Neodymium Magnets Handbook

1. Introduction

This handbook is designed to provide the fundamental basics of magnetic materials, magnets properties, methods of manufacture, and costing so that the user has adequate knowledge when deciding what type or grade of material should be used in various applications.

Magnets are mainly used to help in the conversion of energy.
For example:
Mechanical to Electrical, such as in generators, sensors and microphones
Electrical to Mechanical, such as in motors, actuators and loudspeakers
Mechanical to Mechanical, such as for couplings, bearing and holding devices

Neodymium permanent magnet materials:

2. Neodymium Magnets - Rare Earth Magnets

Neodymium iron boron ($Nd_2Fe_{14}B$), also known as Neo or NIB, is a type of rare earth magnetic material. NdFeB is the strongest and most controversial magnets. They are in the rare earth family because of the Nd, B, Dy, Ga elements in their composition.
NdFeB magnets have the highest energy approaching 52MGOe. Unprotected NdFeB magnets are subject to corrosion. Coating/Plating are developed to overcome this disadvantages. Coating/Plating materials include nickel, copper, silver, gold, zinc, tin and epoxy resin etc. Typical coating is NiCuNi (Nickel).

3. Magnetic Grades

Neodymium Magnets Grade

Type	Grade	Residual Induction /BR(Gauss)	Coercive Force/Hc (Oe)	Intrinsic Coercive Force/Hci (Koe)	Max.Energy Product/Bhmax (MGOe)	Maximum Operating Temp (°C/°F)	Curie Temp (°C/°F)
N	N35	11700	10900	12	35	80/176	310/590
N	N38	12200	11300	12	38	80/176	310/590
N	N40	12500	11400	12	40	80/176	310/590
N	N42	12800	11500	12	42	80/176	310/590
N	N45	13200	11600	12	45	80/176	310/590

N	N48	13800	11600	12	48	80/176	310/590
N	N50	14000	10000	11	50	60/140	310/590
N	N52	14300	10000	11	52	60/140	310/590
M	N33M	11300	10500	14	33	100/212	340/644
M	N35M	11700	10900	14	35	100/212	340/644
M	N38M	12200	11300	14	38	100/212	340/644
M	N40M	12500	11600	14	40	100/212	340/644
M	N42M	12800	12000	14	42	100/212	340/644
M	N45M	13200	12500	14	45	100/212	340/644
M	N48M	13600	12900	14	48	100/212	340/644
M	N50M	14000	13000	14	50	100/212	340/644
H	N35H	11700	10900	17	35	120/248	340/644
H	N38H	12200	11300	17	38	120/248	340/644
H	N40H	12500	11600	17	40	120/248	340/644
H	N42H	12800	12000	17	42	120/248	340/644
H	N45H	13200	12100	17	45	120/248	340/644
H	N48H	13700	12500	17	48	120/248	340/644
SH	N35SH	11700	11000	20	35	150/302	340/644
SH	N38SH	12200	11400	20	38	150/302	340/644
SH	N40SH	12500	11800	20	40	150/302	340/644
SH	N42SH	12800	12400	20	42	150/302	340/644
SH	N45SH	13200	12600	20	45	150/302	340/644

UH	N28UH	10200	9600	25	28	180/356	350/662
UH	N30UH	10800	10200	25	30	180/356	350/662
UH	N33UH	11300	10700	25	33	180/356	350/662
UH	N35UH	11800	10800	25	35	180/356	350/662
UH	N38UH	12200	11000	25	38	180/356	350/662
UH	N40UH	12500	11300	25	40	180/356	350/662
UH	N42UH	12800	11300	25	42	180/356	350/662
EH	N28EH	10400	9800	30	28	200/392	350/662
EH	N30EH	10800	10200	30	30	200/392	350/662
EH	N33EH	11300	10500	30	33	200/392	350/662
EH	N35EH	11700	11000	30	35	200/392	350/662
EH	N38EH	12200	11300	30	38	200/392	350/662
EH	N40EH	12500	11300	30	40	200/392	350/662
AH	N28AH	10400	9900	33	28	230/446	350/662
AH	N30AH	10800	10300	33	30	230/446	350/662
AH	N33AH	11300	10600	33	33	230/446	350/662
AH	N35AH	11700	11000	33	35	230/446	350/662
AH	N38AH	12200	11300	33	38	230/446	350/662

4. Maximum Working Temperatures

The following table shows different magnetic materials and their maximum working temperatures.

	Maximum Working Temperature	
Material	℃	℉

NdFeB N	80	176
NdFeB M	100	212
NdFeB H	120	248
NdFeB SH	150	302
NdFeB UH	180	356
NdFeB EH	200	392

5. Plating & Coatings

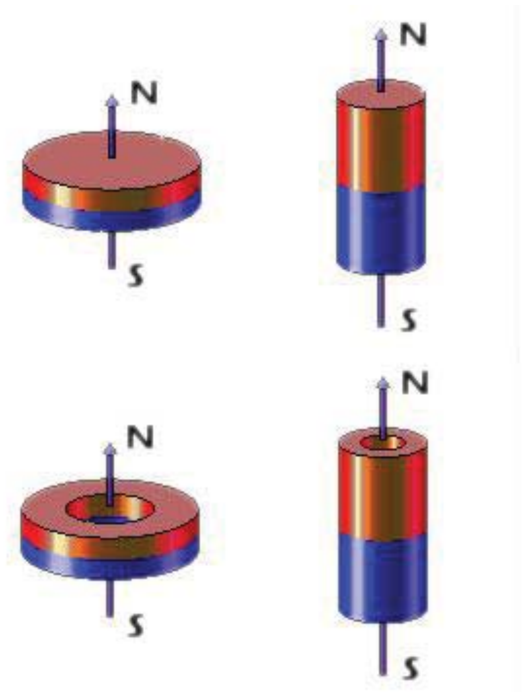
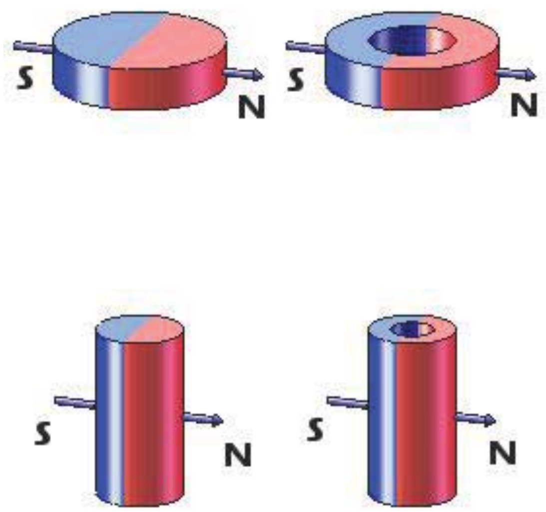
There are various plating/coating available for permanent magnets. NdFeB magnets are prone to corrosion and need plating/coating in most conditions. Typical plating/coating for NdFeB magnets is nickel or Ni-Cu-Ni. Nickel-copper-nickel(Ni-Cu-Ni) plating has proved to be one of the most corrosion resistant and durable types of plating. Magnets can also be coated with organic coatings such as epoxy resins.   Magnets Plating & Coatings

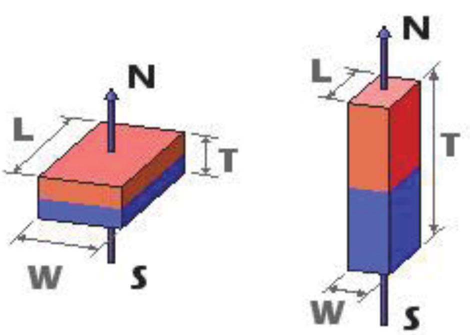
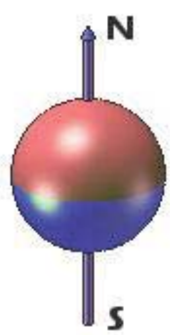
Magnets Plating & Coatings		
Ni-Cu-Ni	Double Ni	Epoxy
Ni	Black Ni	Phosphating
Cu	White Zn	Plastic
Au	Color Zn	Rubber
Ag	Sn	Teflon (PTFE)

6. Magnetic Orientations

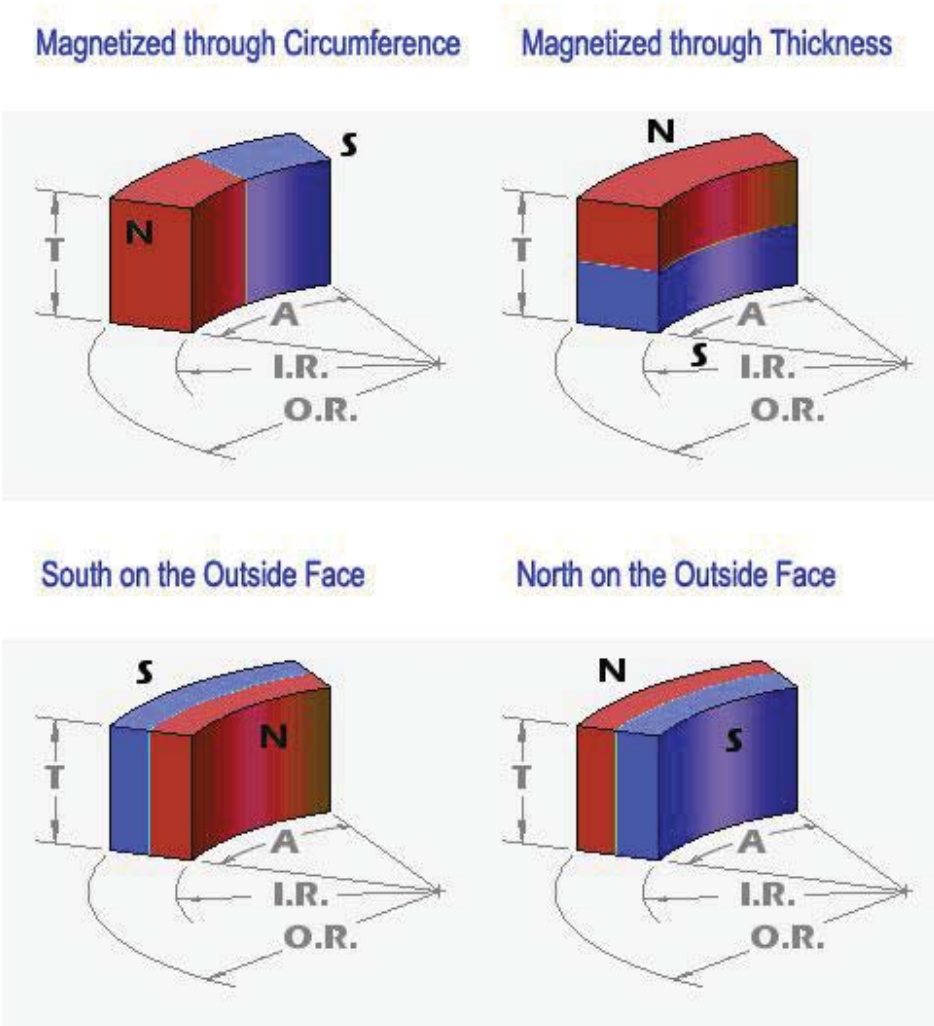
A magnet can be magnetized in a variety of directions. Anisotropic materials must be magnetically oriented during production. Therefore are inclined to a fixed orientation.

Disc & Cylinder Magnets, Ring & Tube Magnets

Axially Magnetized	Diametrically Magnetized
	

Block & Bar & Cube Magnets	Sphere & Ball Magnets
Magnetized Through Thickness	Axially Magnetized
	

Arc & Wedge Magnets



7. Manufacturing Processes

Production Process of Neodymium Magnets:

1) Vacuum Melting

   Compositions of neodymium, iron, iron-boron, dysprosium and minor additions including cobalt, copper, gallium, aluminum and others are mixed and induce-melted to form Nd2Fe14B phase and other necessary structures required for high performance permanent magnets. The melting temperature reaches over 1300o C. Usually repeated melting is needed to produce an even phase and structure distribution.

2) Crushing

The ingots from the vacuum melting process are crushed into coarse powder directly, or strip cast followed by HDDR processing into coarse powder.

3) Jet Milling
The coarse powder further milled into required particles sized about 3 microns in diameter by a jet miller. Those particles become single-domain and anisotropic which are critical for producing a high coercivity magnet. Jet milling is the most effective way to mill the particles so far.

4) Pressing
Compact the fine powder to produce block magnets. Usually a magnetic field is applied during pressing to align those anisotropic particles in order to produce maximum magnetic output in a particular direction. There are two pressing methods, transverse and axial, depending on different applications. Isostatic pressing is normally used to further density magnets to 75-80%.

5) Vacuum Sintering
The compacted magnets are sintered at temperatures above 1000 o C and for many hours to be solidified and compacted further more up to 99% by shrinking it's body. A required microstructure between particles for high performance permanent magnets is also formed in this stage. Some following heat-treatments are needed to stabilize the magnets.

6) Machining
Shrinkage and distortion during sintering is too difficult to control adequately and magnets normally need at least a " clean up" grind on the surface. Small parts are cut or sliced precisely to form a big block to meet the demanding tolerances and different shapes.

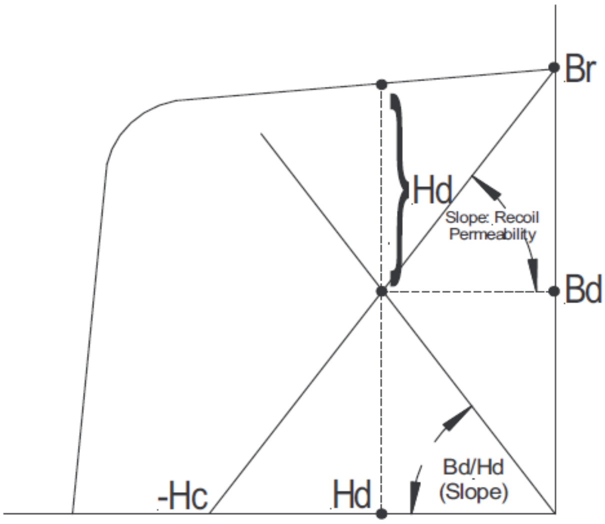
7) Surface Treatment
Various surface treatments can be applied on the final products. They include zinc, nickel, Ni-Cu-Ni multi-layer, e-coating, epoxy and others. They provide different surface finishing, appearance and corrosion resistance, applicable to different application environments.

8) Inspection
This is the final step. Magnets are inspected based on customer specifications and needs, including dimensional and magnetic tests.

8. Measuring Magnets

8.1 Magnetic Moment and BH-Curves

The magnetic moment is a measure of the strength of a magnetic source. Using a fluxmeter and a helmholtz coil, the magnetic moment of a particular permanent magnet can be determined. From the magnetic moment, the operating flux desity (Bd), operating field strength (Hd), coercive force (Hc), residual flux density (Br) and maximum energy product (BHmax) can be derived.



BH-Curve

8.2 Flux Density

The measurement of flux density is made using a gauss/tesla meter. Generally this simple measurement is made at the surface of the magnet. Most gauss meters use a hall effect sensor to produce a flux density measurement. The gauss meter provides a constant input current to the hall sensor which then produces an output voltage that is proportional to the density of the magnetic field passing through it. The resulting measurement is usually expressed as gauss or tesla.

8.3 Pull Force

Pull force measurements are a mechanical method of obtaining a measurement of the holding or pulling strength of a magnet. In this measurement test, a magnet is attached to an actuator with an integrated strain gauge. The opposite side of the magnet is attached to a fixed piece of ferromagnetic material such as a plate of mild steel. As the actuator forces the magnet from the steel plate, the force needed to separate the two is recorded by the strain gauge. Pull force tests are not standardized and pull force values provided by manufacturers vary widely and should not be used as the basis of final magnet selection.

9. Magnets Packing

Magnets are normally shipped in steel lined boxes to shield the magnetic flux from the outside of the box. In actually, the steel provides a circuit or path for the flux to move. Magnetic flux can only be redirected it can never really be adsorbed or blocked.

Strong magnets may require separate packaging or spacers to provide a buffer space between the magnets. These spacers allow the magnets to be separated and more easily handled. In addition to spacers between magnets, boxes of magnets may require rigid material between the boxes to prevent the boxes from attracting each other.

10. Magnets Handling

Magnets are produced in a wide array of sizes, shapes, and strengths, but there are similarities between all magnetic materials. They are all relatively brittle which when coupled with their magnetic strength present a number of issues.
Handling concerns are common for many our customers, whether it’s in protecting the magnets or the individuals that are using the magnets. The lack of familiarity in using magnets is quite common among receiving and inspection personnel.

The two primary issues resulting from incorrect handling are personal injury and damaged magnets. Personal injury can result in a variety of ways. Strong magnets can draw ferrous objects or other magnets towards them with surprisingly strong forces resulting in sharp fragments and pinching hazards. This can happen so fast that the human body is unable to stop the collision. This action is sudden and will typically catch untrained or uninformed technicians by surprise. Magnetic fields can also negatively impact people with pacemakers or other implanted medical devices. Although magnets and magnetic fields are around all of us every day, we are not always aware of the strength of industrial magnets. People with implanted medical devices should avoid handling magnets without previously consulting their doctor.

The second opportunity for an issue is damage to the magnets or actually losing the magnet. Magnets can be damaged both physically and magnetically. Some alloys will lose their magnetism when not handled properly. Always keep and store the magnets in the manner in which they were received from the magnet supplier. This will help ensure the magnets do not chip, get broken, or become demagnetized. The other issue to the magnet is that it can be easily lost because they attract to ferrous objects.

We employ a number of techniques to mitigate handling issues that arise from time to time. When it comes to packaging you should never be concerned about the magnets arriving in a safe manner. We've developed various packaging methods that mean you'll receive your order of magnets packaged appropriately for transit, storage, and ultimately safe removal. As a producer of very powerful magnets and magnetic assemblies, there are occasional and unavoidable situations that involve risk to either the magnet or the persons working with the magnets. By default, extreme caution should be practiced when working with all magnets regardless of one's familiarity when them. Our commitment is to provide the highest level of service which includes educating our customers on safe handling procedures and practices. We urge all of our customers to contact us with any questions regarding handling or storage of our magnetic products.
Please read the magnet safety warnings before you purchase or use magnets: **Magnets Safety Warnings** (https://www.albmagnets.com/content/12-magnet-safety-warning)

11. Applications

Machinery and drive engineering:
Electric motors, textile machines, brakes, drive couplings (permanently magnetic), robots

Electrical engineering:
Hall sensor technology, Reed switch, relay, electric tools, proximity sensors

Automotive engineering:
Antilock braking system, tachometers, window regulators, central locking system, wipers, airbag

Power engineering:
Windmills, dynamos, generators

Conveyer technology:
Pumps, lifts, conveyor bands

Aeronautical and aerospace engineering:
Navigation, control systems, physical facilities

Measurement and regulation technologies:
Scales, magnetic valves, gas, water and electric meters, level measurement

Organization and control technologies:
Warehouse labeling, organization, packaging

Medical engineering:
Magnetic resonance tomography

Textile sector:
Magnetic closures

Telecommunication:
Televisions, microphones, telephones, headsets, loudspeakers

Model making:
For the construction of electric motors, cleaning of rails, sensor technology, automation

Furniture production:
Opening mechanisms, supporters

Office requirements:
Pin boards, classification systems, name badges

Garage and Hobby:
Cleaning of motor oil, find and recover objects, fixation of tools and devices, removal of bumps, fixation of objects

Household:
Pin board, delete media (hard disks, audiotapes, videotapes, cash cards), removal of swarfs

Research and school:
Experiments, atom model

Games and handicraft:
Jewelry, magnetic curtain, decorative magnets, gift ideas, legerdemains

12. Definitions and Terminology

1. Anisotropic Magnet

A magnet having a preferred direction of magnetic orientation, so that the magnetic characteristics are optimum in that direction.

2. Coercive force, Hc

The demagnetizing force, measured in Oersted, necessary to reduce observed induction, B to zero after the magnet has previously been brought to saturation.

3. Curie temperature, Tc

The temperature at which the parallel alignment of elementary magnetic moments completely disappears, and the materials are no longer able to hold magnetization.

4. Flux

The condition existing in a medium subjected to a magnetizing force. This quantity is characterized by the fact that an electromotive force is induced in a conductor surrounding the flux at any time the flux changes in magnitude. The unit of flux in the GCS system is Maxwell. One Maxwell equals one volt x seconds.

5. Gauss, Gs

A unit of magnetic flux density in the GCS system; the lines of magnetic flux per square inch. 1 Gauss equals 0.0001 Tesla in the SI system.

6. Hysteresis Loop

A closed curve obtained for a material by plotting corresponding values off magnetic induction, B (on the abscissa), against magnetizing force, H (on the ordinate).

7. Induction, B

The magnetic flux per unit area of a section normal to the direction of flux. The unit of induction is Gauss in the GCS system Intrinsic Coercive Force, Hci: An intrinsic ability of a material to resist demagnetization. Its value is measured in Oersted and corresponds to zero intrinsic induction in the material after saturation. Permanent magnets with high intrinsic coercive force are referred as "Hard" permanent magnets, which usually associated with high temperature stability.

8. Intrinsic Coercive Force, Hci

An intrinsic ability of a material to resist demagnetization. Its value is measured in Oersted and corresponds to zero intrinsic induction in the material after saturation. Permanent magnets with high intrinsic coercive force are referred as "Hard" permanent magnets, which usually associated with high temperature stability.

9. Irreversible Loss

Defined as the partial demagnetization of a magnet caused by external fields or other factors. These losses are only recoverable by remagnetization. Magnets can be stabilized to prevent the variation of performance caused by irreversible losses.

10. Isotropic Magnets

A magnet material whose magnetic properties are the same in any direction, and which can, therefore, be magnetized in any direction without loss of magnetic characteristics.

11. Magnetic Flex

The total magnetic induction over a given area.

12. Magnetizing Force

The magnetomotive force per unit length at any point in a magnetic circuit. The unit of the magnetizing force is Oersted in the GCS system.

13. Maximum Energy Product, (BH)max

There is a point at the Hysteresis Loop at which the product of magnetizing force H and induction B reaches a maximum. The maximum value is called the Maximum Energy Product. At this point, the volume of magnet material required to project a given energy into its surrounding is a minimum. This parameter is generally used to describe how “strong” this permanent magnet material is. Its unit is Gauss Oersted. One MGOe means 1,000,000 Gauss Oersted.

14. Oersted, Oe

A unit of magnetizing force in the GCS system. 1 Oersted equals 79.58 A/m in SI system.

15. Permeability, Recoil

The Average slope of the minor hysteresis loop.

16. Rare Earths

A family of elements with an atomic number from 57 to 71 plus 21 and 39. They are lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium.

17. Remenance, Bd

The magnetic induction which remains in a magnetic circuit after the removal of an applied magnetizing force. If there is an air gap in the circuit, the remenance will be less than the residual induction, Br.

18. Reversible Temperature Coefficient

A measure of the reversible changes in flux caused by temperature variations.

19. Residual Induction, Br

A value of induction at the point at Hysteresis Loop, at which Hysteresis loop crosses the B axis at zero magnetizing force. The Br represents the maximum magnetic flux density output of this material without an external magnetic field.

20. Saturation

A condition under which induction of a ferromagnetic material has reached its maximum value with the increase of applied magnetizing force. All elementary magnetic moments have become oriented in one direction at the saturation status.

21. Sintering
The bonding of powder compacts by the application of heat to enable one or more of several mechanisms of atom movement into the particle contact interfaces to occur; the mechanisms are: viscous flow, liquid phase solution-precipitation, surface diffusion, bulk diffusion, and evaporation-condensation. Densification is a usual result of sintering.
22. Surface Coatings
Unlike Samarium Cobalt, Alnico and ceramic materials, which are corrosion resistant, Neodymium Iron

13. Conversions

		Reading	G	mT	Oe	kA/m
1	G	Gauss	–	0.1	1	0.07977
1	mT	milli Tesla	10	–	10	0.7977
1	Oe	Oersted	1	0.1	–	0.07977
1	kA/m	kilo Ampere per meter	12.54	1.254	12.54	–