INTERDISIPLIN
Journal of Qualitative and Quantitative Research

ISSN: 3031-4828 | Vol. 2 No. 4 (2025)
DOI: https://doi.org/10.61166/interdisiplin.v2i4.120 | pp. 264-273

Research Article

Properties, Preparation, and Application of Magnesium

Sayyed Abdul Halim Tawana[1], Shafiullah Arghandiwal[2]

1. Department of Chemistry, Education Faculty, Parwan University, Parwan, Afghanistan; tawanasah@gmail.com
2. Department of Chemistry, Education Faculty, Parwan University, Parwan, Afghanistan; shafiullaharghandiwal333@gmail.com

Received : May 15, 2025 | Revised : June 17, 2025
Accepted : July 13, 2025 | Available online : August 16, 2025

How to Cite: Sayyed Abdul Halim Tawana, & Shafiullah Arghandiwal. (2025). Properties, Preparation, and Application of Magnesium. *INTERDISIPLIN: Journal of Qualitative and Quantitative Research*, 2(4), 264–273. https://doi.org/10.61166/interdisiplin.v2i4.120

Abstract. This article reviews comprehensively the chemistry of magnesium, its properties, preparation and applications in various fields. Starting with an overview of its characteristics; chemical and physical to the metal's discovery through the ages with electrochemical and thermal routes to the modern large-scale production processes. Magnesium's sources, alongside conventional mining and concentration techniques for magnesite, dolomite, carnallite, and marine brines are disscussed. Extraction technics; electrolysis and thermal reduction are presented. Then, the article explores magnesium and its alloys principal applications: its metallurgical, electrochemical, pyrotechniques and its compounds application. By combining historical context, processing chemistry, and end-use performance, this article highlights magnesium's marvelous importance and brings opportunities for future technological advances.

Keywords: magnesium, dolomite, magnisite, carnalite, seawater extraction, dry-cell batteries, pyrotechnics

INTRODUCTION

Magnesium is the first of the truly marvelous structural metals. It is moderately priced, strong, light, and easy to cast into machine. Its highly flammability is the only downside it has (Gray, 2009). Magnesium (Mg) is a shiny grayish white metal that has a similar appearance to aluminum (Al) and a 1/3 weight (figure 1). It is the lightest metal of all with the density of 1.74 g/cm^3) compared to Al (2.70 g/cm^3). With a m.p. and b.p. of 649 and 1090 ^{o}C respectively, it has a hexagonal close-packed (hcp) crystalline structure (Rayner-Canham and Overton, 2010). In addition, Mg has excellent machinability, and it can be cast or fabricated by any of the standard metallurgical methods (rolling, extruding. drawing, forging. welding, brazing or riveting). Its major use therefore is as a light-weight construction metal, not only in aircraft but also in luggage, photographic and optical equipment, etc. It is also used for cathodic protection of other metals from corrosion, as an oxygen scavenger, and as a reducing agent in the production of Be, Ti. Zr, Hf and U (Greenwood and Earnshaw, 1997).

In its pure form, it lacks sufficient strength for most structural applications. However, the addition of alloying elements improves its properties to such an extent that both cast and wrought magnesium alloys are widely used, particularly where light weight and high strength are important (Hoy-Peterson and Rizley, 2025). Magnesium alloys typically contain > 90% Mg together with 2-9% Al, 1-3% Zn and 0.2- 1% Mn. Greatly improved retention of strength at high temperature (up to 450°C) is achieved by alloying with rare-earth metals (e.g. Pr/Nd) or Th. These alloys can be used for automobile engine casings and for aeroplane fuselages and landing wheels. Other uses are in light-weight tread-plates, dock-boards, loading platforms, gravity conveyors and shovels. Up to 5% Mg is added to most commercial Al to improve its mechanical properties, weldability and resistance to corrosion (Kirk-Othmer, 1995).

Figure 1. Laboratory pure sample of Mg (Dingle, 2018).

At high temperatures; above 645 °C in dry air, magnesium metal burns with a bright intense white light and heat. So intense that the light can damage the retina of the eye. For this reason, magnesium powders are used in pyrotechnics. Magnesium is stable at room temperature, because a stable film of water-insoluble magnesium hydroxide, $Mg(OH)_2$, forms on the metal's surface, protecting it from corrosion in most atmospheres. Chemical reactivity of Mg is recognised in its compounds that have numerous application in industry, medicine, and agriculture (Rayner-Canham and Overton, 2010).

LITERATURE REVIEW

The name of magnesium is derived from Magnesia, a district of Eastern Thessaly in Greece. An impure sample of magnesium metal was isolated by Anton Rupprecht in 1792 by heating magnesia with charcoal (royal society of chemistry, 2025). However, Sir Humphry Davy the British chemist, isolated magnesium, in 1808 by the electrolysis of MgO in the presence of HgO. He electrolyzed moist magnesium sulfate using mercury as a cathode and produced an amalgam of magnesium (Garg and Singh, 2015 and Hoy-Peterson and Rizley, 2025). Antoine-Alexandre-Brustus Bussy, the French scientist made a sizeable chunk of magnesium metal in 1831 from the reaction of $MgCl_2$ with K and studied his properties (royal society of chemistry, 2025). In 1833 the English scientist Michael Faraday produced magnesium by the electrolysis of molten $MgCl_2$. The German chemist, Robert Bunsen reproduced this experiment and isolated Magnesium (Hoy-Peterson and Rizley, 2025).

Magnesium is produced on a large scale (400,000 tonnes in 1985) either by electrolysis or silicothermal reduction. The major producers are the USA (43%), the former Soviet Union (26%), and Norway (17%). The electrolytic process uses either fused anhydrous $MgCl_2$ at 750°C or partly hydrated $MgCl_2$ from sea water at a slightly lower temperature. The silicothermal process uses calcined dolomite and ferrosilicon alloy under reduced pressure at 1150°C:

$$2(MgO.CaO) + FeSi \rightarrow 2Mg + CaZSiO_4 + Fe$$

Magnesium and its alloys, being light and strong to weight ratio have several important applications in the military because of these properties which are crucial for enhancing the performance and efficiency of military equipments. Post the world wars, Chemical advanced civilian markets by developing wrought products, photoengraving technology, and surface treatment systems. Extraction still is based on electrolysis and thermal reduction. These processes were pollished and refined as the internal heating of retorts, extraction from dehydrated magnesium chloride prills, and improvements in electrolytic cell technology from about 1970. Till 2019, China has produced about 85% of the world's Mg, and much of the rest being isolated Russia, Kazakhstan, Israel, and Brazil (Greenwood and Earnshaw, 1997 and Hoy-Peterson and Rizley, 2025).

Sources of Magnesium

The eighth most abundant element in earth's crust with 2.4% and the third most abundant element dissolved in seawater; it is commercially extracted from seawater and from the mineral dolomite, $CaCO_3{\cdot}MgCO_3$. Because of its strong reactivity, it does not occur in the native state, but rather it is found in a wide variety of compounds in seawater, brines, and rocks (Shriver et al., 2014).

Magnesium occurs in crustal rocks mainly as the insoluble carbonates and sulfates, and (less accessibly) as silicates. Among the ore mineral, large land masses such as the Dolomites in Italy consist predominantly of [$MgCa(CO_3)_2$], and there are substantial deposits of magnesite ($MgCO_3$), epsomite ($MgSO_4.7H_2O$) and other evaporites such as carnallite (a compound of magnesium and potassium chlorides and water, $MgCl_2{\cdot}KCl{\cdot}6H_2O$) and langbeinite [$K_2Mg_2(SO_4)_3$]. Silicates are represented by the common basaltic mineral olivine [$(Mg,Fe)_2SiO_4$] and by soapstone (talc) [$Mg_3Si_4O10(OH)_2$], asbestos (chrysotile) [$Mg_3Si_2O_5(OH)_4$] and micas. Spinel ($MgA1_2O_4$) is a metamorphic mineral and gemstone. The green leaves also contain Mg in its chlorophyl, which is not a commercial source (Greenwood and Earnshaw, 1997).

Magnesium chloride can be isolated from naturally occurring brines such as the Great Salt Lake (1.1% by weight magnesium) and the Dead Sea (3.4%), but by far the largest source is the oceans of the world. Although seawater is only approximately 0.13% magnesium, it represents an almost inexhaustible source (Hoy-Peterson and Rizley, 2025).

Isolation of Magnesium

The seas are a storehouse of chemicals; several metal salts exist in the water and also at the bottom of seas. Sodium and magnesium salts occur abundantly in brine. The isolation of magnesium from seawater is as follow:

Seawater + $CaO(s) \rightarrow Ca(OH)_2 + Mg^{2+}$ (in the seawater) $\rightarrow Mg(OH)_2(s)$ (this is filtered and then HCl is added) $\rightarrow MgCl_2(ag)$ (after evaporation) $\rightarrow MgCl_2(s)$ (after eletrolysis) $\rightarrow$ Mg metal (Gopalan, 2012).

It occurs in substantial deposits such as dolomite, magnesite and carnalite. It is obtained in many ways. Dolomite is an important source from which, after calcination, the calcium is removed by ion exchange using seawater. The most important processes for preparation of magnesium are (a) the electrolysis of fused halide mixtures (e.g., $MgCl_2 + CaCl_2 + NaCl$), and (b) the reduction of MgO or of calcined dolomite (MgO.CaO). The latter is heated with ferrosilicon:

$$CaO.MgO + FeSi \rightarrow Mg + \text{silicates of Ca and Fe}$$

and the magnesium is distilled out. MgO can be heated with coke at 2000° to get Mg metal:

$$MgO + C \rightarrow Mg + CO$$

Magnesium, which currently sells for about twice the price of aluminum, may in the long run replace it in many applications because the supply available in seawater is virtually unlimited (Cotton and Wilkinson, 1980 and National Technical Information Service).

Mining and Concentrating

Both dolomite and magnesite are mined and concentrated by conventional methods. Carnallite is dug as ore or separated from other salt compounds that are brought to the surface by solution mining. Naturally occurring magnesium-containing brines are concentrated in large ponds by solar evaporation (Hoy-Peterson and Rizley, 2025).

Extraction and refining

Magnesium which is very reactive forms stable compounds by reacting with oxygen and chlorine in the liquid and gaseous states also. Therfore, the extraction of magnesium from minerals needs a lot of energy and the process requires well-tuned technologies. Commercial production follows two completely different methods: electrolysis of magnesium chloride or thermal reduction of magnesium oxide through the Pidgeon process (Cotton and Wilkinson, 1980 and Hoy-Peterson and (Rizley, 2025).

Electrolysis

Electrolytic processes consist of two steps: the preparation of a feedstock containing magnesium chloride and the dissociation of this compound into magnesium metal and chlorine gas in electrolytic cells (Hoy-Peterson and Rizley, 2025).

The extraction from seawater relies on the fact that magnesium hydroxide is less soluble than calcium hydroxide because the solubility of the salts of mononegative anions increases down the group. Either CaO (quicklime) or $Ca(OH)_2$ (slaked lime) is added to seawater and $Mg(OH)_2$ precipitates. The hydroxide is converted to the chloride by treatment with hydrochloric acid:

$$CaO(s) + H_2O(l) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

$$Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(s)$$

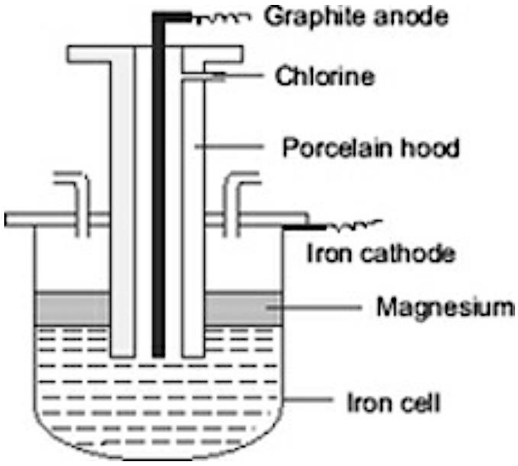
$$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$$

The magnesium is then extracted by electrolysis of molten magnesium chloride:

Cathode: $Mg^{2+}(aq) \rightarrow 2e^- + Mg(s)$
Anode: $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$
(Shriver et al., 2014).

In the case of electrolysis of the dolomite ore, it is calcined and treated with HCl to obtain precipitate of $CaCO_3$ and a solution of $MgCl_2$ which is needed for electrolysis. In case of carnallite ore, equal quantity of the ore is fused with sodium chloride at 973 K and used for electrolysis. The metal thus obtained is 99.9%pure (figure 2).

Figure 2. electrolysis of $MgCl_2$ (Garg and Singh, 2015).



Thermal reduction

Magnesium is also extracted from dolomite. At first, it is heated in an open air to obtain MgO and CaO. This mixture along with FeSi is heated and calcium silicate, Ca_2SiO_4, Fe, and Mg is formed. In this process and temperatures, Mg is in the liquid state and removed by distillation (Shriver et al., 2014).

$$2CaO + 2MgO + FeSi \rightarrow Ca_2SiO_4 + Fe + Mg$$

Magnesium can also be isolated from the ore magnesite. The ore is pulverised and calcined to prepare MgO which on reaction with carbon at about 2270 K gets vapors of the metal. Temperature is decreased to 470 K to obtain solid condensate of magnesium which is further purified by redistillation (Garg and Singh, 2015).

Applications of the metal and its alloys

Primary magnesium is available in 99.90, 99.95, and 99.98% of purity grade, but, in practice, 99.95 and 99.98% grades of purity have only limited use in the uranium and nuclear industries. For the rest use, 99.90 and 99.80% of grades purity are supplied (Hoy-Peterson and Rizley, 2025).

Since Mg has a low density ($1.7 gcm^{-3}$ compared with 2.70 for Al and 7.80 for steel), its best alloy weighs one quarter of a steel with the same strength. While the best alloy of Al weighs about 1/3 of a steel. Apart from this, Magnesium has great machinability, and it can be cast by any of the standard metallurgical methods (rolling, extruding. drawing, welding, or etc). therefore, its major application is as a light-weight construction metal, not only in aircraft and vehicles and also in luggage, photographic and optical equipment, etc. It is also used for cathodic protection of other metals from corrosion, as an oxygen scavenger, and as a reducing agent in the production of Be, Ti. Zr, Hf and U (Greenwood and Earnshaw, 1997).

Metallurgical applications

The greatest use of Mg is in the alloying with the aluminum metal. In amounts ranging from less than 1% to approximately 10%, magnesium enhances the mechanical properties as well as the corrosion resistance of aluminum alloys. Magnesium alloys generally have more than 90% Mg together with 2-9% Al, 1-3% Zn and 0.2-1% Mn. Improved retention of strength at high temperature (up to 450°C) is achieved by alloying of magnesium metal with rare-earth metals (e.g. Pr/Nd) or Th. These alloys can be used for automobile engine casings and for aeroplane fuselages and landing wheels among other uses. Similarly, pure aluminum is used as an alloying element in many magnesium-based alloys. Up to 5% magnesium is added to most commercial Aluminium to enhance its properties such as mechanical properties, weldability and resistance to corrosion (Kirk-Othmer, 1995 and Hoy-Peterson and Rizley, 2025).

In the iron and steel industry, little amounts of Mg are to white cast iron to improve the strength and ductility and malleability of it, and it also enhances the mechanical properties of Steel (Hoy-Peterson and Rizley, 2025).

Magnesium is also used in the production of Ti, Zr, U and Hf. The most important use of magnesium is in the Kroll process in which magnesium is used for reducing titanium tetrachloride to titanium metal (Gopalan, 2012).

Electrochemical applications

Magnesium has a -2.37 (V) reduction potential value, which shows its electronegative nature and ease of its electron donations. This property makes it very useful in dry-cell batteries and as a sacrificial anode in the cathodic protection of steel (Gopalan, 2012).

In dry cells, magnesium is used as an anode and silver chloride, or cuprous chloride is used as a cathode. These cells are ideal for underwater and emergency applications such as; autonomous underwater vehiclas (AUWs), marine sensors and submersible instruments because it is activated by water or brine. Its high energy density, lightweight, long shelf life and operations in extreme temperatures makes it very suitable for usage in military, emergency radios, signal flares and critical rescue missions' equipment among many other applications (Li, 2022 and Wikipedia, 2025).

Pyrotechnics

Magnesium has found a use in pyrotechnics for its intense brightness, high combustion temperature, and reactivity, which makes it an important ingredient in both visual effects and functional devices. It is used in military and emergency flares to produce intense, long-lasting light, used in the rescue missions or combat zones. It is also central to high-visibility fireworks for its intense white flames. In incediary devices, magnesium is used for its intense heat for the igniting fires (Chant, 2024).

Chemical compounds

Magnesium metal forms a group of very important chemicals that has a veriety of applications. The best-known medical compounds are milk of magnesia, or magnesium hydroxide ($Mg(OH)_2$, which is used as an antacid or as a mineral supplement to maintain the body's magnesium balance. Sodium carbonate mixed with a solution of Epsom salt is also used as an antiacid laxative under the name magnesia alba. The hydrous magnesium sulfate also known as Epsom salts,

$MgSO_4 \cdot 7H_2O$, is used as a laxative. It is also used a purgative and is an important reagent in the laboratory. Magnesium peroxide (MgO_2) is used as an antiseptic in toothpastes. Magnesium oxide is used as a refractory and as air insulator (when mixed with asbestos). A mixture of MgO with a saturated solution of $MgCl_2$ is used for dental stoping which is known under the name sorel's cement. Grignard reagent, RMgX, a very important organic reagent is widely used in organic chemistry for the preparations of many important organic compounds (Garg, 2015 and Hoy-Peterson and Rizley, 2025).

RESULTS AND DISCUSSIONS

1. Extraction and Prepartion of Magnesium

Electrolysis of molten $MgCl_2$ yields magnesium metal with the purity above 99.9%. By contrast, the thermal (Pidgeon) process prepares 99.8% pure metal, making it more favorable in regions with inexpensive thermal sources.

2. Development of Magnesium's Alloys and Mechanical Performance

Magnesium alloys of 2–9% aluminum, 1–3% zinc, and trace manganese exhibit tensile strengths and considerable enhanced resistance at high temperatures (up to 300°C) when alloyed with rare-earth elements such as praseodymium and neodymium. These alloys achieve weight savings compared to aluminum alloys with comparable weights, while maintaining comparable shellf-life and resistance to corrosion.

3. Electrochemical Performance in Batteries

Dry-cells batteries are ideal for underwater and emergency applications. It is activated by water or brine, then it is ideal for autonomous underwater vehiclas, marine sensors and submersible instruments. Its high energy density, lightweight, long shelf life and operations in extreme temperatures makes it very suitable for usage in military, emergency radios, signal flares and critical rescue missions' equipment among many other applications.

4. Pyrotechnic Efficacy

Magnesium powders used in illumination flares burn at very high temperatures producing luminous intensities, which is twice that of aluminum-based formulations. Sparkler compositions with 20–30% magnesium deliver rapid spark generation and enhanced white-flash duration, improving visibility in both civilian and military signaling applications.

5. Chemical Compound Production

Production of magnesium hydroxide via seawater precipitation yields over 95% crystalline $Mg(OH)_2$, suitable for pharmaceutical and environmental applications. Conversion of $Mg(OH)_2$ to magnesium chloride for electrolysis achieves 98% efficiency, with hydrochloric acid recovery through diffusion dialysis reducing reagent costs by 20%. Sorel's cement formulations combining MgO and $MgCl_2$ deliver compressive strengths, rivaling Portland cement in non-structural applications.

CONCLUSION

This review brings in focus the importance, performance, efficiency, and sustainability of magnesium application and production. Isolation technics, i.e., electrolysis and the Pidgeon process both offer unique trade-offs in purity, energy use, and environmental impact. Alloys of magnesium shows the outstanding strength-to-weight ratios, finds sues in aerospace and automotive sectors. Electrochemical systems reveal promising energy-storage potential, albeit with challenges in rechargeability. Pyrotechnic uses large amounts of magnesium's luminous combustion, while compounds of magnesium find roles in industry and healthcare. Future advances in renewable-powered extraction, alloy design, and battery chemistries are poised to expand magnesium's contribution to lightweight, high-performance, and low-carbon technologies.

REFERENCE

Chant, Justin. (2024). 10 Chemicals Used in Fireworks and Pyrotechnics. Accessed from Monarch Chemical in July 30 from https://www.monarchchemicals.co.uk/Information/News-Events/1014-/10-chemicals-used-in-fireworks-and-pyrotechnics

Cotton, F. Albert, Wilkinson, Geoffrey. (1980). Advanced Inorganic Chemistry: A Comprehensive Text. 4th edition. John willey and Sons, New York.

Dingle, Adrian. (2018). The Elements: Discover the chemical elements that make up the periodic table and learn about their properties and uses. DK Eyewitness. Penquin Random House, London

Garg, Rajini and Singh, Randhir. (2015). Inorganic Chemistry. McGraw Hill Education (India) Private Ltd., New Delhi

Gopalan, R. (2012). A Textbook of Inorganic Chismistry. University Press. New Delhi

Gray, Theodore. (2009). The Elements: A Visual Exploration of Every Known Atom in the Univers. Black Dog and Leventhal Publications. New York

Greenwood, N. N. and Earnshaw, A. (1997). Chemistry of Elements. 2nd edition. Butterworth Heinemann. Oxford

Hoy-Peterson, Nils and Rizley, John H. (2025). Magnesium Processing, Accessed from Britanica in 29th of July from https://www.britannica.com/technology/magnesium-processing

Kirk-Othmer *Encyclopedia* of *Chemical Technology,* 4th edn., 1995, Vol. 15, pp. 622-74.

Li, Lucky. (2022). Development of magnesium battery – applications and difficulties, accessed from Tycorun in 31 of July 2025 from https://www.takomabattery.com/magnesium-battery/#Application-of-magnesium-battery

Periodic Table. (2025). Magnesium. Accessed from Royal Scociety of Chemistry in 28th of July from https://periodic-table.rsc.org/element/12/magnesium

Rayner-Canham, Geoff and Overton, Tina. (2010). Descriptive Inorganic Chemistry. 5th edition. W.H. Freeman and Company. New York

Shriver, Duward, Weller, Mark, Overton, Tina, Rourke, Jonathan and Armstrong, Fraser. (2014). Inorganic Chemistry. 6th edition. W. H. Freeman and Company. Britain

Trends in the Usage of Magnesium, National Technical Information Service, Springfield, Va. 22161, Report No. PB254, 1976.

Wikipedia. (2025). Magnesium battery. Accessed from Wikipedia in 31 of July 2025 from https://en.wikipedia.org/wiki/Magnesium_battery