Ferromagnetic Material

Dr. Einstein's group proved in their experiments that the origin of ferromagnetism lies in electron spins. But, as all kinds of atoms have rotating electrons, why is ferromagnetism limited to such elements as iron, nickel and cobalt ?

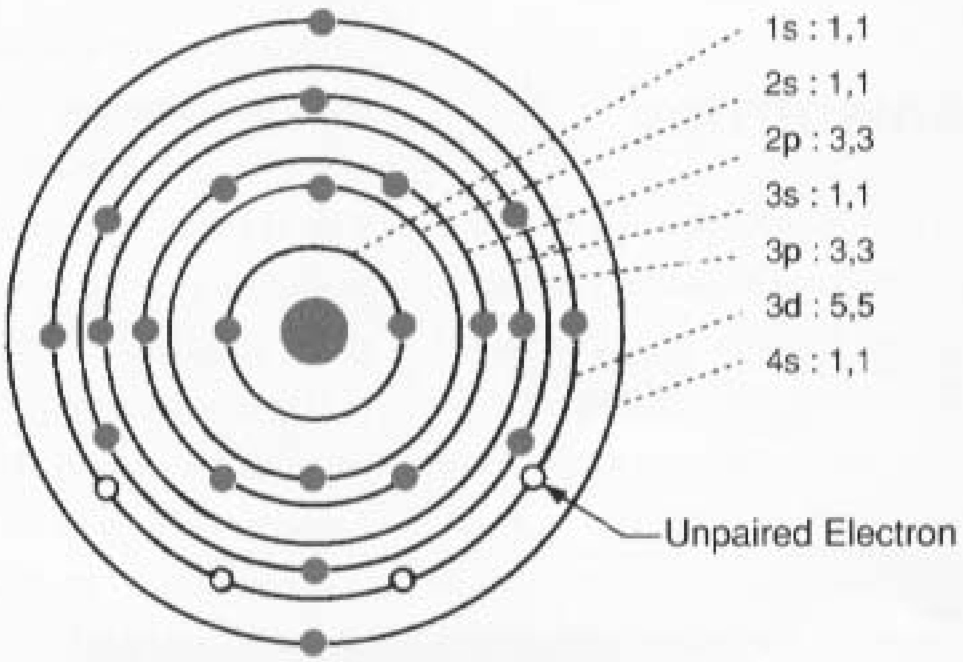
Each of these atoms has about two dozens of electrons. Do all the electrons have something to do with ferromagnetism ?

To answer these questions, it is necessary to know the electron configurations of the atoms of ferromagnetic elements.

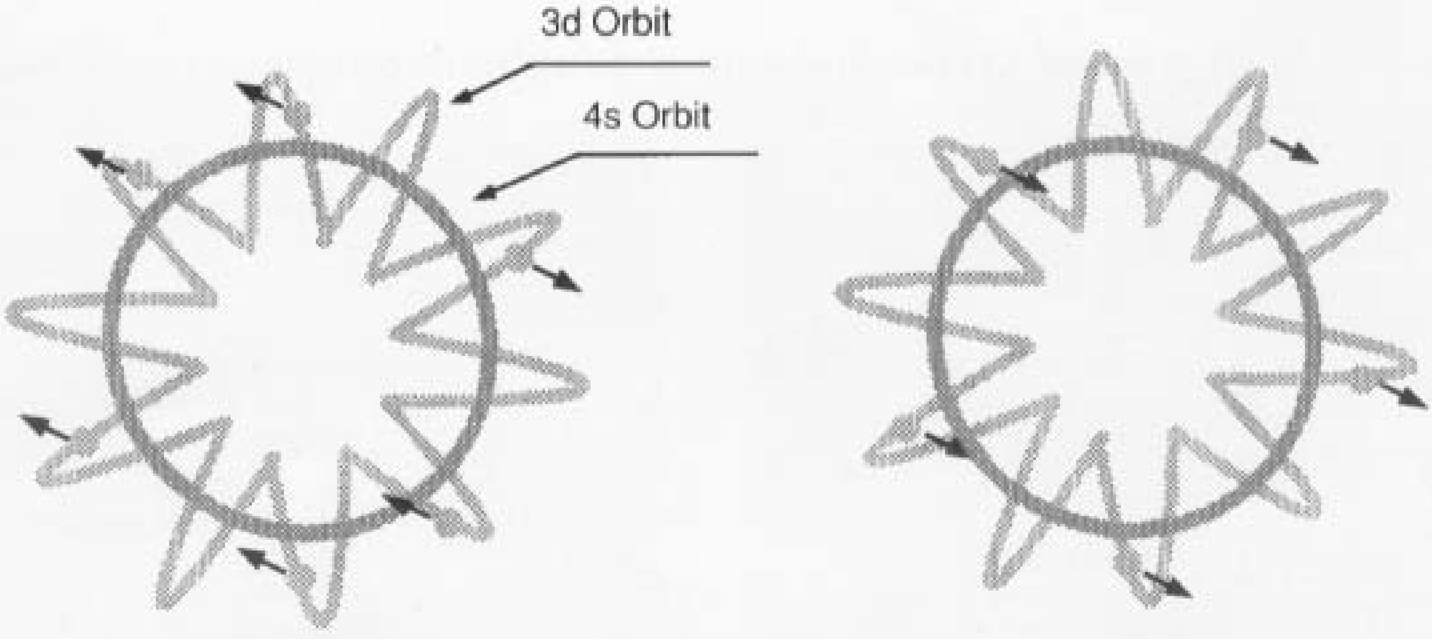
In ordinary atoms, as their number of electrons increases, paired electrons having opposite (right and left) spin directions first fill up their innermost orbits, then their outer ones in order.

In case of an iron atom, there are 26 electrons. The electrons fill up in order, with the innermost vacant orbit first, then the outer ones. However, before what should be the outermost orbit (3d orbit), is filled up, the 25th and 26th electrons are forced to enter the outer most orbit (4s orbit). In ordinary atoms, the 3d orbit accommodate 5 pairs of electrons with opposite (right and left) spin directions, 10 electrons in total. Regardless of this, in the case of iron atom the 3d orbit has 5 electrons with a right direction spin and 1 with a left, only 6 in total in its 3d orbit.

In such an irregular orbit, 5 − 1 = 4 electron spins cannot find any pairing partners. In other words, the four



Atomic Model of Iron



Fe

Mn

Atomic Structure Model Taking Into Account Electronic Energy Levels have the same spin direction, just like four magnets being aligned in the same direction, revealing the function of electron magnets. Nickel and cobalt atoms have similar electron configurations.

Such atoms, aligning themselves horizontally, vertically and longitudinally, form crystal structures and exhibit ferromagnetism only below a fixed temperatures (called Curie Temperature : see page 38).

Above Curie temperature, thermal energy causes electrons to move in various directions with the force exceeding the one aligning the electron spins, resulting in randomization of the electron magnet spin directions, which leads to mutual cancellation of the spins and disappearance of ferromagnetism.

Therefore, ferromagnetism can be said to only appear in very special cases.

Magnetic Anisotropy

If a surface of a magnet is polished like a mirror, slightly etched in a dilute acid and placed under a microscope for observation, a view similar to a sun-cracked paddy field is observed.

Each of the small zones surrounded by an irregular line is a crystal grain. This grain is called a single crystal. Boundaries between the single crystals are "grain boundaries." Shown below are microscopic photographs of a polycrystalline ferrite magnet.

Many solids we see daily are polycrystalline substance, which are an aggregate of single crystals. To imagine what a single crystal is like, just think of a Jungle gym.

Iron pipes are cross-jointed vertically, horizontally and longitudinally to form a framework. If an iron atom, for example, is spit at each intersection, it forms the basic structure of a single crystal, which is called a crystal lattice.

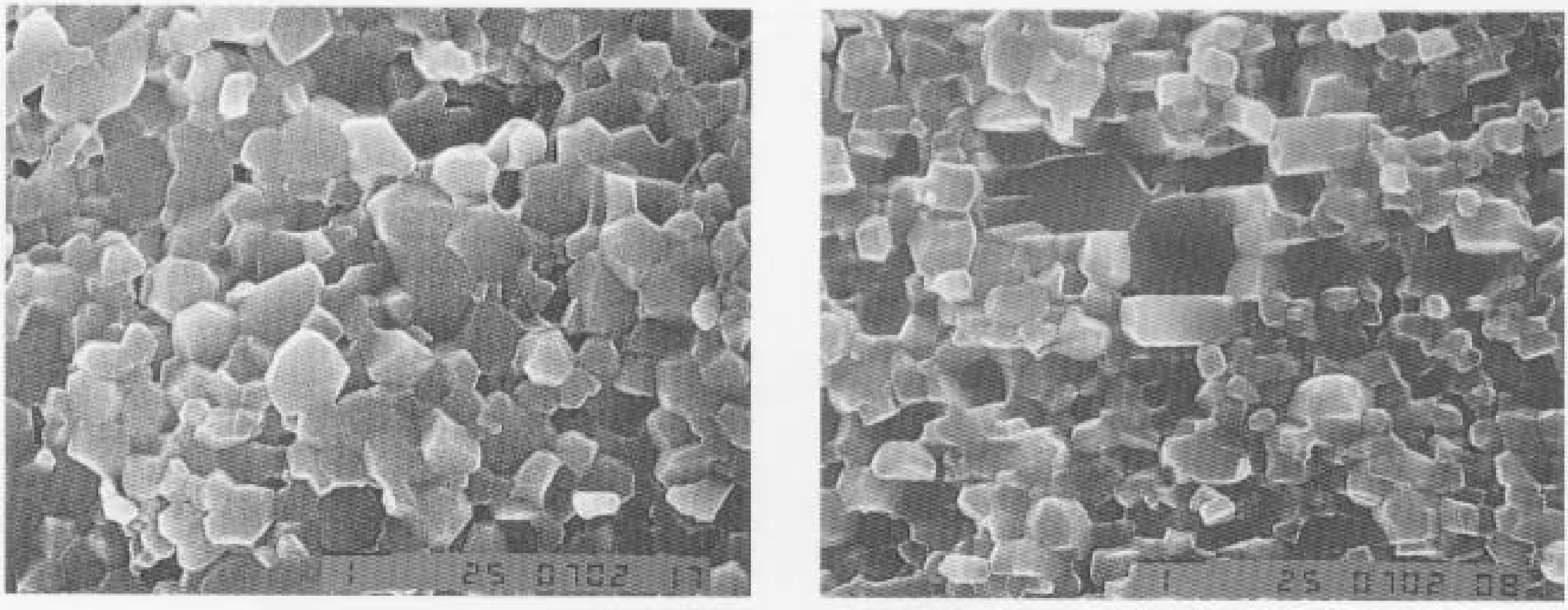
The figures P-36 show the crystal lattices of nickel, cobalt and iron. These crystal lattices, have different atomic arrangements. Consequently, differences in direction to the crystal lattice gives rise to differences in magnetic properties.

In the case of iron, for instance, it is easily magnetized in its cubic edge directions even with a weak magnetic field, but in its diagonal directions, it is difficult to magnetize.

Thus, the direction in which magnetization is easy is called the "direction of easy magnetization." And when magnetized in such directions, the magnet is stabilized with its energy minimized. The dependency of magnetic properties on crystal direction is called magnetocrystalline anisotropy.

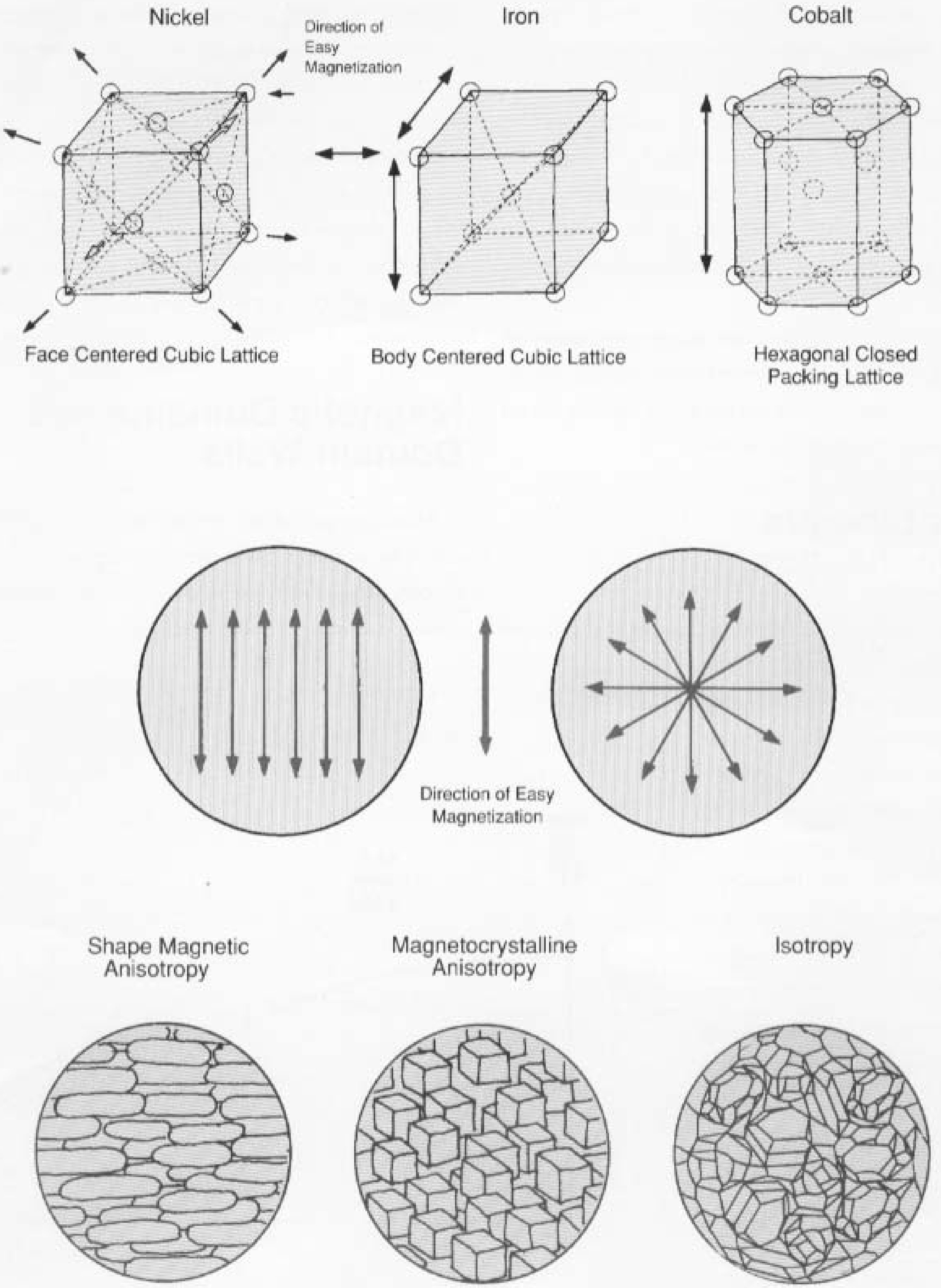
Magnetic anisotropy is caused not only by the crystal structure but also by the shape of the crystal or grain. Anisotropy caused by the latter is called "shape magnetic anisotropy." For instance, a needle suspended in a magnetic field points in the direction of the field, and when it is carefully floated on the surface of water, it is magnetized in the geomagnetic field to point to the north and south, as you well know, indicating that the longitu-

Electron Micrograph of Crystal Structure of Anisotropic Strontium Ferrite Magnet



▲ Perpendicular to c axis

▲ Parallel to c axis



Origin of Magnetic Anisotropy

dinal direction is the direction of easy magnetization.

When a magnet is cooled in a magnetic field from around its Curie Temperature, its direction of easy magnetization may be induced in the direction of the applied field, in some cases. Anisotropy thus induced is called "induced magnetic anisotropy."

A permanent magnet is made of a material having some kind of high magnetic anisotropy. By orienting the axes of easy magnetization, and taking full advantage of the characteristics of the magnetic anisotropy, one can make a strong magnet. This is called an anisotropic magnet.

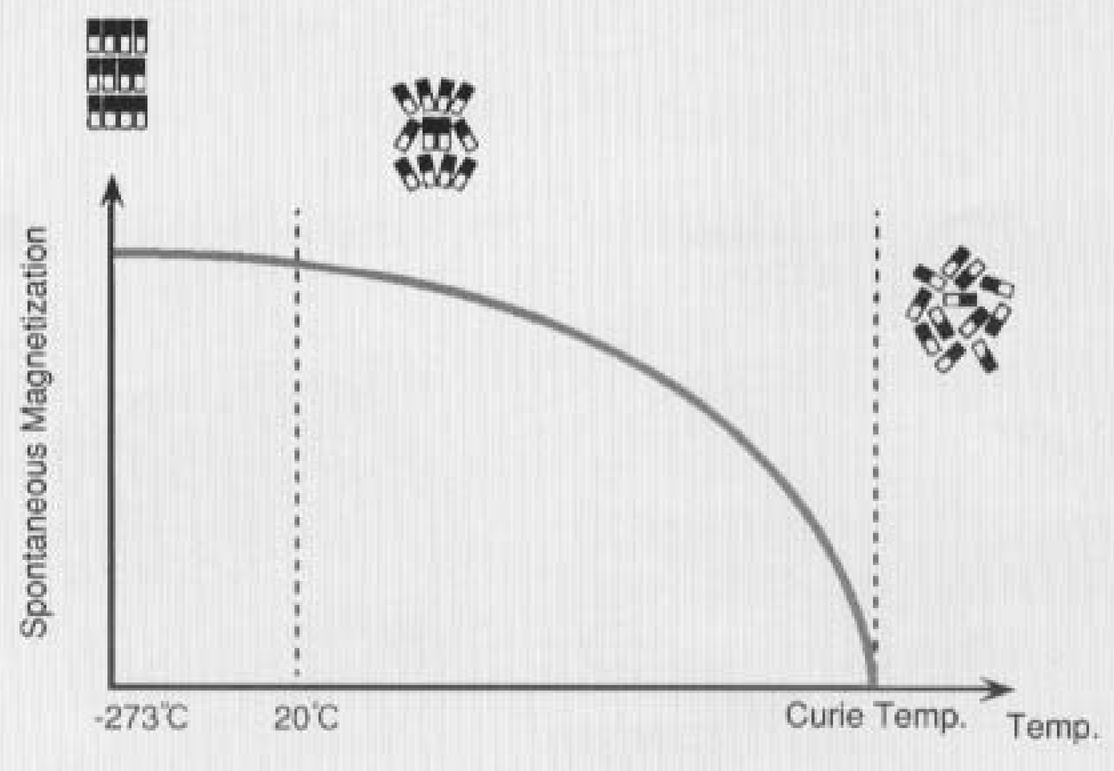
If, on the other hand, the same magnetic properties are desired in all directions (isotropy) in the magnet, orientation of easy magnetization axes is not done. In which case, an isotropic magnet is obtained.

Spontaneous Magnetization

Electron spins have a very strong power to align themselves in parallel. Apart from the theoretical reason, the difference in electronic structure of ferromagnetic atoms from those of ordinary atoms forces their electron spins to align in parallel abiogenetically.

Besides iron, ferromagnetic materials in general have their electron spins paralleled so long as the temperatures of them are below their Curie temperatures. In such substances, they are naturally magnetized without any external field. This natural magnetism is called "spontaneous magnetization."

The strength of spontaneous magnetization is maximized at absolute zero (−273℃). Namely, all the spins align themselves perfectly and calmly without any disturbances from the surroundings. If the temperature goes up, the situation changes, just like people become more active on warmer days than on cold.



Temperature Dependence of Spontaneous Magnetization

In solids such as iron, the atoms cannot move about as in the gas phase, but vibrate around fixed positions. The vibration gets more intense as the temperature goes up. So does the vibration of the spins. As the temperature goes up, the alignment of the spins is disturbed, thus reducing spontaneous magnetization.

And the direction of the spins becomes completely randomized at the Curie temperature, when spontaneous magnetization disappears.

The elevated temperature at which the transition from ferromagnetism to paramagnetism occurs, is the Curie temperature.

Magnetic Domains and Domain Walls

When you polish the surface of an iron block very carefully, avoiding strain, then let a drop of soapy water homogeneously mixed with extra fine iron powders fall onto it, and place it under a microscope, the pattern as shown in Fig. p-39 appears.

There are subdivided zones in a crystal. They are delineated by the extra fine iron powders floated in the soapy water, which is attracted to the boundaries between small zones called magnetic domains.

Electron spins align themselves in parallel in a domain, making a small magnet. The same situation also prevails in the neighboring domains but with different directions. Although the size of the magnetic domains depends on the kind of magnetic material and the method of preparation, they can be observed under a microscope .

As already described, ferromagnetic materials have spontaneous magnetization. Without any external field, they are by naturally magnetized. This spontaneous magnetization explains the situation in a single domain.

It goes without saying that they must be magnetized in an easily magnetizing direction. In the case of iron, spontaneous magnetization must lie along one of the 6 axes (3 cubic edge directions of the crystal lattice including negative and positive directions for each).

In a magnetic material like iron, the spontaneous magnetizations of individual magnetic domains lie along the 6 axes in order to be energetically stable, cancelling each other out on the whole and not making a magnet as seen from outside.

There are thin walls called "magnetic domain walls" between the magnetic domains. Inside these walls, the direction of spin gradually rotates and twists to connect one domain with others having different spin directions.

Let's look at the changes, using Fig. p-40, when an external magnetic field is applied to a magnetic material having some directions of easy magnetization. Although not all the magnetizations go through this process, it is used as a typical example for easy understanding.

(a) Initial State: Magnetic domains take different directions of magnetization, cancelling each other out on the whole and not making a magnet as seen from outside.

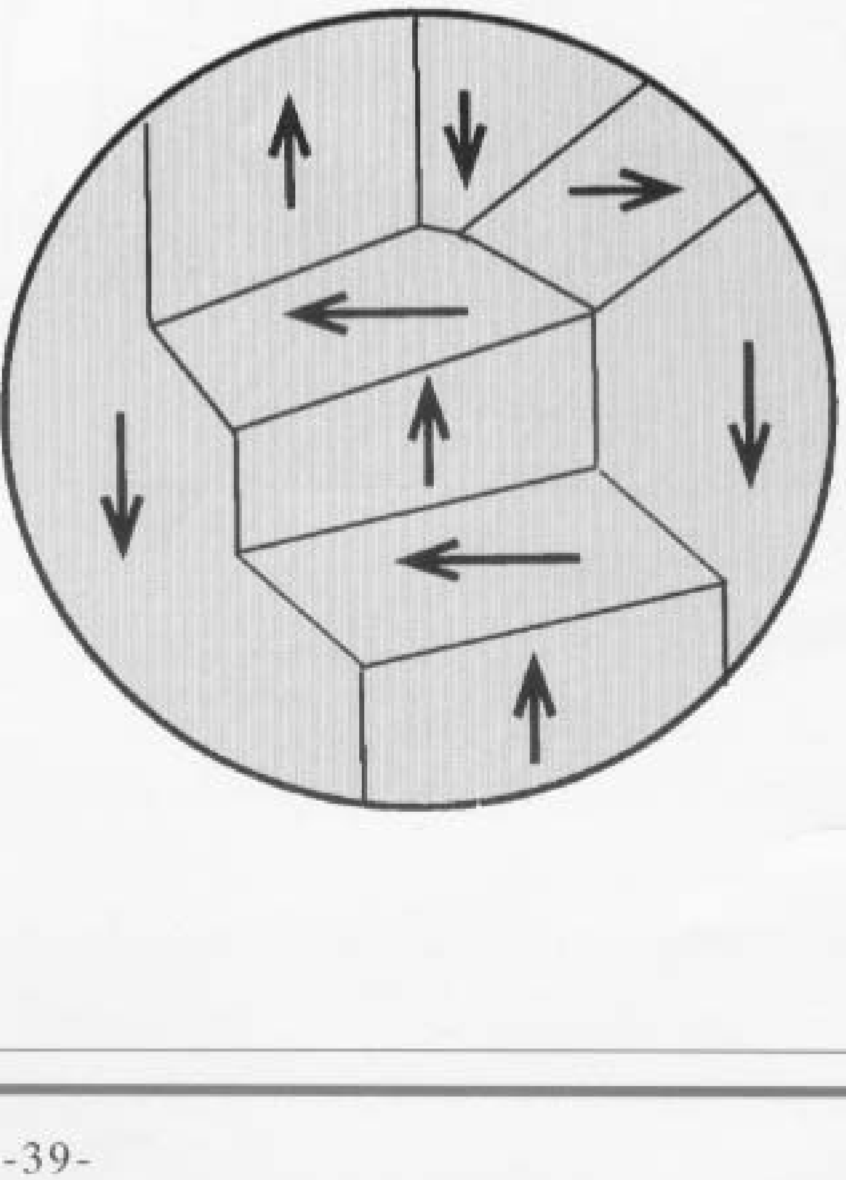
(b) A state where a weak external magnetic field with a direction different from the direction of easy magnetization is applied. Each location of domain wall moves. Consequently the area of the magnetic domain with same direction of vector component as that of an applied field increases and others decrease.

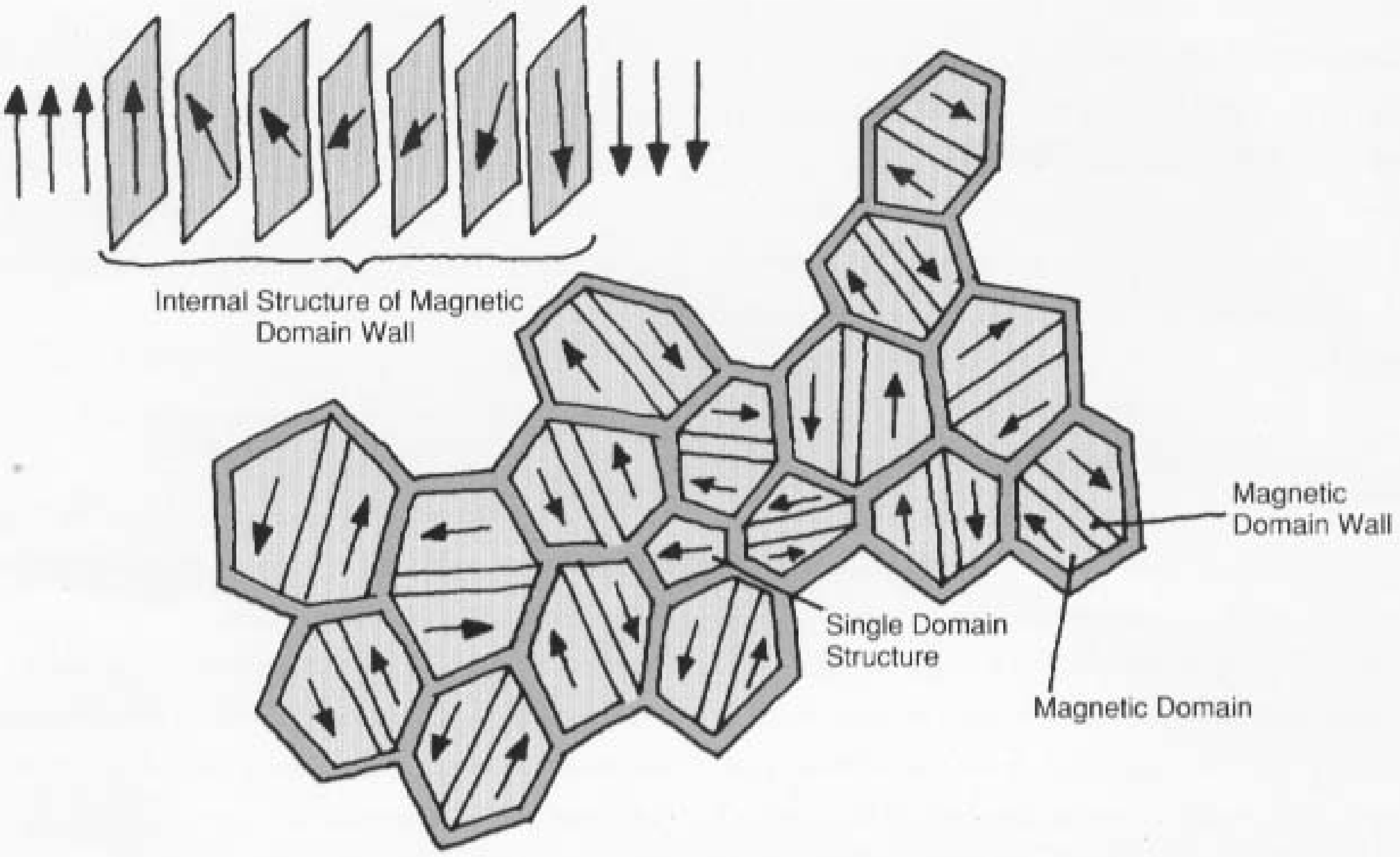
(c) Further increasing the field makes a single domain on the whole.

(d) And finally, magnetization follows the direction of the external field, reaching magnetic saturation.

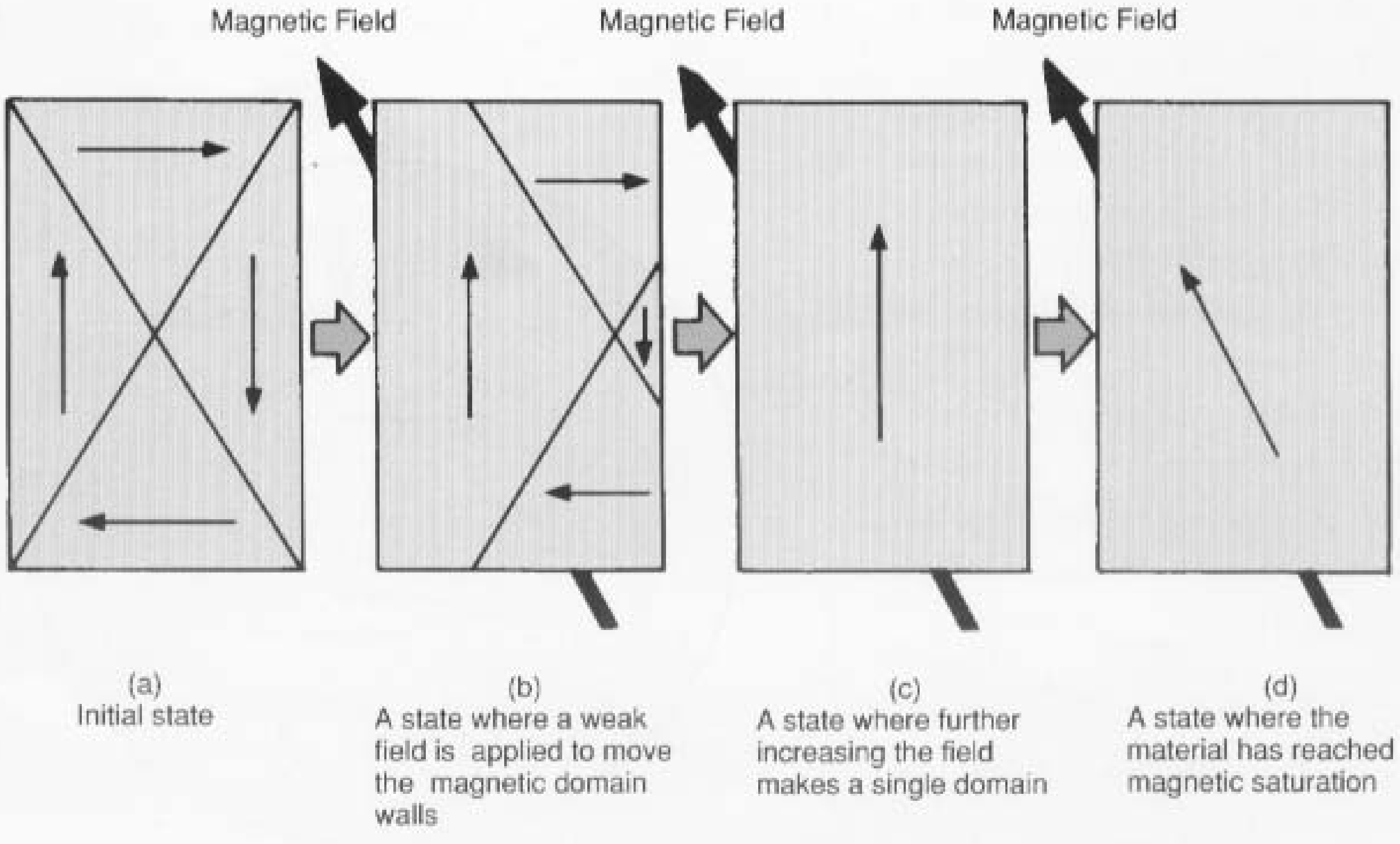
When the external field is removed during this process, all the domains do not always go back to their initial states, but remain in a different state according to circumstances. This is why magnetic material exhibits the hysteresis loop characteristics described later. As a result, the magnetic material goes into a state where it generates a magnetic field even after the external field is removed. This makes formation of a permanent magnet possible.

Domain Pattern of Iron





Pictorial Explanation of Domain Structure of a Magnet (In the case of a single direction of easy magnetization)



(a)
Initial state

(b)
A state where a weak field is applied to move the magnetic domain walls

(c)
A state where further increasing the field makes a single domain

(d)
A state where the material has reached magnetic saturation

Changes in Ferromagnetic Materials Caused by External Magnetic Fields

Magnetic Charge and Moment

Magnetic charge corresponds to "Electric charge" in electricity, having N and S as the symbol. The product of the magnetic charge on N and S poles, and the distance between N and S poles, is equivalent to "moment" in dynamics and called "magnetic moment." A magnet is an aggregate of numberless magnetic moments, which expose themselves on the surface of the magnet as N and S poles.

The magnetic moment per unit volume of a magnetic material when it is uniformly magnetized is called "Magnetic Polarization" (J) or "Intensity of Magnetization" (M), and expressed in a formula $J=\mu_0 H$.

Magnetic Field

The Earth has a magnetic field. Magnetic fields also exist, near permanent magnets and around wires carrying electric currents. The magnetic field is expressed in A/m in the SI unit system (or in Oe in the CGS unit system). To take an example, the geomagnetic field is about 24 A/m (0.3 Oe). A magnetic fields up to around 1.6 MA/m (20,000 Oe) can be generated relatively easily by electromagnets. But generation of stronger fields needs various contrivances.

Magnetization

If a magnet material is placed in a magnetic field, the material undergoes a magnetic change. This change is called "Magnetization." And the degree of change is called "Strength of Magnetization," using M as the symbol, and expressed in units of A/m (or Gauss in the CGS unit system, using $4\pi M$ or $4\pi I$ as the symbol).

Saturation Magnetization

As the magnetic field applied to a magnet material is increased, magnetization of the material increases and eventually reach saturation, which is called "Saturation magnetization." For example, the saturation magnetization (Js) of barium ferrite magnet is about 0.44 T (4,400 G), that of 2-17 samarium-cobalt magnet is about 1.1 T and that of neodymium-iron-boron magnet is about 1.6 T.

The saturation magnetization of bonded magnets can be calculated using the following formula:

$$\begin{pmatrix}\text{Saturation}\\ \text{Magnetization of}\\ \text{Magnet Powder}\end{pmatrix} \times \begin{pmatrix}\text{Volume Content of}\\ \text{Magnet Powder}\end{pmatrix}$$

Both barium ferrite and strontium ferrite powder, frequently used for bonded magnets, have a saturation magnetization of about 0.45 T in full density.

The true density (so called true specific gravity) of magnet powder is often required to calculate the saturation magnetization. The approximate true densities of representative magnet powders are 7.6 g/cm^3 for Nd-Fe-B magnets, 8.4 g/cm^3 for 2-17 Sm-Co based magnets, 5.1 g/cm^3 for strontium ferrite magnets and 5.3 g/cm^3 for barium ferrite magnets.

Magnetizing

Working to apply a large enough magnetic field to a magnet material until it reaches magnetic saturation, is called "Magnetizing." Even after removing the magnetic field required for, a certain portion of the strength of magnetization continues to exist in the material. This is the first moment after the magnet material is converted into a permanent magnet.

A field strength of "3～5 times the intrinsic coercive force H_{cJ}" is a commonly practiced indication to decide the field required for magnetizing.

Magnetic Flux Density (Magnetic Induction)

As described above, a magnet material is magnetized through the magnetizing process, when the magnetic flux generally passes through the material. The flux per unit area is called "Magnetic Flux Density" (Magnetic Induction), and B is the symbol. The unit has the same A/m as that for strength of magnetization. Flux density B can be expressed as $J+\mu_0 H$ (H : Field Strength), which equals the sum of the magnetic flux density $\mu_0 H$ applied to the material from outside and the intrinsic magnetization J induced in the material (in strict terms, magnetic polarization). The strength of intrinsic magnetization of air is almost zero regardless of the field strength (magnetization of the air is nearly zero), therefore, after magnetizing, the strength of flux density around the magnet becomes the magnetic field there.

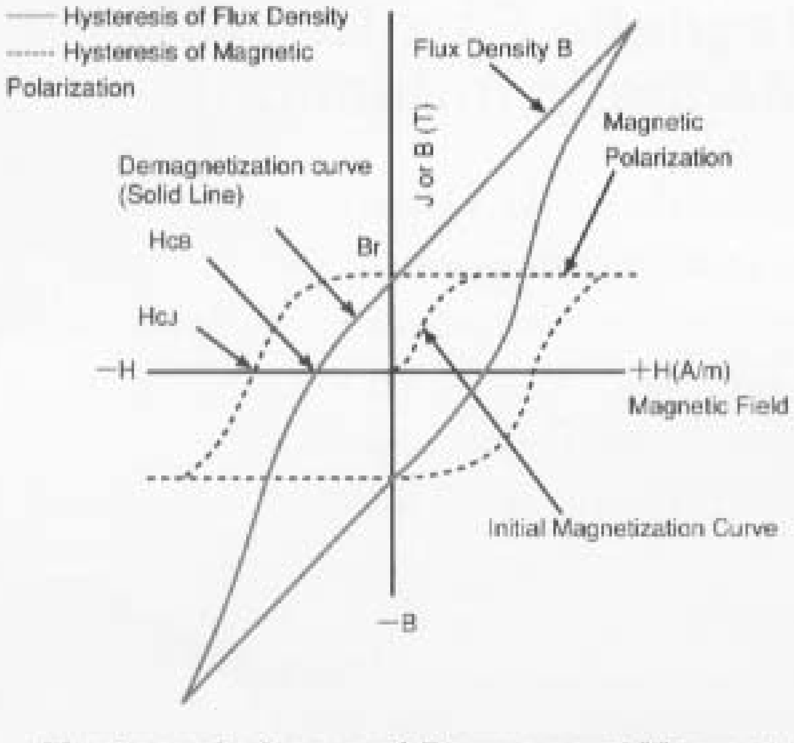
Remanent Flux Density, Coercive Force and Hysteresis Loop

Let us check how the magnetic flux density or magnetization changes, when the magnetic field applied to the material.

First, as the external field applied to the magnet material is increased, the magnetization of the magnet material gradually increases until it reaches saturation, which has already been described. This is called the "Initial Magnetization Process."

Next, when the external field is decreased to zero, the flux density is called "Remanent Flux Density" (Br) or Residual Magnetic Induction. Further increasing the field in the negative direction causes both the intrinsic magnetization and flux density to start decreasing, resulting in a state where no magnetic flux passes through the magnet material. This magnetic field strength then being applied to the material is called "Coercive Force" · (H_{cB}).

As the reverse magnetic field is further increased, the magnetic flux starts to flow in the opposite direction until the intrinsic magnetization disappears, and this field strength is called "Intrinsic Coercive Force" (H_{cJ}). In short, there are two coercive forces, H_{cB} for demagnetizing the flux density B to zero, and H_{cJ} for the intrinsic magnetization J to zero.



Hysteresis Loop of Permanent Magnet

Then as the reverse field is increased surpassing H_{cJ}, the intrinsic magnetization is reversed (opposite to the initial direction) and coincides with the reverse field to eventually reach magnetic saturation.

The B-H curve or the J-H curve depicted by repeating all these processes is called a "Magnetic Hysteresis Loop."

Demagnetizing Field

While a permanent magnets generates an external magnetic field with its N and S poles, the same poles generate a magnetic field inside the magnet called a "Demagnetizing Field," whose strength and direction are different from those of the flux density inside the magnet. The demagnetizing field acts so as to reduce the magnet's own magnetization. The closer its N and S poles are to each other or the smaller the dimensional ratio (length/diameter) of the magnet, the more reduction in magnetization occurs.

Demagnetization Curve

A permanent magnet utilizes the magnetic flux remaining as a result of magnetizing. Therefore, the more magnetic flux density that remains despite its high demagnetizing field, the better the magnetic performance of the magnet. In short, a high remanent magnetic flux density Br and a high coercive force H_{cB} are requirements for the magnet to have excellent performance. To know how magnetization changes as the applied reverse field is varied, the demagnetization curve is applied. The curve itself is the second quadrant of the hysteresis loop, showing the relationship between the magnetic flux density and the magnetic field. The first step to technically evaluate a permanent magnet is to look into this demagnetization curve.

Operating Point

When an effective magnetic field (demagnetizing field

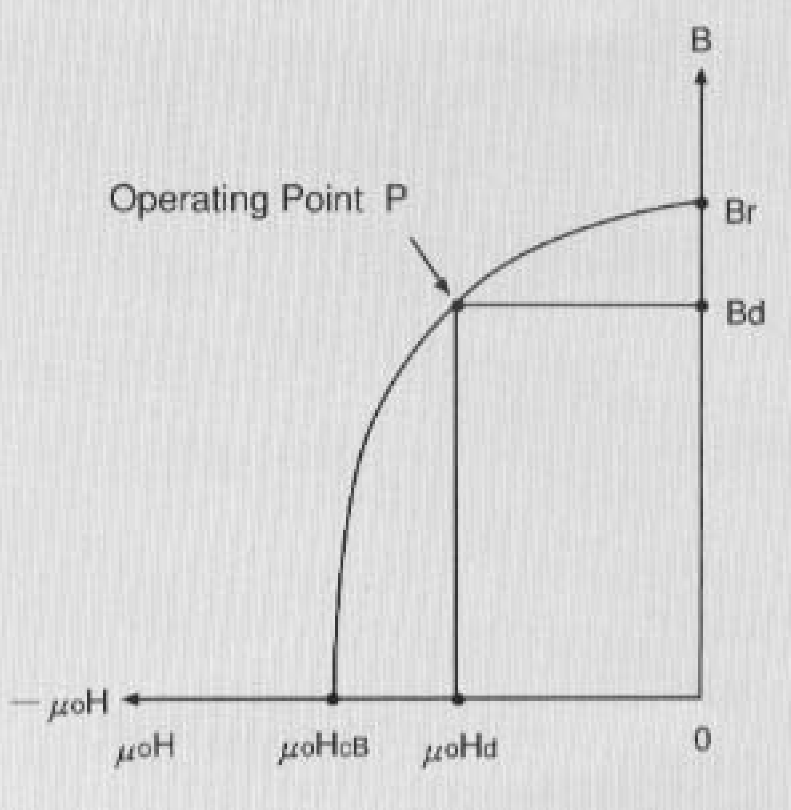
+ external field) operating on a magnet is $-Hd$ ($Hd>0$), the magnet generates a magnetic flux Bd corresponding to $H=-Hd$ on a B-H demagnetization curve, where $p=Bd/\mu_0 Hd$ is called the permeance coefficient. Permeance means the ease with which the magnet allows the permeation of magnetic flux. This comes from an analogy that the Bd/Hd corresponds to electrical conductivity (current/voltage), while the flux corresponds to electric current. A line with a slope of $-Bd/\mu_0 Hd$ passing through the origin is called a "Operating Line," and the point at which the operating line crosses the demagnetization curve is called the "Operating Point" of the magnet.

The operating point varies depending on the surroundings of the magnet. For example, if the magnet's operating point, immediately after magnetization, is at p in the Fig. p-43, the effective magnetic field inside the magnet is shifted toward the positive side when a piece of iron comes near the magnet. The magnetization induced in the piece of iron exerts an "attractive magnetic force" on the magnet, partially cancelling the demagnetizing field. As a result, the operating point shifts toward the high magnetic flux density side.

This change is often called a "Shift Toward a Higher Permeance Side." If an attractive force operates between the magnet and the piece of iron, the magnetic energy of the whole system is lowered, thus stabilizing the system with the demagnetization of the magnet becoming more difficult than when it is alone. "A Higher Permeance" is a state where demagnetization is more difficult. In an isolated magnet, "Shift Toward a Higher Permeance Side" means either a greater distance between the N and S poles (elongated), or a shorter distance between them by deforming the magnet into a U or horseshoe shape, or the magnet becoming difficult to demagnetize.

Maximum Energy Product

As described in the Demagnetization Curve section of this booklet, a criterion for evaluating the magnetic performance of a magnet is to look first at its demagnetization curve, namely to know how much a magnetic flux density Bd can be taken out under a given demagnetizing field Hd.



Operating Point of Permanent Magnet

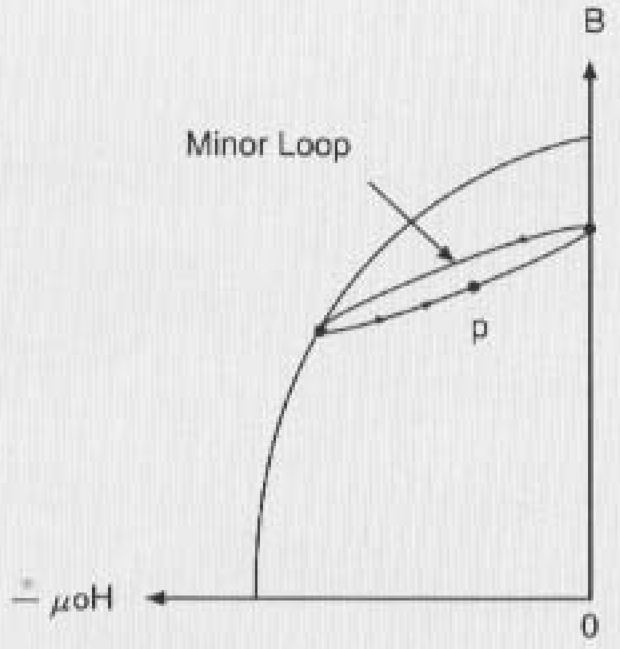
A much simpler way to evaluate the magnetic performance of the magnet is to use the maximum value of the product Bd × Hd on the operating point. The Bd × Hd is a quantity proportional to the energy that can be taken out from the unit volume of the magnet, the maximum value of which is called the "Maximum Energy Product." The maximum energy product is measured in J/m^3(Joule/cubic meter) in the SI unit system, and in GOe in the CGS unit system.

The optimum magnet design is said to have been made when its operating point comes to the point of the maximum energy product. The reason is that this is the point of the minimum magnet volume required to take out the necessary energy.

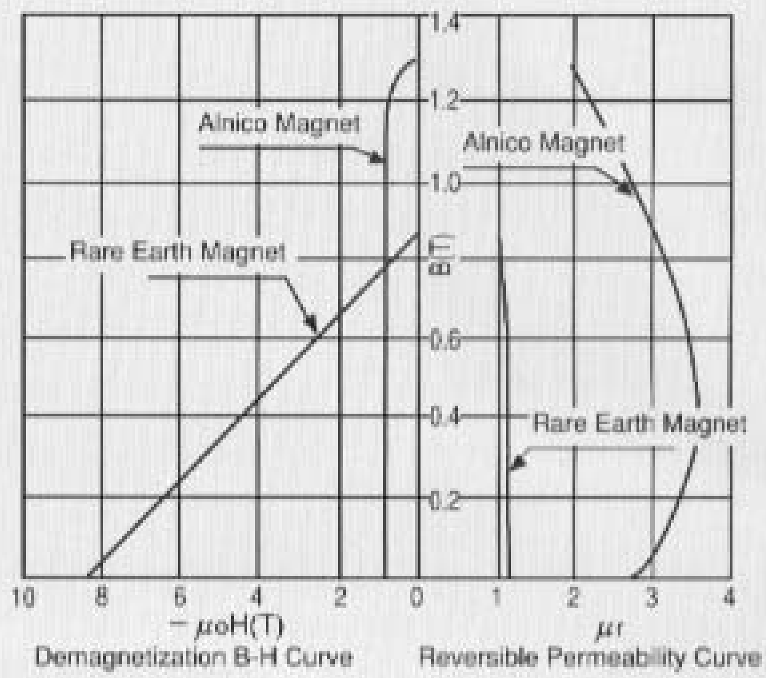
Minor Loop

As already described, the operating point of a magnet is shifted according to its application environments.

This shift does not generally occur on the demagnetization curve but commonly on a small hysteresis loop called a minor loop traced by the operating point, which starts from its initial operating point on the demagnetizing curve, goes (tracing the lower curve) to another point on the B axis and returns (tracing the upper curve) back to the initial point, as shown on the next page. On the other hand, there are cases where the operating points do not shift, such as in the case of loudspeaker magnets, whose operating points naturally lie on the magnetization curve.



Minor Loop and Operating Point on the Loop



Demagnetization Curve

Reversible Relative Permeability (Recoil Relative Permeability)

The minor loop has a small area covered by the hysteresis so that both the upper and lower lines of the loop can generally be represented as a single line. The slope of this line, B/μ_0H ($H>0$) is called reversible relative permeability and termed μ_r. Values of the reversible relative permeability depend on the starting points on the demagnetizing curve. Recoil means "rebound or go back," describing the operating point going and coming back along the linear minor loop.

The reversible relative permeabilities of rare earth magnets and alnico magnets are compared on the same scale in Fig. p-44 (shown right). Reversible relative permeability at an operating point of the maximum energy product is commonly taken as a typical value. Magnetic materials having a demagnetization curve (B-H curve) inclined nearly 45° return to almost the same initial operating point even after temporary application of a strong magnetic field, due to the fact that their reversible relative permeability is nearly equal to one and their coercive force is high. These magnets are useful not only for applications that require generation of magnetic fields or utilize attractive forces, but also for applications that make use of repulsive forces.

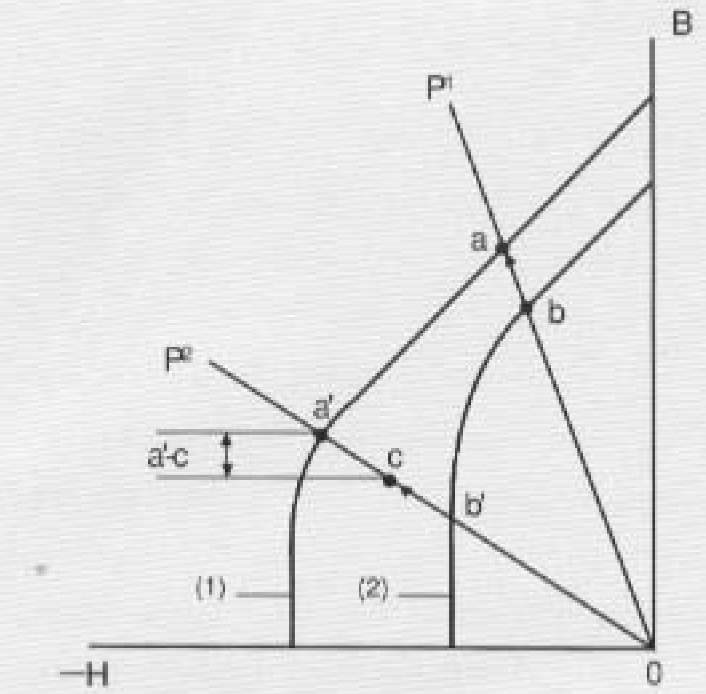
Irreversible Loss at High and Low Temperature

1. Irreversible Loss at High Temperature

When magnets magnetized at room temperature are exposed to high temperatures, their magnetic flux temporarily decreases due to thermal fluctuation of the magnetic moments, but reversibly recovers on cooling them back to room temperature. This is called "Reversible Temperature Changes in Magnetization." This temperature change ratio is called the "Reversible Temperature Coefficient." On the other hand, magnets magnetized at room temperature and exposed to high temperatures may not recover even after they are cooled down to room temperature again, which is called "Irreversible Temperature loss in Magnetization." There are three cases of irreversible temperature loss.

A. Initial Temperature Loss in Magnetization

Assuming a demagnetization curve at room temperature of a certain magnet to be curve (1) on the next page, a high temperature one to be curve (2), and the magnet to operate at permeance coefficient p^1, the operating point temporarily shifts from point (a) to (b) on increasing the temperature but returns to (a) on cooling the magnet back to room temperature. However, if the permeance coefficient is p^2, the operating point initially at point (a') shifts to (b') below the inflection point of curve (2) on increasing the temperature. And in this case, the once shifted



Mechanism of Initial Temperature Loss in Magnetization

operating point does not return to initial point (a') on cooling, but only recovers to point (c). The resulting demagnetization (a' − c) is called "Initial Temperature Loss in Magnetization." Thus, in the case of initial temperature loss in magnetization, following the three factors affect its demagnetization ;

- The kind of magnet
- Its operating temperature
- The adopted operating permeance coefficient

B. Time Change of Flux Loss

Time change of flux loss of rare earth magnets has a close relationship with the operating temperatures and operating points. Especially in relation to the operating points, irreversible loss is high at low operating points and low at high operating points as same as initial temperature losses in magnetization.

C. Metallurgical Structural Change

Even below the Curie temperature, the magnet may lose its flux due to its metallurgical structural changes.

This is one of the causes of permanent flux loss. The temperature range over which metallurgical changes might occur, is 350∼500℃ for samarium-cobalt magnets depending on their compositions, and 300℃ for neodymium-iron-boron magnets. Therefore, it is necessary to use them below these temperatures.

Besides these, permanent flux loss is also caused by oxidation and rusting.

2. Irreversible Loss at Low Temperature of Ferrite Magnets

Magnetized anisotropic ferrite magnets, whose permeance coefficients are not high, once cooled down to around −40℃ and warmed up again to room temperature, generate large flux loss. The Br and Hc of ferrite magnet generally have separate coefficients :

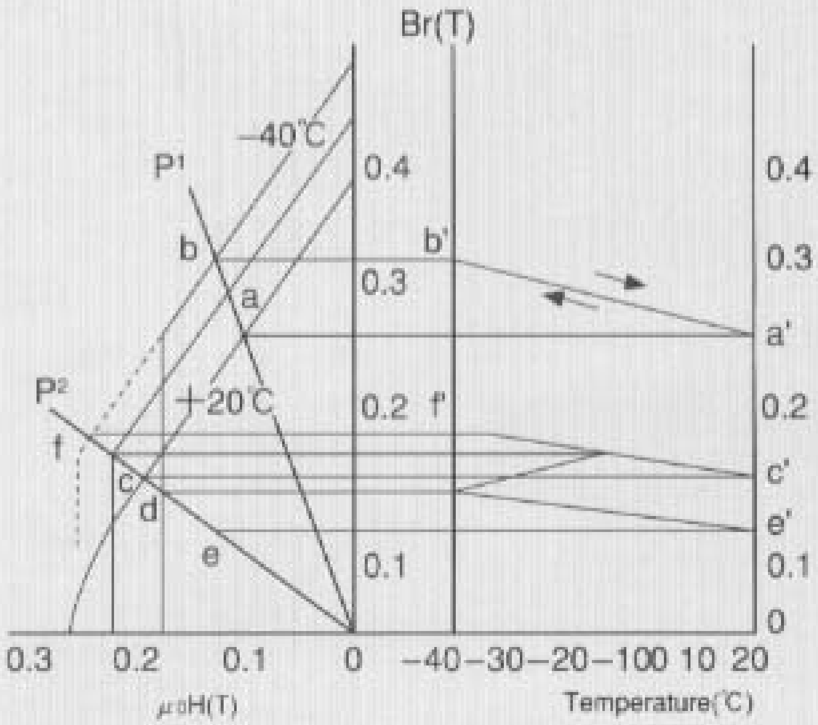
$\Delta Br / Br / K \fallingdotseq -0.18 \sim -0.19$ %/K

$\Delta Hc / Hc / K \fallingdotseq +0.35 \sim +0.50$ %/K

These temperature changes in their B-H curve cause the operating points to shift.

The magnet with a permeance coefficient P^1 shown below in the Fig. p-45, has its operating point (a) at +20℃ shifted to point (b) at −40℃. Slope (a'→b') comes from the temperature coefficient, −0.18 ∼ −0.19 %/K. On warming the magnet back to +20℃, its operating point comes back again to point (a).

The magnet with a permeance coefficient P^2, however, has its operating point(c) at +20℃ shifted to (d) at −40℃ after reversing its changing direction from (c→f) to (c→d) on the way, because the Br changes according to the temperature coefficient −0.18 ∼ −0.19 %/K, while the Hc changes according to +0.35 ∼ +0.50 %/K. On shifting the temperature once again to +20℃, the operating point comes from point (d) to (e) according to the temperature coefficients, after which temperature shifts between −40℃ and +20℃ cause the operating points to shift between (d) and (e) again.



Mechanism of Irreversible Loss at Low Temperature

Magnetizing Method

Various Configurations Possible

There are various magnetizing methods depending on the magnet's application. In the case of a simple N-S polar magnet it is possible to magnetize it with a magnetic field applied by an air-core solenoid or electromagnet, but to magnetize a multipolar magnet or a magnet after assembly, specific magnetizing yokes become necessary.

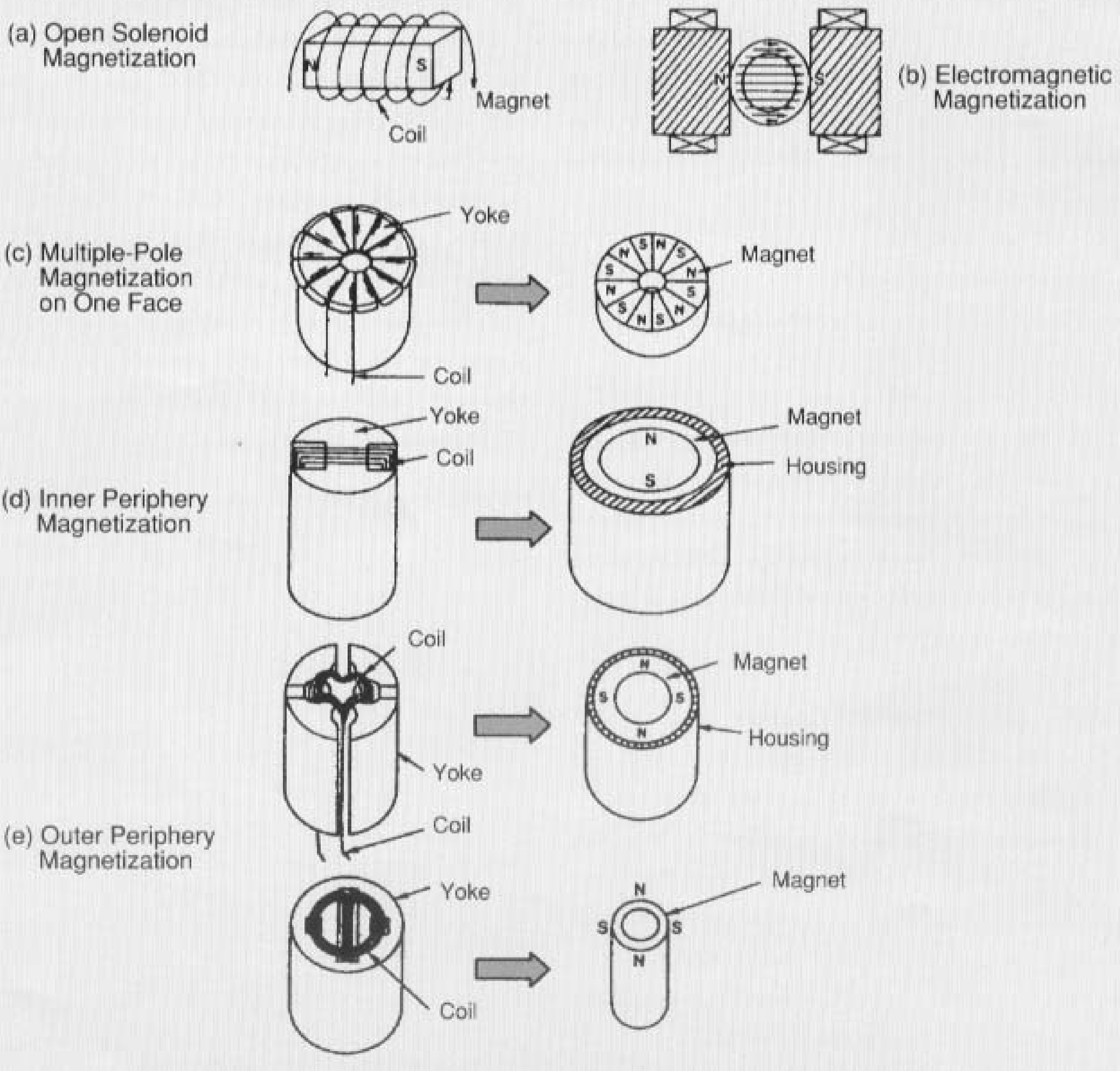
Required Factors for Magnetizing Field

When using an pulse power supply, take enough time and current capacity, taking into account the inductance and eddy current loss of the electromagnet. When magnetizing with an air-core solenoid or a multipolar yoke, make sure that the field directions coincide with the intended magnetizing directions.

Magnetizing Conditions

Except for a magnet with a linear demagnetization curve, magnetization must be carried out after final assembly of the magnetic circuit. Assembling separately magnetized magnets causes loss of the magnetic flux.

Enough attention must be paid to the handling of magnetized magnets or magnetized magnetic circuits. Handling of such a magnet or circuit is not only dangerous but causes demagnetization to occur if work tools are attracted. Unexpected failures will result when iron powder or the like is attracted to the surface.



Magnetization Yoke Shape and Magnetized Pattern

Measuring Method

Two Methods

There are two methods of testing the magnetic properties of magnets. One is to measure the basic magnetic properties to ensure the material and/or production lot qualities, free from any practical application influence. The other is a simplified method in which the magnetic flux generated by magnets in practical use is measured.

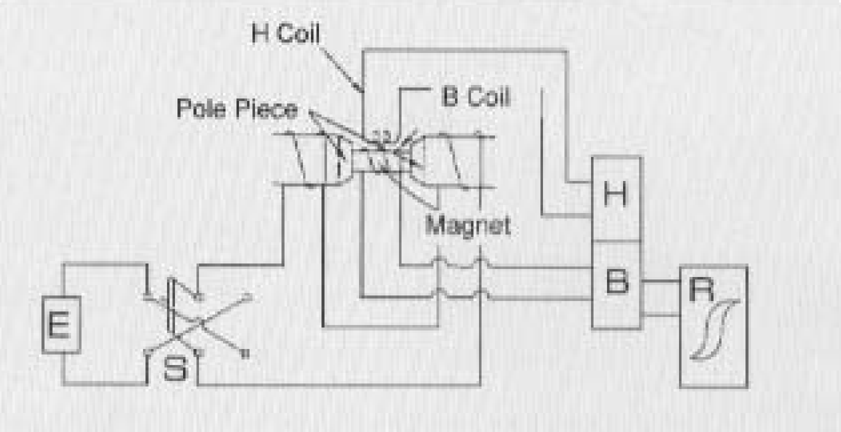
Method for Measuring Demagnetization Curve

The methods of testing the basic magnetic properties of magnets, such as Br, Hc and (BH)max, are specified in the JIS(Japanese Industrial Standards) C 2501 . The B and H components are measured by gaplessly fitting the magnet between electromagnets made of low carbon soft iron.

Simplified Measuring Method

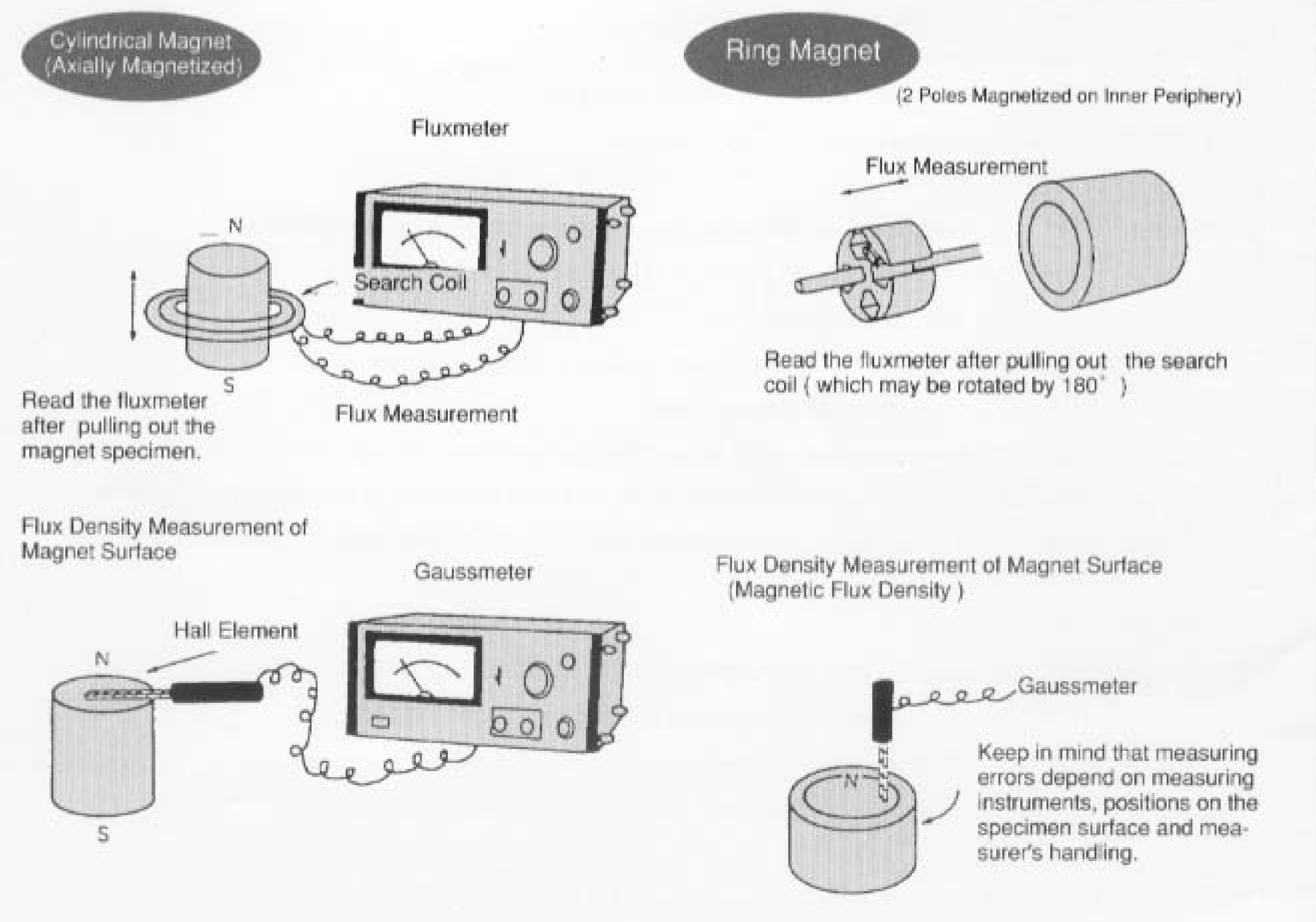
Usually a search coil and a fluxmeter are used to measure magnetic flux density, while a gaussmeter is mainly used to measure magnetic flux. In these measurements, calibration of the search coil and the Hall probe (semiconductor probe using a Hall element as its sensor) is all-important. The following two calibration methods are generally available:

- To select standard samples taken from production lots for comparative measurement.
- To calibrate them with a precisely measured magnet, such as a standard magnet.



Automatic Recording Fluxmeter

E: Magnetizing Power Suppy
S: Change-over Switch
H: H Measuring Part
B: B Measuringt Part
R: Recorder



Read the fluxmeter after pulling out the magnet specimen.

Flux Density Measurement of Magnet Surface

Read the fluxmeter after pulling out the search coil (which may be rotated by 180°)

Flux Density Measurement of Magnet Surface (Magnetic Flux Density)

Keep in mind that measuring errors depend on measuring instruments, positions on the specimen surface and measurer's handling.

Measuring Methods of Magnetic Flux and Flux Density

Standards for Permanent Magnets

1.International Electrotechnical Commission(IEC)

(1)Publication 60050[221](1990)
International Electrotechnical Vocabulary Chapter 221:Magnetic materials and components
Amendment 1(1993)

(2)Pubilcation 60404-1(1979)
Magnetic materials Part 1:Classification

(3)Pubilcation 60404-5(1993)
Magnetic materials Part 5:Permanent Magnet(magnetically hard)materials-Methods of measurement of magnetic properties

(4)Publication 60404-7(1982)
Magnetic materials Part 7:Methods of measurement of the coercivity of magnetic materials in an open magnetic circuit

(5)Publication 60404-8-1(1982)
Magnetic materials Part 8:Specifications for individual materials Section 1:Standard specifications for magnetically hard materials
Amendment 1(1991)
Amendment 2(1992)

2.Japanese Industrial Standards(JIS)

(1)JIS C 2501(1998)	Methods of test for permanent magnet
(2)JIS C 2502(1998)	Materials for permanent magnet

3.Standard of Electronic Materials Manufacturers Association of Japan(EMAS)

(1)EMAS-0001(1984)	Japanese version of IEC Publication 50[901]:Magnetism
(2)EMAS-7001(1977)	Permanent magnets
(3)EMAS-7002(1985)	Dimensions of casting magnet for electroacoustic transducers
(4)EMAS-7003(1980)	Conversion of magnetic units
(5)EMAS-7004(1986)	Dimensions of ferrite magnet for electroacoustic transducers
(6)EMAS-7005(1986)	Methods of measurement of the magnetic properties of permanent magnets
(7)EMAS-7006(1996)	Testing method of measuring shear strength by punching-out small specimen of bonded magnets

4.Standards of Electronic Industries Association of Japan(EIAJ STD)

(1)RC-8102(1991)	Dimensions of ferrite magnet for electroacoustic transducers
(2)RC-8103(1991)	Dimensions of casting magnet for electroacoustic transducers
(3)RC-8105(1992)	Dimensions of rare earth magnet for electroacoustic transducers

5.Magnetic Materials Producers Association(MMPA)...USA

(1)No.0100(1990)	Permanent magnet materials