264) | 108 **Hs** (277) | 109 **Mt** (268) | 110 **Ds** (271) | 111 **Rg** (272) | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lanthanide Series | 58 **Ce** 140.12 | 59 **Pr** 140.91 | 60 **Nd** 144.24 | 61 **Pm** (145) | 62 **Sm** 150.4 | 63 **Eu** 151.97 | 64 **Gd** 157.25 | 65 **Tb** 158.93 | 66 **Dy** 162.50 | 67 **Ho** 164.93 | 68 **Er** 167.26 | 69 **Tm** 168.93 | 70 **Yb** 173.04 | 71 **Lu** 174.97 |
| †Actinide Series | 90 **Th** 232.04 | 91 **Pa** 231.04 | 92 **U** 238.03 | 93 **Np** (237) | 94 **Pu** (244) | 95 **Am** (243) | 96 **Cm** (247) | 97 **Bk** (247) | 98 **Cf** (251) | 99 **Es** (252) | 100 **Fm** (257) | 101 **Md** (258) | 102 **No** (259) | 103 **Lr** (262) |



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STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

| Half-reaction | | | $E°$(V) |
|---|---|---|---|
| $F_2(g) + 2e^-$ | $\rightarrow$ | $2F^-$ | 2.87 |
| $Co^{3+} + e^-$ | $\rightarrow$ | $Co^{2+}$ | 1.82 |
| $Au^{3+} + 3e^-$ | $\rightarrow$ | $Au(s)$ | 1.50 |
| $Cl_2(g) + 2e^-$ | $\rightarrow$ | $2Cl^-$ | 1.36 |
| $O_2(g) + 4H^+ + 4e^-$ | $\rightarrow$ | $2H_2O(l)$ | 1.23 |
| $Br_2(l) + 2e^-$ | $\rightarrow$ | $2Br^-$ | 1.07 |
| $2Hg^{2+} + 2e^-$ | $\rightarrow$ | $Hg_2^{2+}$ | 0.92 |
| $Hg^{2+} + 2e^-$ | $\rightarrow$ | $Hg(l)$ | 0.85 |
| $Ag^+ + e^-$ | $\rightarrow$ | $Ag(s)$ | 0.80 |
| $Hg_2^{2+} + 2e^-$ | $\rightarrow$ | $2Hg(l)$ | 0.79 |
| $Fe^{3+} + e^-$ | $\rightarrow$ | $Fe^{2+}$ | 0.77 |
| $I_2(s) + 2e^-$ | $\rightarrow$ | $2I^-$ | 0.53 |
| $Cu^+ + e^-$ | $\rightarrow$ | $Cu(s)$ | 0.52 |
| $Cu^{2+} + 2e^-$ | $\rightarrow$ | $Cu(s)$ | 0.34 |
| $Cu^{2+} + e^-$ | $\rightarrow$ | $Cu^+$ | 0.15 |
| $Sn^{4+} + 2e^-$ | $\rightarrow$ | $Sn^{2+}$ | 0.15 |
| $S(s) + 2H^+ + 2e^-$ | $\rightarrow$ | $H_2S(g)$ | 0.14 |
| $2H^+ + 2e^-$ | $\rightarrow$ | $H_2(g)$ | 0.00 |
| $Pb^{2+} + 2e^-$ | $\rightarrow$ | $Pb(s)$ | – 0.13 |
| $Sn^{2+} + 2e^-$ | $\rightarrow$ | $Sn(s)$ | – 0.14 |
| $Ni^{2+} + 2e^-$ | $\rightarrow$ | $Ni(s)$ | – 0.25 |
| $Co^{2+} + 2e^-$ | $\rightarrow$ | $Co(s)$ | – 0.28 |
| $Cd^{2+} + 2e^-$ | $\rightarrow$ | $Cd(s)$ | – 0.40 |
| $Cr^{3+} + e^-$ | $\rightarrow$ | $Cr^{2+}$ | – 0.41 |
| $Fe^{2+} + 2e^-$ | $\rightarrow$ | $Fe(s)$ | – 0.44 |
| $Cr^{3+} + 3e^-$ | $\rightarrow$ | $Cr(s)$ | – 0.74 |
| $Zn^{2+} + 2e^-$ | $\rightarrow$ | $Zn(s)$ | – 0.76 |
| $2H_2O(l) + 2e^-$ | $\rightarrow$ | $H_2(g) + 2OH^-$ | – 0.83 |
| $Mn^{2+} + 2e^-$ | $\rightarrow$ | $Mn(s)$ | – 1.18 |
| $Al^{3+} + 3e^-$ | $\rightarrow$ | $Al(s)$ | – 1.66 |
| $Be^{2+} + 2e^-$ | $\rightarrow$ | $Be(s)$ | – 1.70 |
| $Mg^{2+} + 2e^-$ | $\rightarrow$ | $Mg(s)$ | – 2.37 |
| $Na^+ + e^-$ | $\rightarrow$ | $Na(s)$ | – 2.71 |
| $Ca^{2+} + 2e^-$ | $\rightarrow$ | $Ca(s)$ | – 2.87 |
| $Sr^{2+} + 2e^-$ | $\rightarrow$ | $Sr(s)$ | – 2.89 |
| $Ba^{2+} + 2e^-$ | $\rightarrow$ | $Ba(s)$ | – 2.90 |
| $Rb^+ + e^-$ | $\rightarrow$ | $Rb(s)$ | – 2.92 |
| $K^+ + e^-$ | $\rightarrow$ | $K(s)$ | – 2.92 |
| $Cs^+ + e^-$ | $\rightarrow$ | $Cs(s)$ | – 2.92 |
| $Li^+ + e^-$ | $\rightarrow$ | $Li(s)$ | – 3.05 |



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## ATOMIC STRUCTURE

$$E = h\nu \qquad c = \lambda \nu$$

$$\lambda = \frac{h}{m\upsilon} \qquad p = m\upsilon$$

$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

$E$ = energy
$\nu$ = frequency
$\lambda$ = wavelength
$p$ = momentum
$\upsilon$ = velocity
$n$ = principal quantum number
$m$ = mass

Speed of light, $c = 3.0 \times 10^8 \text{ m s}^{-1}$

Planck's constant, $h = 6.63 \times 10^{-34} \text{ J s}$

Boltzmann's constant, $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

Avogadro's number $= 6.022 \times 10^{23} \text{ mol}^{-1}$

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

1 electron volt per atom $= 96.5 \text{ kJ mol}^{-1}$

## EQUILIBRIUM

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

$$K_b = \frac{[\text{OH}^-][\text{HB}^+]}{[\text{B}]}$$

$$K_w = [\text{OH}^-][\text{H}^+] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\text{C}$$
$$= K_a \times K_b$$

$$\text{pH} = -\log[\text{H}^+], \ \text{pOH} = -\log[\text{OH}^-]$$

$$14 = \text{pH} + \text{pOH}$$

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

$$\text{pOH} = \text{p}K_b + \log\frac{[\text{HB}^+]}{[\text{B}]}$$

$$\text{p}K_a = -\log K_a, \ \text{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where $\Delta n$ = moles product gas − moles reactant gas

Equilibrium Constants

$K_a$ (weak acid)
$K_b$ (weak base)
$K_w$ (water)
$K_p$ (gas pressure)
$K_c$ (molar concentrations)

## THERMOCHEMISTRY/KINETICS

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= -RT\ln K = -2.303\,RT\log K$$
$$= -n\mathcal{F}E^\circ$$

$$\Delta G = \Delta G^\circ + RT\ln Q = \Delta G^\circ + 2.303\,RT\log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[\text{A}]_t - \ln[\text{A}]_0 = -kt$$

$$\frac{1}{[\text{A}]_t} - \frac{1}{[\text{A}]_0} = kt$$

$$\ln k = \frac{-E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

$S^\circ$ = standard entropy
$H^\circ$ = standard enthalpy
$G^\circ$ = standard free energy
$E^\circ$ = standard reduction potential
$T$ = temperature
$n$ = moles
$m$ = mass
$q$ = heat
$c$ = specific heat capacity
$C_p$ = molar heat capacity at constant pressure
$E_a$ = activation energy
$k$ = rate constant
$A$ = frequency factor

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Gas constant, $R = 8.31 \text{ J mol}^{-1}\text{ K}^{-1}$
$= 0.0821 \text{ L atm mol}^{-1}\text{ K}^{-1}$
$= 8.31 \text{ volt coulomb mol}^{-1}\text{ K}^{-1}$



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**GASES, LIQUIDS, AND SOLUTIONS**

$$PV = nRT$$

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \ldots$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = {}^\circ\text{C} + 273$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{\boldsymbol{M}}}$$

$$KE \text{ per molecule} = \frac{1}{2} m \upsilon^2$$

$$KE \text{ per mole} = \frac{3}{2} RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\boldsymbol{M}_2}{\boldsymbol{M}_1}}$$

molarity, $M$ = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

$P$ = pressure
$V$ = volume
$T$ = temperature
$n$ = number of moles
$D$ = density
$m$ = mass
$\upsilon$ = velocity

$u_{rms}$ = root-mean-square speed
$KE$ = kinetic energy
$r$ = rate of effusion
$\boldsymbol{M}$ = molar mass
$\pi$ = osmotic pressure
$i$ = van't Hoff factor
$K_f$ = molal freezing-point depression constant
$K_b$ = molal boiling-point elevation constant
$A$ = absorbance
$a$ = molar absorptivity
$b$ = path length
$c$ = concentration
$Q$ = reaction quotient
$I$ = current (amperes)
$q$ = charge (coulombs)
$t$ = time (seconds)
$E^\circ$ = standard reduction potential
$K$ = equilibrium constant

**OXIDATION-REDUCTION; ELECTROCHEMISTRY**

$$Q = \frac{[\text{C}]^c [\text{D}]^d}{[\text{A}]^a [\text{B}]^b}, \text{ where } a\,\text{A} + b\,\text{B} \rightarrow c\,\text{C} + d\,\text{D}$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{n\mathcal{F}} \ln Q = E^\circ_{\text{cell}} - \frac{0.0592}{n} \log Q \quad @\ 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

Gas constant, $R$ = 8.31 J $\text{mol}^{-1}\ \text{K}^{-1}$
= 0.0821 L atm $\text{mol}^{-1}\ \text{K}^{-1}$
= 8.31 volt coulomb $\text{mol}^{-1}\ \text{K}^{-1}$

Boltzmann's constant, $k$ = $1.38 \times 10^{-23}$ J $\text{K}^{-1}$

$K_f$ for $H_2O$ = 1.86 K kg $\text{mol}^{-1}$

$K_b$ for $H_2O$ = 0.512 K kg $\text{mol}^{-1}$

1 atm = 760 mm Hg
= 760 torr

STP = 0.00°C and 1.0 atm

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons