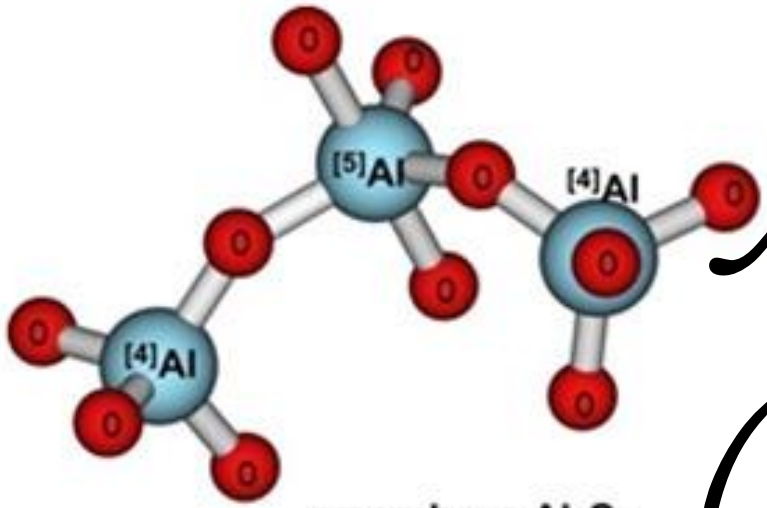
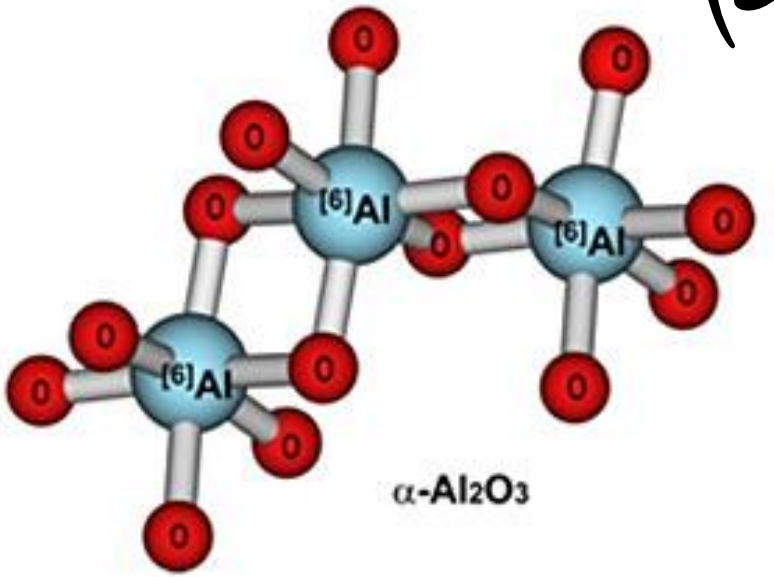


amorphous Al_2O_3



α-Al_2O_3

Aluminium (Aluminum) (Al)

pranjoto utomo

Amphoterism & Hydrolisis

- Hydration energy (-4665 $kJ.mol^{-1}$)
- Total ionization energy (+ 5137 $kJ.mol^{-1}$)
- Aluminium(II) ion:
  - Written as $[Al(H_2O)_6]^{3+}$
  - NOT as Al^{3+}

Amphoterism

- Amphoteric

$$2Al(s) + 6H_3O^+(aq) \rightarrow 2[Al(H_2O)_6]^{3+}(aq) + 3H_2(g)$$

$$2Al(s) + 2OH^-(aq) + 6H_2O(\ell) \rightarrow 2[Al(OH)_4]^-(aq) + 3H_2(g)$$

Hydrolisis

- Hydrolysis of aluminum ion (in base condition)

$$[Al(H_2O)_6]^{3+}(aq) + H_2O(l) \rightarrow [Al(H_2O)_5(OH)]^{2+} + H_3O^+(aq)$$

$$[Al(H_2O)_5(OH)]^{2+} + H_2O(l) \rightarrow [Al(H_2O)_4(OH)_2]^{+} + H_3O^+(aq)$$

$$[Al(H_2O)_4(OH)_2]^{+} + H_2O(l) \rightarrow [Al(H_2O)_3(OH)_3](s) + H_3O^+(aq)$$

Bauxite

Ore

- bauxite (hydrated aluminum oxide → an impure aluminum oxide)
- cryolite (Na_3AlF_6) → rare and expensive

Bauxite

- Composition of bauxite

  Al_2O_3 : 50 – 60%

  Fe_2O_3 : 1 – 20%

  silicon dioxide : 1 – 10%

  water : 20 – 30%

  (Ti, Zr, V) – oxide : minor concentration

Aluminum production

- Two processes
  - 1st : Bayer Process
    - convert bauxite into pure aluminum oxide
  - 2nd : Hall- Héroult process
    - electrolysis of aluminum oxide in solution of molten cryolite

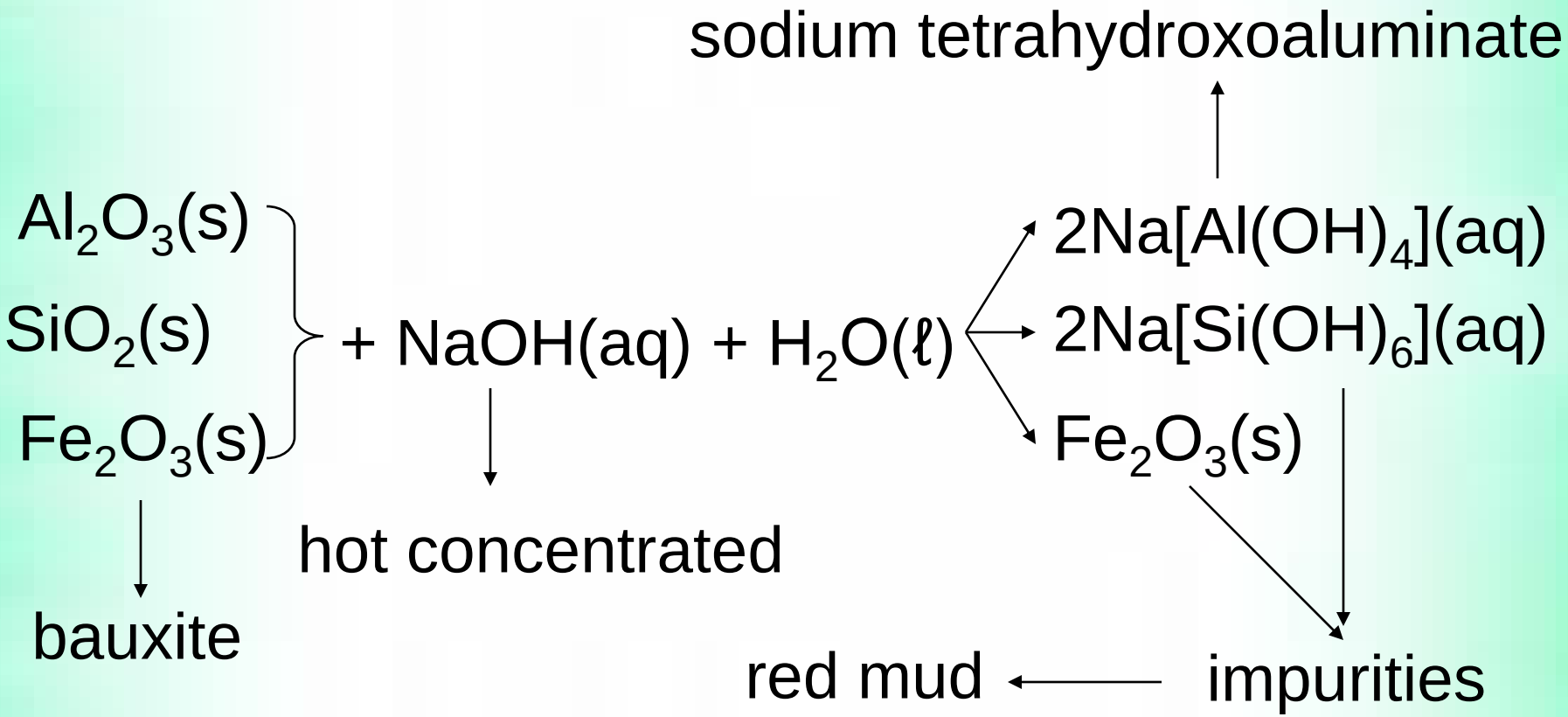
Bayer Process

- Bayer Process: purifiying the aluminum oxide
  - Reaction with sodium hydroxide solution
  - Precipitation of hydrated aluminum oxide
  - Calcination

Bayer Process

a. Reaction with sodium hydroxide solution
   - T>>
   - P>> (to keep the water in the sodium hydroxide solution liquid at T>100°C)

Bayer Process



Bayer Process

b. Precipitation of hydrated aluminum oxide

$$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$$

$$H_2CO_3(aq) + Na[Al(OH)_4](aq) \rightarrow Al_2O_3.3H_2O(s) + 2Na_2CO_3(aq) + 2H_2O(\ell)$$

Note $Al_2O_3 \cdot 3H_2O \approx 2\ Al(OH)_3$

$$Al_2O_3 \cdot 3H_2O\ (s) \rightarrow Al_2O_3\ (s) + 3H_2O\ (\ell)$$

Bayer Process

c. Calcination

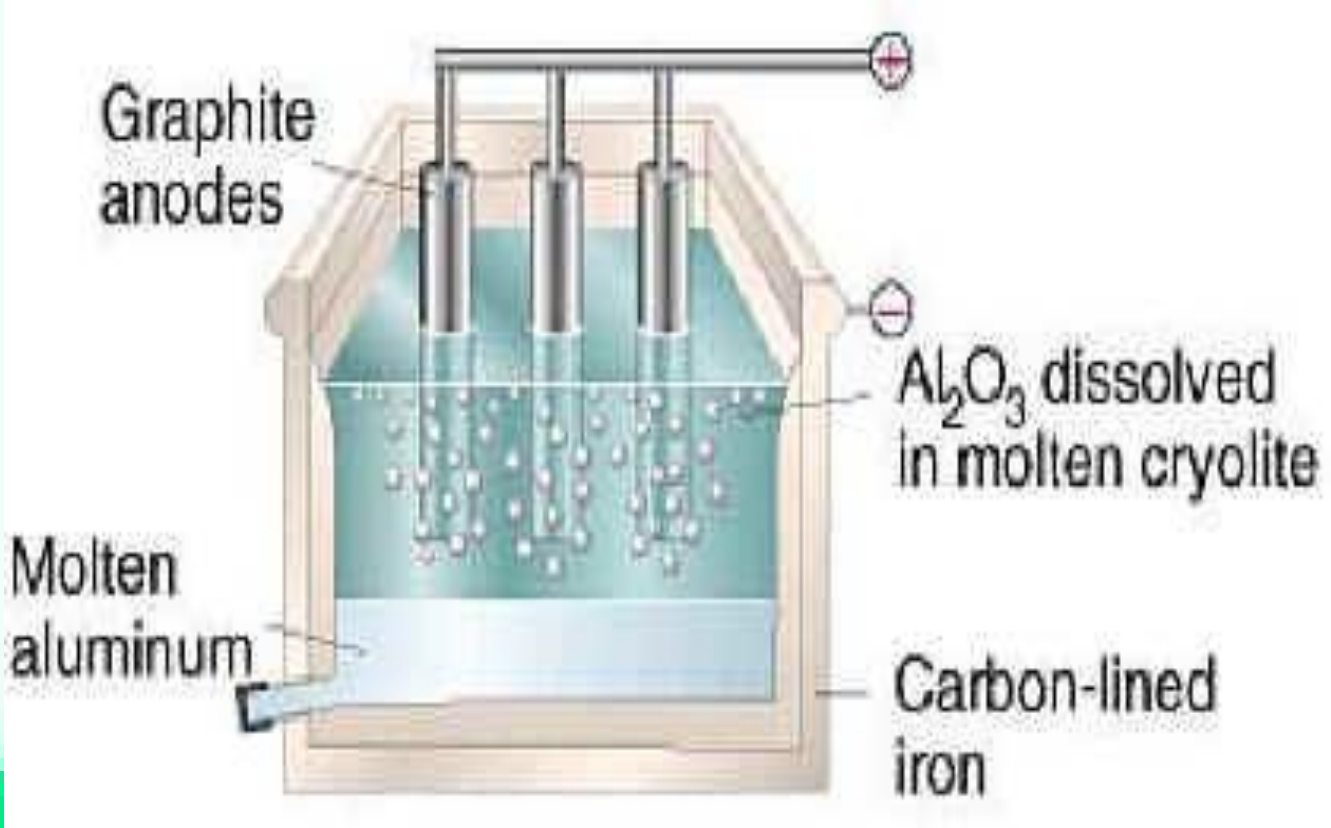
- Formation of pure aluminum oxide,
- T = 1100 – 1200^{o}C

$$Al_2O_3 \cdot 3H_2O(s) \rightarrow Al_2O_3\,(s) + 3H_2O(\ell)$$

corundum

Hall- Héroult process

- electrolysis of aluminum oxide to aluminum



Hall- Héroult process

- Cathode
  - carbon lining (steel) (the effective cathode is molten aluminum)
- Anode
  - carbon (graphite)

Hall- Héroult process

The electrode reactions

- Anode:

$$6O^{2-} \rightarrow 3O_2(g) + 12e^-$$

- Catodhe

$$4Al^{3+} + 12e^- \rightarrow 4Al(\ell)$$

- Net

$$2Al_2O_3(\ell) \rightarrow 4Al(\ell) + 3O_2(g)$$

Hall- Héroult process

The electrode reactions

- Aluminium is deposited in cathode
- Oxygen is initially produced at the anode
- Oxygen that produced,
  - Burn the anode yield CO_2 and CO
  - Anode must be placed (major expense)

Hall- Héroult process

- To produce 1 kg aluminum need:
  - 2 kg aluminum oxide
  - 0,6 kg graphite
  - 0,1 kg cryolite
  - 16 kWh electric power

The uses of aluminium

- aluminum is usually alloyed with other elements such as silicon, copper or magnesium. Pure aluminum isn't very strong, and alloying it adds to it strength.
- aluminum is especially useful because it
  - has a low density (2,73 g cm^{-3});
  - is a good conductor of electricity (worse than copper)

The uses of aluminium

- aluminum is especially useful because it
  - is strong when alloyed;
  - has a good appearance;
  - resists corrosion because of the strong thin layer of aluminum oxide on its surface. This layer can be strengthened further by anodizing the aluminum.

The uses of aluminium

- Mixture of rocket fuel (NH_4ClO_4 + Al)

  $2\ NH_4ClO_4 \rightarrow\ N_2(g) + Cl_2(g)\ +\ 4\ H_2O(g)$

  $\Delta H = -376{,}7\ kJ\ mol^{-1}$

  $½\ Al\ +\ 1½\ O_2 \rightarrow Al_2O_3$

  $\Delta H = -1670\ kJ\ mol^{-1}$

- once gas expanded → lift the rocket

The uses of aluminium

- Railway welding (a termite reaction)

  $Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(\ell) + Fe(\ell)$

  $\Delta H = -852 kJ\ mol^{-1}$

  $T \approx 3000^oC$

- Water purification (potash aluminum sulfate, $KAl(SO_4)_2.12H_2O$) and dyer

  $Al^{3+}(aq) + SO_4^{2-}(aq) + Ca^{2+}(aq) + 3OH^- \rightarrow Al(OH)_3(s) + CaSO_4(s)$

The uses of aluminium

- Extinguisher (+$NaHCO_3$)

  $Al^{3+} + 6H_2O \rightarrow Al(OH)_3 + 3H_3O^+$ (x1)

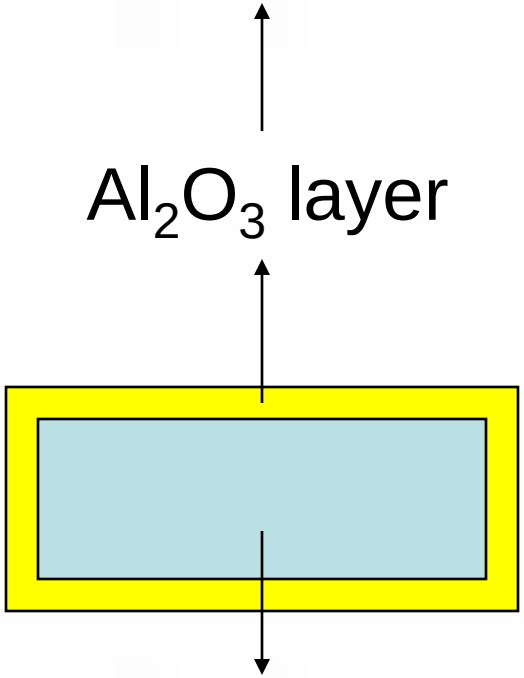
  $H_3O^+ + HCO_3^- \rightarrow 2H_2O + CO_2$ (x3)

  $Al^{3+} + 3HCO_3^- \rightarrow Al(OH)_3(s) + 3CO_2(g)$

- $Al(OH)_3 + CO_2$:
  - Foam
  - Cover the fire

Corrosion resistance

non-porous layer ?



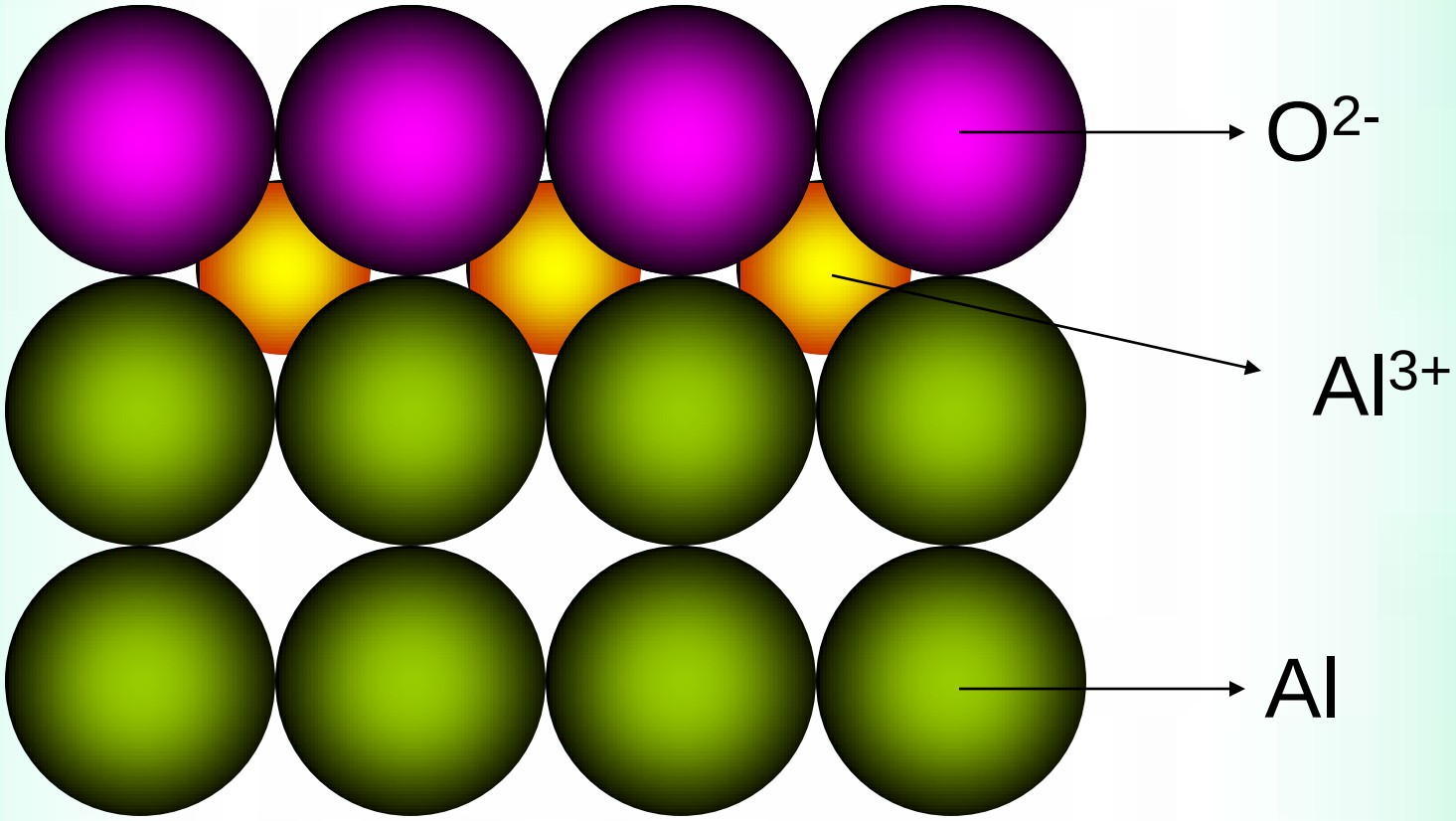
Al_2O_3 layer

Aluminium metal

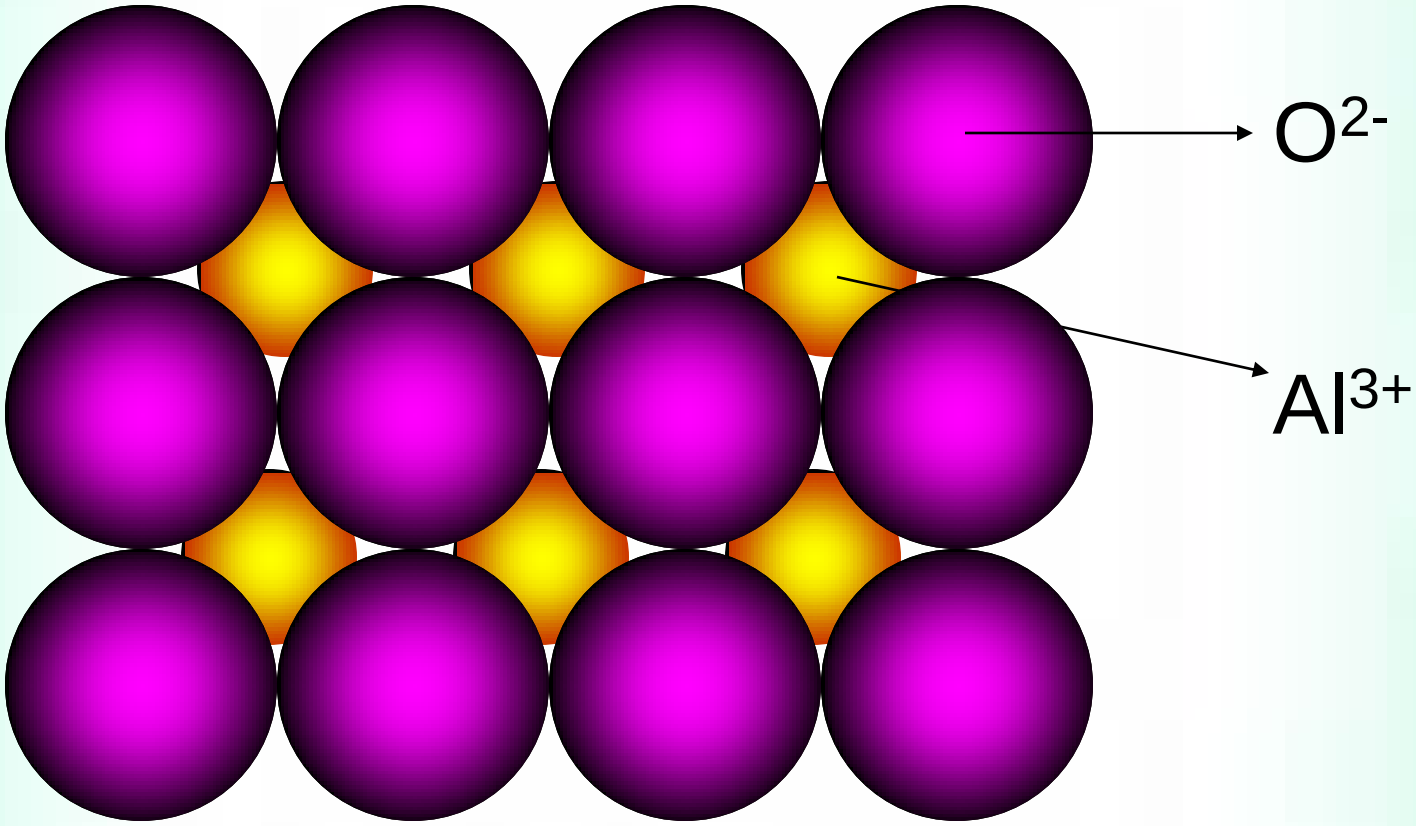
Corrosion resistance

- Ionic radii of O^{2-} ion = 124 pm
- Metallic radii of Al = 143 pm
- Ionic radii of Al^{3+} ion = 68 pm

Corrosion resistance



The formation of monolayer of Al_2O_3 on aluminum surface



The formation of monolayer of Al_2O_3 on aluminum surface

Anodizing of aluminum

- aluminum oxide-coated aluminum by electrolysis
- Cathode : carbon (graphite)
- Anode : aluminum
- Electrolyte : dilute sulfuric acid

Anodizing of aluminum

Reactions:

- Cathode:

$$6H_3O^+(aq) + 6e^- \rightarrow 6H_2O(\ell) + 3H_2(g)$$

- Anode :

$$2Al(s) \rightarrow 2Al^{3+}(aq) + 6e^-$$

$$2Al^{3+}(aq) + 9H_2O(\ell) \rightarrow Al_2O_3(s) + 6H_3O^+(aq)$$

- Net: $2Al(s) + 3H_2O(\ell) \rightarrow Al_2O_3(s) + 3H_2(aq)$

Aluminium coloring by anodazing

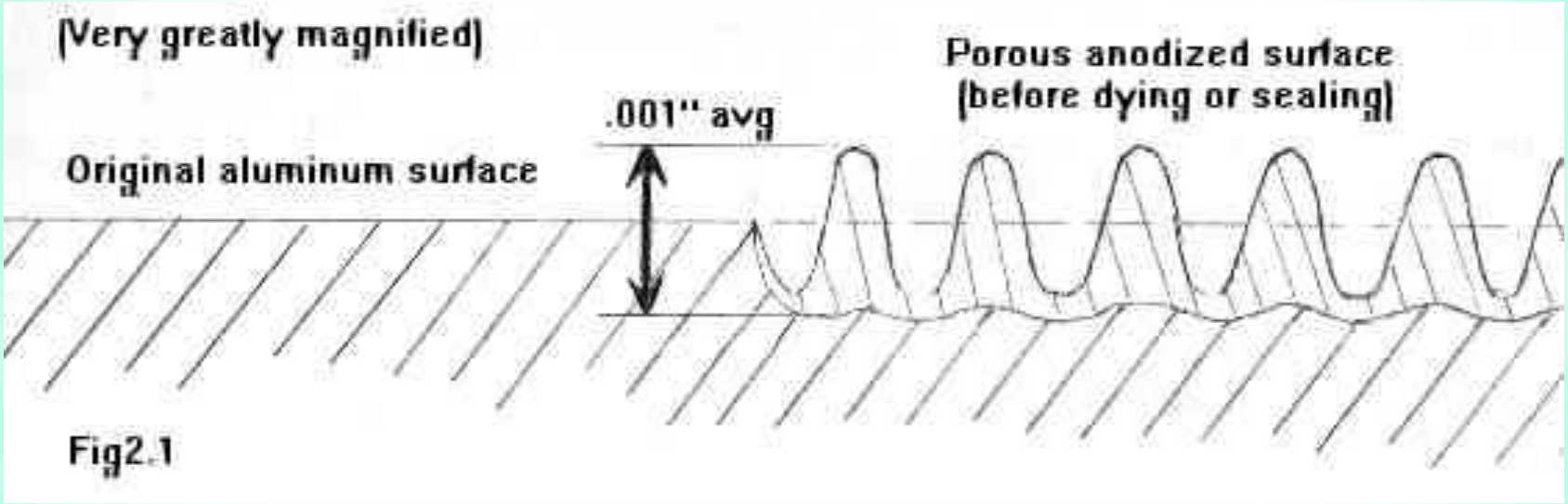


Fig2.1

Aluminium coloring by anodazing

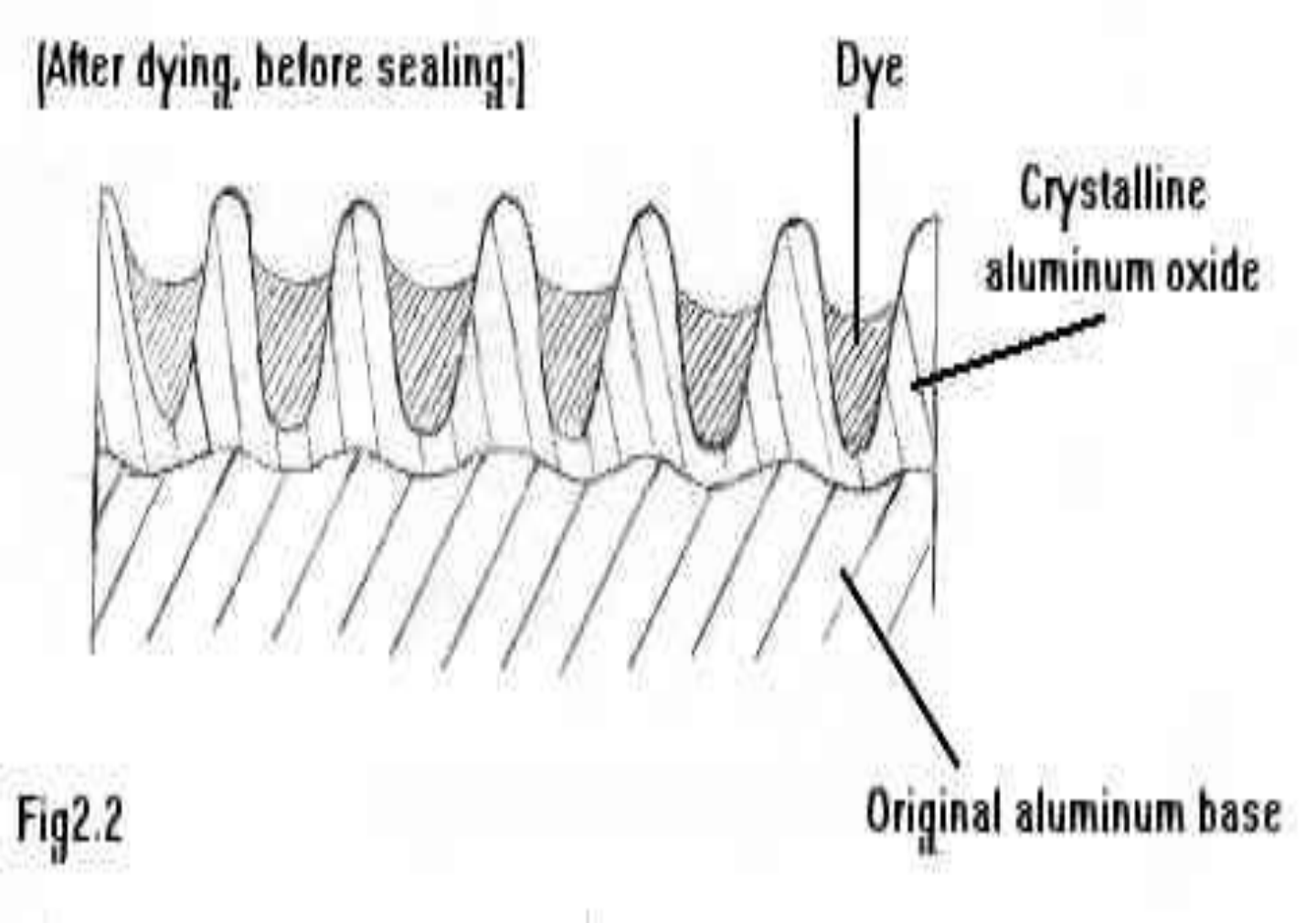


Fig2.2

Aluminium coloring by anodazing

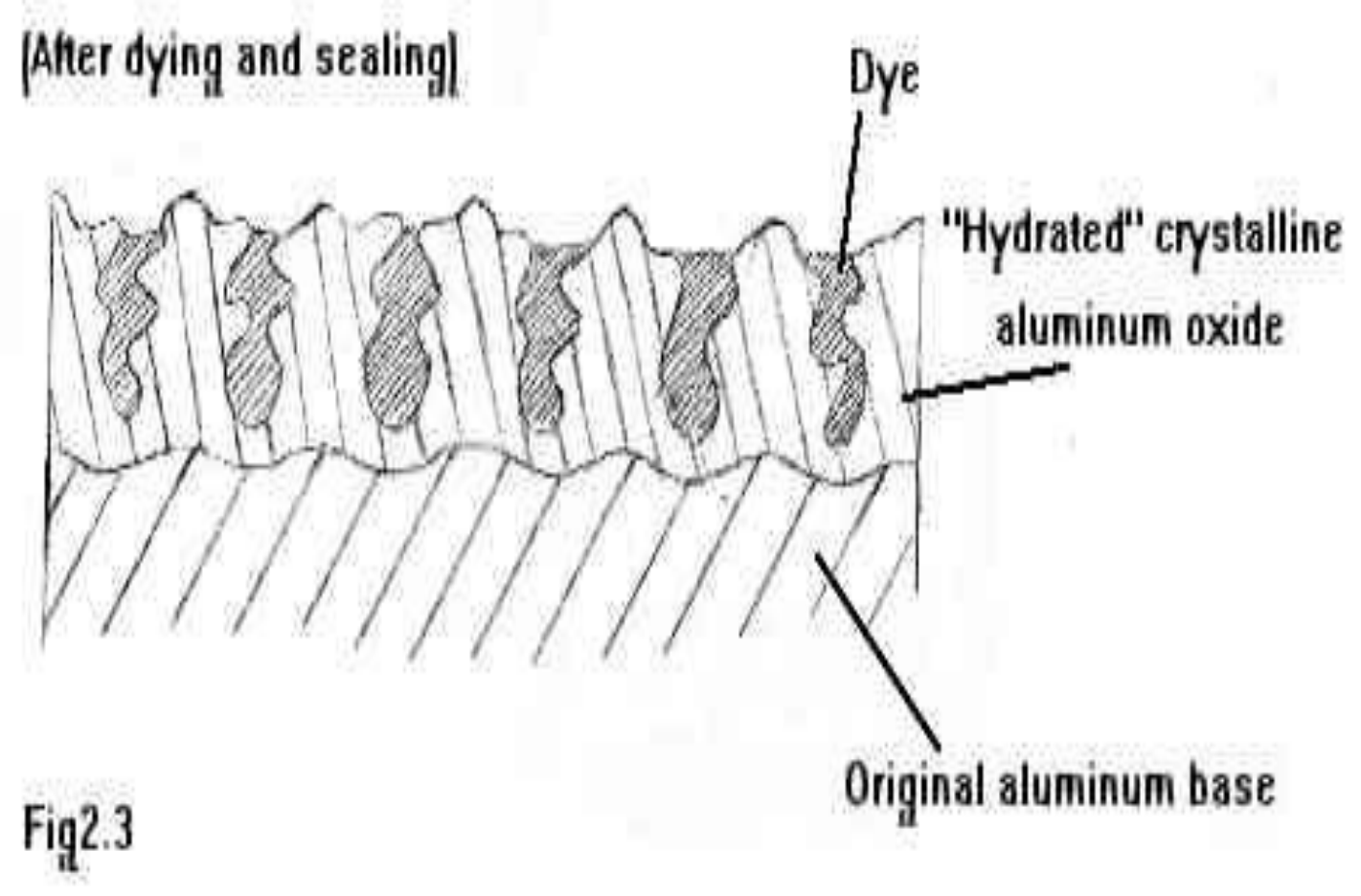


Fig2.3

Aluminum production scheme