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BOARD OF PATENT APPEALS
AND INTERFERENCES

Paper No. 21

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE BOARD OF PATENT APPEALS
AND INTERFERENCES

Ex parte THOMAS A. PERRY,
JOHN R. BRADLEY,
THADDEUS SCHROEDER,
and CARLTON D. FUERST

Appeal No. 94-3541
Application 07/789,702[1]

ON BRIEF

Before THOMAS, SCHAFER, JERRY SMITH, and HARKCOM, Administrative Patent Judges[2].

THOMAS, Administrative Patent Judge.

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[1] Application for patent filed November 8, 1991. According to appellants, the application is a division of Application 07/589,359, filed September 28, 1990, now U.S. Patent No. 5,091,021.

[2] The Commissioner of Patents and Trademarks has authorized the Examiners-in-Chief of the Board of Patent Appeals and Interferences to use the title Administrative Patent Judge. See 1156 O.G. 32, November 9, 1993.

DECISION ON APPEAL

This is a decision by Examiners-in-Chief designated in accordance with 35 U.S.C. § 7 on appeal taken under 35 U.S.C. § 134 to the Board of Patent Appeals and Interferences.

Appellants have appealed to the board from the examiner's final rejection of claims 13 to 23. Claims 1 to 12 have been cancelled earlier. As a result of appellants' submission of an amendment, filed on March 22, 1993, after final rejection cancelling claim 23 and substituting therefore new claim 24, the examiner indicated the entry of this claim for purposes of appeal in an advisory action on April 2, 1993. Therefore, the claims on appeal constitute claims 13 to 22 and 24.[3]

Claim 24 is reproduced below:

24. A magnet comprising a body of permanent magnet material, said body consisting essentially of a substrate of unmagnetized permanent magnet material and a pattern of one or more magnetized volumes in said substrate extending from a surface of the substrate to a depth therein, where each of said magnetized volumes is produced by

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[3] Appellants' subsequently filed notice of appeal listing only claims 13 to 23 is in error. It is believed that this error is inadvertent in its noninclusion of claim 24 due to the above-noted facts relating to the entry of the amendment after final rejection cancelling claim 23 and substituting therefor new claim 24.

directing energy onto an unmagnetized substrate surface in a pattern to selectively heat a volume in the substrate to lower its coercivity below the coercivity of the surrounding portion of the substrate;

imposing a magnetic field to selectively magnetize the heated volume; and

cooling the treated volume in said magnetic field.

The following references are relied on by the examiner:

Chraplyvy et al. (Chraplyvy)	4,312,684	Jan. 26, 1982
Hattori et al.[4] (Hattori)	4,835,505	May 30, 1989

Ara et al. (Ara), "Formation Of Magnetic Grating On Steel Plates By Electron/Laser Beam Irradiation", IEEE Transactions On Magnetics, Vol. 25, No. 5, September 1989, pp. 3830-3832.

We list here a reference provided by appellants as an attachment to the brief, which reference discusses the magnetic behavior of materials:

Van Vlack, Elements Of Materials Science, Second Edition, Addison-Wesley Publishing Company, Reading, Massachusetts (1964), pp. 123-127.

[4] At the bottom of page 2 of the examiner's answer, there is an incorrect listing for the patent number attributed to Hattori. It should be the correct number as listed above rather than 4,857,786. Since the examiner has relied upon Hattori since the first Office action, no impact on the stated rejections in the answer is seen to exist by this inadvertent error.

Claims 13, 14, 16 to 20, and 24 stand rejected under 35 U.S.C. § 102(b) and, in the alternative, under 35 U.S.C. § 103 as being obvious over Ara alone.[5] Claim 15 stands rejected under 35 U.S.C. § 103. As evidence of obviousness, the examiner relies upon Ara in view of Hattori.[6] Finally, claims 13 to 22 and 24 stand rejected under 35 U.S.C. § 103 as being obvious over Chraplyvy alone.

Rather than repeat the positions advocated by the appellants and the examiner, reference is made to the briefs and the answer for the respective details thereof.

[5] The examiner's second advisory action issued on April 2, 1993 may give the reader the impression that the examiner has withdrawn the alternative rejection of claims 13, 14, 16 to 20, and 23 in view of the submission of new claim 24 and the cancellation of old claim 23. However, the examiner's answer makes clear that the examiner has maintained this alternative statutory basis to reject claims 13, 14, 16 to 20, and 24. The principal brief on appeal apparently construes the rejection to be under 35 U.S.C. § 102 only. Appellants' reply brief makes no comment as to the examiner's continued reliance upon both 35 U.S.C. §§ 102 and 103 to alternatively reject the above-noted claims under Ara.

[6] This claim was rejected by the examiner in the first action and final rejection as noted above. Neither the brief nor reply brief make any mention of this rejection, yet it was clearly present in the final rejection.

OPINION

We have carefully studied the positions of the appellants and the examiner along with the particular teachings of the three references relied upon by the examiner as the basis of the various rejections of the claims on appeal. As a result of such a review, we agree with the examiner that claims 13 to 22 and 24 would have been either anticipated or obvious to one of ordinary skill in the art within the respective meanings of 35 U.S.C. §§ 102/103 based upon the evidence provided by Ara alone as to claims 13, 14, 16 to 20, and 24 under 35 U.S.C. §§ 102 and 103, in addition to the separate rejection under 35 U.S.C. § 103 of claim 15 in light of the collective teachings of Ara and Hattori. We do not, however, sustain the rejection of claims 13 to 22 and 24 under 35 U.S.C. § 103 based upon Chraplyvy alone.

Turning to independent claim 24, the only independent claim presented for our review, it is our conclusion that Chraplyvy fails to render obvious the subject matter of this claim. Claim 24 recites a body of permanent magnet material, which body is essentially a substrate of unmagnetized permanent magnet material and a pattern of one or more magnetized volumes in the substrate, where the volumes extend from the surface of the substrate to a depth therein. A key question to a proper reading of this claim as well as in light of the arguments by the appellants and the examiner is what is a permanent magnet material.

The examiner takes the view at page 7 of the answer that a permanent magnet is characterized by having a large remanence of magnetism retained after an external magnetic field is removed and which also requires a large coercive force which is the opposing magnetic intensity that must be applied to a magnetized material to remove the residual magnetism. This definition is consistent with the definition used by appellants and that which is shown in the hysteresis curve in Figure 5-29, page 127, of the Van Vlack text on the Elements Of Material Science supplied by the appellants. The examiner's definition is consistent with this reference's text discussion which contrasts soft and hard magnets at pages 126 and 127. Independently, a permanent magnet material has been defined[7] as:

[7] Graf, Modern Dictionary of Electronics, Fourth Edition, Howard W. Samms & Co., Inc., (1972), pg. 416. A copy is attached to this opinion.

> "Ferromagnetic material which, once having been magnetized, resists external demagnetizing forces (i.e., requires a high coercive force to remove the magnetism)."

Even a common dictionary[8] definition of ferromagnetic yields this:

> "[O]f or relating to substances with an abnormally high magnetic permeability, a definite saturation point, and appreciable residual magnetism and hysteresis" [emphasis added].

Thus, this definition of a ferromagnetic material is consistent with that which describes a permanent magnet material, which in turn is consistent with the definition relied upon by appellants to define the same material. With this understanding in mind, we must reverse the examiner's rejection relying upon Chraplyvy but, at the same time, the propriety of the examiner's rejections based upon Ara will be clear.

Columns 1 and 2 of Chraplyvy indicate that, in its initial state as taught, the manganese-aluminum alloy is in a nonmagnetic state. Therefore, it cannot be fairly stated to be a permanent magnet material as required by claim 24 on appeal and the requirement of claim 24 that it be in an initial unmagnetized

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[8] Webster's Ninth New Collegiate Dictionary, Merriam-Webster Inc., 1985, page 457. A copy is attached to this opinion.

state has no meaning in the context of the properties of this alloy in its initial state.

On the other hand, the examiner has taken the view that since this material may be magnetized to become a permanent magnet, it would therefore retain a large amount of magnetism after the external magnetic field is removed and would therefore have a large magnetic coercivity. In accordance with the above definitions of permanent magnet materials, this reference would appear to be proper as a basis for the rejection of claim 24. However, we also disagree with this reasoning. What is taught in Chraplyvy is that once a source of energy has been applied to the manganese-aluminum alloy, after the magnetic transition temperature has been reached, the internal crystal structure of the material is transformed to a different magnetically cohesive structure which essentially allows it to become ferromagnetic in its properties. If we were to consider this state the initial starting state of claim 24 on appeal, there would, in fact, be a body of permanent magnet material in its unmagnetized state since the magnetic field in Chraplyvy is applied later, after cooling. However, the rejection must also be reversed on the basis of this interpretation because there is no additional teaching of the required pattern of one or more magnetized volumes formed in the surface of the substrate as required in claim 24. There is no teaching in Chraplyvy to achieve this since the only teaching relating to achieving the permanent magnet material state of the manganese-aluminum alloy in Chraplyvy is to expose it to radiation only once to change it from its nonmagnetic state to its ferromagnetic state. Therefore, the rejection under 35 U.S.C. § 103 of claim 24 and its respective dependent claims based upon Chraplyvy must be reversed.

However, we agree with the examiner's reasoning advanced in the answer as to the interpretation of Ara in its application to claim 24. Since appellants in their brief and reply brief have advanced no reasoning and position and do not point to any particulars of any dependent claim on appeal, they all fall with our consideration of the sole independent claim 24 on appeal. In re Nielson, 816 F.2d 1567, 2 USPQ2d 1525 (Fed. Cir. 1987); In re Kaslow, 707 F.2d 1366, 217 USPQ 1089 (Fed. Cir. 1983); and In re Wiseman, 596 F.2d 1019, 201 USPQ 658 (CCPA 1979).

We will sustain the two rejections based upon Ara because of the teaching therein relating to ferromagnetic carbon steel. To the extent appellants' brief and reply brief assert that such a material is softly magnetic and does not have permanent magnet properties, we respectfully disagree. Initially, the reference teaches that the carbon steel is "ferromagnetic." The meaning of this term has already been established and is essentially that it is generally regarded as exhibiting properties associated with a permanent magnet-type material. It is generally regarded that a common ordinary carbon steel such as the AISI 1035 carbon steel in Ara would exhibit properties of residual magnetism and hysteresis in accordance with the definition of a hard magnetic material even in the Van Vlack text referenced by appellants.

Ara teaches that the ferromagnetic carbon steel utilized changes its phase from mixed ferrite/pearlite to martensite. To fully assess the meaning of this, we have obtained additional pages from the same Van Vlack text[9] as

[9] We are dealing with pages 247, 249, 253 to 255 and 257. Copies are attached to this opinion.

appellants have submitted for our consideration. Page 249 of this text indicates that a ferrite or alpha iron state is a ferromagnetic material at temperatures under 1414 degrees F.[10] Ara's alternative or mixed phase description of the common ferromagnetic carbon steel used therein is the pearlite state. This phase state is defined in Van Vlack as a specific mixture of two phases formed by transforming austenite to ferrite and carbide. See pages 253 to 255 of Van Vlack's text. Again, because of the ferrite nature of the pearlite state, it would also be fairly characterized as being a ferromagnetic material. Therefore, the pearlite state would be reasonably expected to exhibit properties of a permanent magnet material in accordance with the definitions and understanding established earlier in this opinion. These are consistent with appellants' reliance upon other referenced Van Vlack text pages and arguments regarding permanent magnet materials. Therefore, the position that the initial state of the common carbon steel in Ara is that it is softly magnetic and does not have permanent magnetic material properties is contrary to the weight of the evidence.

[10] Page 249 of Van Vlack also indicates that the austenite state is not ferromagnetic at any temperature. This is consistent with the nomenclature used to describe the stainless steel alternatively taught in Ara which is said to be in a nonmagnetic austenite state.

In contrast to appellants' broad assertions at page 3 of the reply brief, there is no clear refutation of the examiner's position based upon his definition of ferromagnetic materials as well as his view of Ara's teachings as they relate to ferromagnetic carbon steel taught therein. We have shown that the examiner's view of this reference is consistent with appellants' reliance upon the initially submitted pages of the Van Vlack reference as to what is a permanent magnet material. It is also consistent with appellants' own disclosed views of the type of materials they utilized with which to embody the claimed invention.

Appellants' position at page 8 of the principal brief on appeal that Ara's practice would not work on a permanent magnet material apparently because the magnetic field would magnetize the whole of the permanent magnet body would appear to us to apply to appellants' disclosed invention as well. While the claim requires that a magnetic field be imposed upon a heated volume to selectively magnetize it, in fact, the disclosed invention in Figure 1 clearly indicates that a magnetic field is not selectively imposed but is imposed upon the entire substrate of unmagnetized permanent magnet material. Therefore, we would reasonably expect that, because the substrate is a permanent magnet material, once it is exposed to a magnetic field, irrespective of whether or not the entire substrate is heated, the unheated portions of the substrate would have reasonably been expected to become magnetized because it is a permanent magnet material. Additionally, if appellants' position is correct that the magnetic field in Ara would magnetize the whole of the permanent magnet body, it is an implied admission that Ara's ferromagnetic carbon steel is a permanent magnet material.

Appellants' additional arguments that the product produced by the process set forth in claim 24 on appeal relies on an assessment of what the substance of the product actually is in the initial lines of the claim is no proof provided by appellants that a product so produced by the claimed method is any different than that which has been provided by Ara. The method of making the claimed magnet is immaterial in view of In re Thorpe, 777 F.2d 695, 227 USPQ 964 (Fed. Cir. 1985) and In re Brown, 459 F.2d 531, 173 USPQ 685 (CCPA 1972). Ordinarily, the patentability of the product claim does not depend on its method of production. If the product claim is the same as or obvious from a product of the prior art, the claim is unpatentable even though the prior product was made by a different process. In re Marosi, 710 F.2d 799, 218 USPQ 289 (Fed. Cir. 1983). The manner of making the claimed magnet has not been shown by appellants by appropriate evidence to be a structural feature. Note In re Thorpe, supra;

In re Marosi, supra; In re Fessmann, 489 F.2d 742, 180 USPQ 324 (CCPA 1974). Additionally, it is noted that attorney arguments are not evidence. In re Wiseman, supra, and In re Scarbrough, 500 F.2d 560, 182 USPQ 298 (CCPA 1974).

Finally, we make note that the additional pages of the same Van Vlack text cited to us by appellants and the two dictionary definitions are considered standard reference works and are relied upon by us to substantiate facts in the evidentiary showing made by the examiner. In re Boon, 439 F.2d 724, 169 USPQ 231 (CCPA 1971). As such, they are not considered to be a basis of a new ground of rejection.

To clarify the record, we note in passing that the table of properties of selected hard magnetic materials from the enclosed pages of the McGraw-Hill Encyclopedia of Science and Technology[11] would have indicated to the artisan that the essence of appellants' claimed methodology appears to have been known in the art. The designation "MFA" at page 37 of the encyclopedia indicates that to form a hard or permanent magnet, it was known in the art to cool a heated[12] permanent magnet material in a

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[11] McGraw-Hill Encyclopedia of Science and Technology, Vol. 8, McGraw-Hill, Inc., (1971), pages 36-37. Copies are attached to this opinion.

[12] Page 125 of those pages of the Van Vlack text supplied by appellants indicates that annealing promotes randomization of any (continued...)

magnetic field through the Curie temperature and below. It may well have been obvious to the artisan to have applied this well-known knowledge in the art to the teachings of Ara to form selected strong or relatively stronger magnetic field regions in a hard magnetic material. Additionally, the obviousness of using a higher carbon content steel than Ara's 0.35% would have been apparent to the artisan in view of common knowledge in the art that the 1% carbon steel (item 1, page 36) in this encyclopedia has been considered a hard magnetic material.

In summary, we have reversed the rejection of claims 13 to 22 and 24 under 35 U.S.C. § 103 in light of Chraplyvy alone. However, we have sustained the rejection of claims 13, 14, 16 to 20 and 24 under 35 U.S.C. §§ 102/103 over Ara alone and the rejection of claim 15 under 35 U.S.C. § 103 over Ara in view of Hattori. Accordingly, the decision of the examiner is affirmed-in-part since no outstanding rejection remains as to claims 21 and 22.

[12](...continued)
magnetic domain alignments. Cooling in or not in a magnetic field would have been inferred as desired.

No time period for taking any subsequent action in connection with this appeal may be extended under 37 C.F.R. § 1.136(a).

AFFIRMED-IN-PART

JAMES D. THOMAS)
Administrative Patent Judge)
)
RICHARD E. SCHAFER)
Administrative Patent Judge)
) BOARD OF PATENT
) APPEALS
) AND
) INTERFERENCES
JERRY SMITH)
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)
GARY V. HARKCOM)
Administrative Patent Judge)

Appeal No. 94-3541
Application 07/789,702

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MODERN DICTIONARY of ELECTRONICS

Rudolf F. Graf

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peripheral electron—*Also called a valence* electron. One of the outer electrons of an atom. Theoretically, it is responsible for visible light, thermal radiation, and chemical combination.

peripheral equipment—*Units which work in* conjunction with a computer but are not part of it (e.g., tape reader, analog-to-digital converter, typewriter, etc.).

peripheral transfer—The transmission of data *between two peripheral units.*

permalloy—A high-permeability magnetic alloy composed mainly of iron and nickel.

permanent echo—A radar echo from a fixed target.

permanent-field synchronous motor—A type of synchronous motor in which the member carrying the secondary laminations *and windings also carries* permanent-magnet field poles that are shielded from the alternating magnetic flux by the laminations. It behaves as an induction motor when starting but runs at synchronous speed.

permanent magnet—*A piece of hardened* steel or other magnetic material which has been so strongly magnetized that it retains the magnetism indefinitely.

permanent-magnet centering—Vertical or *horizontal shifting of a television picture* by means of magnetic fields from permanent magnets mounted around the neck of the picture tube.

permanent-magnet focusing—Focusing of the electron beam in a television picture tube by means of one or more permanent magnets located *around the neck.*

permanent-magnet material—Ferromagnetic material which, once having been *magnetized,* resists external demagnetizing forces (i.e., requires a high coercive force to remove the magnetism).

permanent-magnet, moving-coil instrument—Also called D'Arsonval instrument. *An instrument in which a reading is pro*duced by the reaction between the current in a movable coil or coils and the field of a fixed permanent magnet.

permanent-magnet, moving-iron instrument—Also called polarized-vane instrument. An instrument in which a reading is produced by an iron vane *as it aligns itself in* the magnetic field produced by a permanent magnet and by the current in an adjacent coil of the instrument.

permanent-magnet speaker—A moving-con*ductor speaker in which the steady magnetic* field is produced by a permanent magnet.

permanent-magnet stepping motor—A type of motor in which a permanent magnet serves as the rotor. Current is switched *sequentially through different stator coils,* and the rotor aligns itself with the energized stator poles.

permanent magnistor—A saturable reactor which has the properties of memory and the ability to handle appreciable power.

permanent memory—A type of storage de*vice that retains data intact when the com*puter has been shut down.

permanent-memory computer—A computer in which the stored information remains intact, even after the power has been turned *off.*

permanent set—The deformation that remains in a specimen after it has been stressed in tension for a definite time interval and released for a definite time in*terval.*

permanent storage—A computer storage device which retains the stored data indefinitely.

permatron—A thermionic gas diode, the dis*charge of which is controlled by an external* magnetic field. It is used mainly as a controlled rectifier and functions like a thyratron.

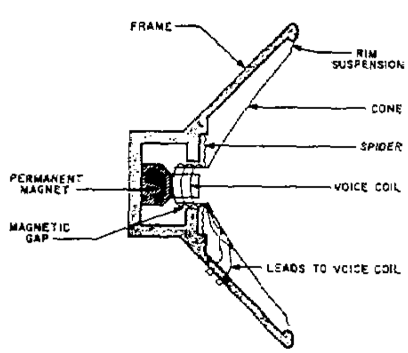
permeability—Symbolized by the Greek letter *mu* (μ). The measure of how much better a given material is than air as a path for magnetic lines of force. (Air is assumed to have a permeability of 1.) It is equal to the magnetic induction (B) in gausses, divided by the magnetizing force (H) in oersteds.

permeability tuning—A method of tuning a circuit by moving a magnetic core into or out of a coil to vary its inductance.

permeameter—An apparatus for determining *the magnetizing force and flux density in a* test specimen. From these values, the normal induction curves or hysteresis loops can then be plotted and the magnetic permeability computed.

permeance—The reciprocal of reluctance. Through any cross section of a tubular portion of a magnetic circuit bounded by lines of force and by two equipotential surfaces, permeance is the ratio of the flux to the magnetic potential difference between the surfaces under consideration. In the cgs system, *it is equal to the magnetic flux (in* maxwells) divided by the magnetomotive force (in gilberts).

permissive control device—*Generally a two-*position, manually operated switch which in one position permits the closing of a cir-



Permanent-magnet speaker.

cuit breaker or the placing
into operation, and in th
prevents the circuit break
ment from being operated.

permittivity—*See* Dielectric

permutation table—In co
for use in the systematic
code groups. It may also
correction of garbles in gro

peroxide of lead—A lead
forms the principal part
plate in a charged lead-ac.

perpendicular magnetizat
recording, magnetization t
ular to the line of *travel*
the smallest cross-sectional
medium. Either single- or
magnetic heads may be use

persistence—The length of
dot glows on the screen
tube before going out—i.e
time it *takes to decay* fro
ness (reached during fluo
can no longer be seen.

persistence characteristic
cent screen)—Also called
acteristic. *The relationship*
by a graph) between the ti
screen is excited and the t
ant power.

persistence of vision—T
whereby the eye *retains*
short time after the field
appeared.

persistent current—A cur
netically induced and flows
a superconducting material

persistor—A bimetallic circ
age or readout in a compu
near absolute zero, and ch
sistive to a superconductive
current value.

persistron—A device in w
nescence and photocondu
bined into a single panel
ducing a steady or persist
pulsed signal input.

persuader—In a storage t
that *directs secondary emi*
electron-multiplier dynode

perveance—The space-charg
current divided by the th
of the anode voltage in a

petticoat insulator—An in
outward flaring lower par
to increase the length of
age path and keep part of
all times.

pF—Abbreviation for picof
pg—Abbreviation for power

pH—*A measure of the deg*
alkalinity of a solution. I
tion the pH value is 7. In
ranges from 0 to 7, and in
it ranges from 7 to 14.

phanotron—A term used pr
trial electronics to mean a
diode.

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Abbr

ied by a fence including
of indecision or neutral-
sitter *n*
:k and defense with the
the fences of a property
vt (14c) 1 : DEFEND 2
ith *off* 3 *dial Brit* : to
ke an effort : STRUGGLE
b : to provide a liveli-
esp. for oneself
ts: as a : a cushion (as
) between a boat and a
nd prevents chafing b
and streetcars to lessen
ısion d : a guard over
rame or a screen before
ield of leather attached
ider's legs — **fend·ered**
ident
.. fr. L, window] (1844)
ıs a : an oval opening
g the base of the stapes
led also *fenestra ova·lis*
:\ b : a round opening
d also *fenestra cochleae,*
; cut in bone — **fe·nes-**
fenestratus, fr. *fenestra*]
rovided with or charac-
openings or pores ⟨~
ıe arrangement, propor-
building 2 : an open-
:he operation of cutting
ıner ear and tympanum
ıal
ann, legendary band of
and of warriors defend-
: a member of a secret
zation dedicated to the
adj — **Fe·ni·an·ism** \-ə-
pale-fawn African fox
ssumed) VL *fenuculum,*
.. akin to L *fetus* fruitful
European herb (*Foen-*
e in No. America and
fen] (bef. 12c) 1 : hav-
uliar to or found in a fen
IF *fenugrec,* fr. L *fenum*
nous annual Asian herb
ls
offment is made
. AF, fr. *feoffer* to invest
f a fee
ef-ər, 'fēf-\ *n* (15c) : one
bearing, one that bears,
-**ars** (aqui**fer**)
a wild nature] (1661)
wild animal, fr. fem. of
elating to, or suggestive
.ted or cultivated : WILD
ome wild
-de-lance [F, lit., lance
enomous pit viper (*Bo-*
: *faran* to go, travel —
.ON, COMRADE 2 *archaic*
— more at FAIR] (1844)
ce of a religious holiday
(1853) : a weekday of a
al \-ē-əl\ *adj*
: FERAL
: the quality or state of
rly strange, fr. OE *fǣrlic*
FEAR] *Scot* (13c) : WON-
· to stop, fr. L *firmare* to
etion of the performer of
:n time value; *also* : the
o *hold*
fermentation 2 : to be
1 : to cause to undergo
f agitation) : FOMENT —
rmentum yeast — more
a yeast) that causes fer-
ME 2 a : a state of un-
disorderly development
William Barrett)
601) 1 a : a chemical
lly controlled anaerobic

breakdown of an energy-rich compound (as a carbohydrate to carbon dioxide and alcohol or to an organic acid); *broadly* : an enzymatically controlled transformation of an organic compound 2 : FERMENT 2

fer·men·ta·tive \(,)fər-'ment-ət-iv\ *adj* (1661) 1 : causing or producing a substance that causes fermentation ⟨~ organisms⟩ 2 : of, relating to, or produced by fermentation

fer·men·ter \(,)fər-'ment-ər\ *n* (1918) 1 : an organism that causes fermentation 2 *or* **fer·men·tor** : an apparatus for carrying out fermentation

fer·mi \'fe(ə)r-(,)mē, 'fər-\ *n* [Enrico *Fermi*] (1955) : a unit of length equal to 10^{-13} centimeter

fer·mi·on \'fer-mē-,än, 'fər-\ *n* [Enrico *Fermi* + E ²-*on*] (1947) : a particle (as an electron, proton, or neutron) whose spin quantum number is an odd multiple of ½

fer·mi·um \'fer-mē-əm, 'fər-\ *n* [Enrico *Fermi*] (1955) : a radioactive metallic element artificially produced (as by bombardment of plutonium with neutrons) — see ELEMENT table

fern \'fərn\ *n* [ME, fr. OE *fearn*; akin to OHG *farn* fern, Skt *parṇa* wing, leaf] (bef. 12c) : any of numerous flowerless seedless plants constituting a class (Filicineae) of lower vascular plants; *esp* : any of an order (Filicales) resembling seed plants in being differentiated into root, stem, and leaflike fronds and in having vascular tissue but differing in reproducing by spores — **fern·like** \-,līk\ *adj* — **ferny** \'fər-nē\ *adj*

fern·ery \'fərn-(ə-)rē\ *n, pl* **-er·ies** (1840) 1 : a place or stand where ferns grow 2 : a collection of growing ferns

fern seed *n* (1596) : the dustlike asexual spores of ferns formerly taken for seeds and thought to make the possessor invisible

fe·ro·cious \fə-'rō-shəs\ *adj* [L *feroc-, ferox,* lit., fierce looking, fr. *ferus* + *-oc-, -ox* (akin to Gk *ōps* eye) — more at EYE] (1646) 1 : exhibiting or given to extreme fierceness and unrestrained violence and brutality 2 : extremely intense ⟨~ heat⟩ *syn* see FIERCE — **fe·ro·cious·ly** *adv* — **fe·ro·cious·ness** *n*

fe·roc·i·ty \fə-'räs-ət-ē\ *n* (1606) : the quality or state of being ferocious

-f·er·ous \f-(ə-)rəs\ *adj comb form* [ME, fr. MF & L; MF *-fere* -fer, fr. L *-fer*] : bearing : producing ⟨carboni*ferous*⟩

fer·rate \'fe(ə)r-,āt\ *n* [ISV, fr. L *ferrum* iron + ¹-*ate*] (1854) : a compound containing iron and oxygen in the anion; *esp* : a red salt analogous to the chromates and sulfates

fer·re·dox·in \,fer-ə-'däk-sən\ *n* [L *ferrum* + E *redox* + *-in*] (1962) : any of a group of iron-containing plant proteins that function as electron carriers in photosynthetic organisms and in some anaerobic bacteria

¹**fer·ret** \'fer-ət\ *n* [ME *furet, ferret,* fr. MF *furet,* fr. (assumed) VL *furittus,* lit., little thief, dim. of L *fur* thief — more at FURTIVE] (14c) 1 : a partially domesticated usu. albino European polecat that is sometimes classed as a separate species (*Mustela furo*) and is used esp. for hunting rodents 2 : an active and persistent searcher — **fer·rety** \-ət-ē\ *adj*

²**ferret** *vi* (15c) 1 : to hunt with ferrets 2 : to search about ~ *vt* 1 a (1) : to hunt (as rabbits) with ferrets (2) : to drive esp. from covert b : to find and bring to light by searching — usu. used with *out* ⟨~ out the answers⟩ 2 : HARRY, WORRY — **fer·ret·er** *n*

³**ferret** *n* [prob. modif. of It *fioretti* floss silk, fr. pl. of *fioretto,* dim. of *fiore* flower, fr. L *flor-, flos* — more at BLOW] (1649) : a narrow cotton, silk, or wool tape — called also *ferreting*

ferri- *comb form* [L, fr. *ferrum*] 1 : iron ⟨*ferri*ferous⟩ 2 : ferric iron ⟨*ferri*cyanic⟩

fer·ri·age \'fer-ē-ij\ *n* [ME] (14c) 1 : the fare paid for a ferry passage 2 : the act or business of transporting by ferry

fer·ric \'fer-ik\ *adj* (1799) 1 : of, relating to, or containing iron 2 : being or containing iron usu. with a valence of three

ferric ammonium citrate *n* (1938) : a complex salt containing varying amounts of iron and used esp. for making blueprints

ferric chloride *n* (ca. 1895) : a deliquescent dark salt $FeCl_3$ that readily hydrates to the yellow-orange form and that is used in sewage treatment and as an astringent

ferric hydroxide *n* (ca. 1909) : a hydrate $Fe_2O_3{\cdot}nH_2O$ of ferric oxide that is capable of acting both as a base and as a weak acid

ferric oxide *n* (1882) : the red or black oxide of iron Fe_2O_3 found in nature as hematite and as rust and also obtained synthetically and used as a pigment and for polishing

fer·ri·cy·a·nide \,fer-,ī-'sī-ə-,nīd, ,fer-i-\ *n* [ISV] (1845) 1 : the negative trivalent radical $Fe(CN)_6$ 2 : a compound containing the negative trivalent radical $Fe(CN)_6$; *esp* : the red salt $K_3Fe(CN)_6$ used in making blue pigments

fer·rif·er·ous \fə-'rif-(ə-)rəs, fe-\ *adj* (1811) : containing or yielding iron

fer·ri·mag·net·ic \'fer-,ī-mag-'net-ik, ,fer-i-\ *adj* (1951) : of or relating to a substance (as ferrite) characterized by magnetization in which one group of magnetic ions is polarized in a direction opposite to the other — **fer·ri·mag·net** \'fer-,ī-,mag-nət, 'fer-i-\ *n* — **fer·ri·mag·net·i·cal·ly** \'fer-,ī-mag-'net-i-k(ə-)lē, ,fer-i-\ *adv* — **fer·ri·mag·ne·tism** \-'mag-nə-,tiz-əm\ *n*

Fer·ris wheel \'fer-əs-\ *n* [G. W. G. *Ferris* †1896 Am. engineer] (1893) : an amusement device consisting of a large upright power-driven wheel carrying seats that remain horizontal around its rim

fer·rite \'fe(ə)r-,īt\ *n* (1851) 1 : any of several magnetic substances that consist essentially of an iron oxide combined with one or more metals (as manganese, nickel, or zinc), have high magnetic permeability and high electrical resistivity, and are used esp. in computer memories 2 : a solid solution in which alpha iron is the solvent — **fer·rit·ic** \fə-'rit-ik, fe-\ *adj*

fer·ri·tin \'fer-ət-ᵊn\ *n* [*ferrite* + *-in*] (1937) : a crystalline iron-containing protein that functions in the storage of iron and is found esp. in the liver and spleen

ferro- *comb form* [ML, fr. L *ferrum*] 1 : iron ⟨*ferro*concrete⟩ 2 : iron and ⟨*ferro*nickel⟩ — chiefly in names of alloys 3 : ferrous iron ⟨*ferro*cyanic⟩

fer·ro·cene \'fer-ō-,sēn\ *n* [*ferro-* + cyclopentadi*ene*] (1952) : a crystalline stable organometallic coordination compound $(C_5H_5)_2Fe$; *also* : an analogous compound with a heavy metal (as chromium)

fer·ro·con·crete \,fer-ō-'kän-,krēt, -kän-'\ *n* (1900) : REINFORCED CONCRETE

fer·ro·cy·a·nide \-'sī-ə-,nīd\ *n* (1845) 1 : the negative tetravalent radical $Fe(CN)_6$ 2 : a compound containing the negative tetravalent radical $Fe(CN)_6$; *esp* : the salt $K_4Fe(CN)_6$ used in making blue pigments (as Prussian blue)

fer·ro·elec·tric \,fer-ō-i-'lek-trik\ *adj* (1935) : of or relating to crystalline substances having spontaneous electric polarization reversible by an electric field — **ferroelectric** *n* — **fer·ro·elec·tric·i·ty** \-,lek-'tris-ət-ē, -'tris-tē\ *n*

fer·ro·mag·ne·sian \-mag-'nē-zhən, -shən\ *adj* (1899) : containing iron and magnesium ⟨~ minerals⟩

fer·ro·mag·net·ic \-'net-ik\ *adj* (1850) : of or relating to substances with an abnormally high magnetic permeability, a definite saturation point, and appreciable residual magnetism and hysteresis — **fer·ro·mag·net** \'fer-ə-,mag-nət\ *n* — **fer·ro·mag·ne·tism** \,fer-ō-'mag-nə-,tiz-əm\ *n*

¹**fer·ro·type** \'fer-ə-,tīp\ *n* (1844) 1 : a positive photograph made by a collodion process on a thin iron plate having a darkened surface 2 : the process by which a ferrotype is made

²**ferrotype** *vt* (ca. 1890) : to give a gloss to (a photographic print) by squeegeeing facedown while wet on a ferrotype plate and allowing to dry

fer·rous \'fer-əs\ *adj* [NL *ferrosus,* fr. L *ferrum*] (1865) 1 : of, relating to, or containing iron 2 : being or containing iron with a valence of two

ferrous oxide *n* (1873) : a black easily oxidizable powder FeO that is the monoxide of iron

ferrous sulfate *n* (1865) : a salt $FeSO_4$; *esp* : COPPERAS

fer·ru·gi·nous \fə-'rü-jə-nəs, fe-\ *also* **fer·ru·gin·e·ous** \,fer-(y)ü-'jin-ē-əs\ *adj* [L *ferrugineus, ferruginus,* fr. *ferrugin-, ferrugo* iron rust, fr. *ferrum*] (1661) 1 : of, relating to, or containing iron ⟨a ~ soil⟩ 2 : resembling iron rust in color

¹**fer·rule** \'fer-əl\ *n* [alter. of ME *virole,* fr. MF, fr. L *viriola,* dim. of *viria* bracelet, of Celtic origin; akin to OIr *fiar* oblique — more at VEER] (15c) 1 : a ring or cap usu. of metal put around a slender shaft (as a cane or a tool handle) to strengthen it or prevent splitting 2 : a short tube or bushing for making a tight joint (as between pipes)

²**ferrule** *vt* **fer·ruled; fer·rul·ing** (15c) : to supply with a ferrule

¹**fer·ry** \'fer-ē\ *vb* **fer·ried; fer·ry·ing** [ME *ferien,* fr. OE *ferian* to carry, convey; akin to OE *faran* to go — more at FARE] *vt* (bef. 12c) 1 a : to carry by boat over a body of water b : to cross by a ferry 2 a : to convey (as by aircraft or motor vehicle) from one place to another : TRANSPORT b : to fly (an airplane) from the factory or other shipping point to a designated delivery point or from one base to another ~ *vi* : to cross water in a boat

²**ferry** *n, pl* **ferries** (13c) 1 : a place where persons or things are carried across a body of water (as a river) in a boat 2 : FERRYBOAT 3 : a franchise or right to operate a ferry service across a body of water 4 : an organized service and route for flying airplanes esp. across a sea or continent for delivery to the user

fer·ry·boat \'fer-ē-,bōt\ *n* (14c) : a boat used to ferry passengers, vehicles, or goods

fer·ry·man \-mən\ *n* (12c) : a person who operates a ferry

fer·tile \'fərt-ᵊl\ *adj* [ME, fr. MF & L; MF, fr. L *fertilis,* fr. *ferre* to carry, bear — more at BEAR] (15c) 1 a : producing or bearing fruit in great quantities : PRODUCTIVE b : characterized by great resourcefulness of thought or imagination : INVENTIVE ⟨a ~ mind⟩ c *obs* : PLENTIFUL 2 a (1) : capable of sustaining abundant plant growth ⟨~ soil⟩ (2) : affording abundant possibilities for development ⟨a ~ area for research⟩ b : capable of growing or developing ⟨~ egg⟩ c (1) : capable of producing fruit (2) *of an anther* : containing pollen (3) : developing spores or spore-bearing organs d : capable of breeding or reproducing 3 : capable of being converted into fissionable material ⟨~ uranium 238⟩ — **fer·tile·ly** \-ᵊl-(l)ē\ *adv* — **fer·tile·ness** \-ᵊl-nəs\ *n*

syn FERTILE, FECUND, FRUITFUL, PROLIFIC mean producing or capable of producing offspring or fruit. FERTILE implies the power to reproduce in kind or to assist in reproduction and growth; applied figuratively, it suggests readiness of invention and development; FECUND emphasizes abundance or rapidity in bearing fruit or offspring; FRUITFUL adds to FERTILE and FECUND the implication of desirable or useful results; PROLIFIC stresses rapidity of spreading or multiplying by or as if by natural reproduction.

fer·til·i·ty \(,)fər-'til-ət-ē\ *n* (15c) 1 : the quality or state of being fertile 2 : the birthrate of a population

fer·til·iza·tion \,fərt-ᵊl-ə-'zā-shən\ *n* (ca. 1787) : an act or process of making fertile: as a : the application of fertilizer b (1) : an act or process of fecundation, insemination, impregnation, or pollination (2) : the process of union of two germ cells whereby the somatic chromosome number is restored and the development of a new individual is initiated

fertilization membrane *n* (1931) : a resistant membranous layer of many eggs that prevents multiple fertilization by separating from the surface immediately after entry of a sperm

fer·til·ize \'fərt-ᵊl-,īz\ *vt* **-ized; -iz·ing** (1648) : to make fertile: as a : to cause the fertilization of b : to apply a fertilizer to ⟨~ land⟩ — **fer·til·iz·able** \-,ī-zə-bəl\ *adj*

fer·til·iz·er \-,ī-zər\ *n* (1661) : one that fertilizes; *specif* : a substance (as manure or a chemical mixture) used to make soil more fertile

fer·ule \'fer-əl\ *also* **fer·u·la** \'fer-(y)ə-lə\ *n* [L *ferula* giant fennel, ferule] (1599) 1 : an instrument (as a flat piece of wood) used to punish children 2 : school discipline

fe·ru·lic acid \fə-,rü-lik-\ *n* [*ferula*] (1876) : a white crystalline acid that is structurally related to vanillin and is obtained esp. from plant sources (as aspen bark)

fer·ven·cy \'fər-vən-sē\ *n, pl* **-cies** (15c) : FERVOR

fer·vent \'fər-vənt\ *adj* [ME, fr. MF & L; MF, fr. L *fervent-, fervens,* prp. of *fervēre* to boil, glow — more at BURN] (14c) 1 : very hot : GLOWING 2 : exhibiting or marked by great intensity of feeling : ZEALOUS ⟨~ prayers⟩ *syn* see IMPASSIONED — **fer·vent·ly** *adv*

URGY

elements of materials science

AN INTRODUCTORY TEXT FOR ENGINEERING STUDENTS

by

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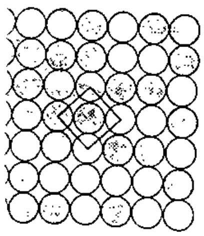

(c)

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ition may arise from
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opper-rich dendrites
on, Chase Brass and

h engineer specifies

A segregation of the atoms may remain in the solid if the cooling is slow enough to permit diffusion in the liquid (where it can take place quite rapidly) but too fast for complete diffusion to occur in the solid* (Fig. 9–16).

• **Example 9–7**

Describe the diffusion necessary for the equilibrium solidification of a melt containing 75% SiO_2 and 25% Al_2O_3 (Fig. 9–9).

Answer: The liquid phase above 1750°C has an amorphous structure composed of SiO_4 tetrahedra and AlO_6 octahedra (Figs. 8–9, 8–16c, and 8–17).

Below the liquidus, the aluminum, silicon, and oxygen atoms segregate from the liquid in the ratios of 6, 2, and 13, respectively, to form the crystal structure of mullite, $Al_6Si_2O_{13}$. The remaining liquid is reduced in alumina and enriched in silica until the eutectic composition is reached, at 1595°C. At this temperature, if equilibrium is to be maintained, the remaining aluminum atoms and some of the silicon and oxygen atoms form mullite. The excess silicon and oxygen form cristobalite.

Because strong Si—O and Al—O bonds must be broken, this diffusion process is extremely slow.

IRON-CARBON ALLOYS

9–10 Introduction. Steels, which are primarily alloys of iron and carbon, offer illustrations of the majority of reactions and microstructures available to the engineer for adjusting material properties. Also, the iron-carbon alloys have become the most predominant among structural engineering materials. Current production of iron and steel exceeds 120,000,000 tons per year (Fig. 9–17), a rate equivalent to more than 400 tons of steel per year for each engineer in this country. It is almost certain that an engineer will at some time find it part of his task to make, to specify, or to utilize steel in one form or another.

The versatility of the steels as engineering materials is evidenced by the many kinds of steel that are manufactured. At one extreme are the very soft steels used for deep-drawing applications such as automobile fenders and refrigerator panels. At the other are the extremely hard and tough steels used for gears and bulldozer blades. Some steels must have abnormally high resistance to corrosion. Steels for such electrical purposes as transformer sheets must have special magnetic characteristics so that they may be magnetized and demagnetized many times each second with low power losses. Other steels must be completely nonmagnetic, for such applications as wrist watches and minesweepers. Phase diagrams can be used to help explain each characteristic described above.

9–11 The Fe-C phase diagram. ~~Pure iron changes its crystal structure from body-centered to face-centered cubic~~ as it is heated beyond 1670°F (910°C). This change and a subsequent one at 2550°F (1400°C) are indicated in Fig. 9–18, and are compared with phase changes in water.

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* Diffusion will always be much more rapid in a liquid than in a solid because the atoms are more tightly bonded in the latter.

Ferrite, or α-iron. The structural modification of pure iron at room temperature is called either *α-iron* or *ferrite*. Ferrite is quite soft and ductile; in the purity which is encountered commercially, its tensile strength is less than 45,000 psi. It is a ferromagnetic material at temperatures under 1414°F.

Since ferrite has a body-centered cubic structure, the interatomic spaces are small and pronouncedly oblate, and cannot readily accommodate even a small spherical carbon atom (Fig. 9-19). Therefore, solubility of carbon in ferrite is very low. The carbon atom is too small for substitutional solid solution, and too large for extensive interstitial solid solution (Section 4-3).

Austenite, or γ-iron. The face-centered modification of iron is called *austenite*, or *γ-iron*. It is the stable form of pure iron at temperatures between 1670°F and 2550°F. Making a direct comparison between the mechanical properties of austenite and ferrite is difficult because they must be compared at different temperatures. However, at its stable temperatures, austenite is soft and ductile and consequently is well suited to fabrication processes. Most steel forging and rolling operations are performed at 2000°F or above, when the iron is face-centered cubic. Austenite is not ferromagnetic at any temperature.

The face-centered cubic structure of iron (Fig. 9-20) has larger interatomic spacings than does ferrite. Figures 9-20 and 9-19 provide a direct comparison between the possibility for interstitial solid solution in austenite and in ferrite. Even so, in the fcc structure the holes are barely large enough to crowd the carbon atoms into the interstices, and this crowding introduces strains into the structure. As a result, not all the holes can be filled at any one time. The maximum solubility is only 2% (8.7 a/o) carbon (Fig. 9-21). By definition, steels contain less than 2% carbon; thus steels may have their carbon completely dissolved in austenite at high temperatures.

δ-iron. Above 2550°F austenite is no longer the most stable form of iron, since then the crystal structure changes back to a body-centered cubic phase called *δ-iron*. δ-iron is the same as α-iron except for its temperature range, and so it is commonly called δ-ferrite. The solubility of carbon in δ-ferrite is small, but it is appreciably larger than in α-ferrite, because of the higher temperature.

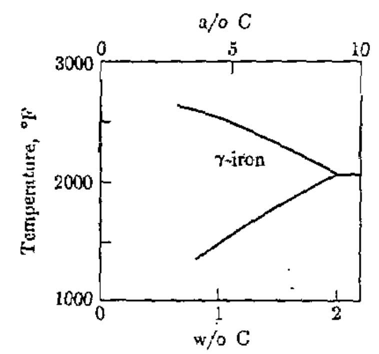
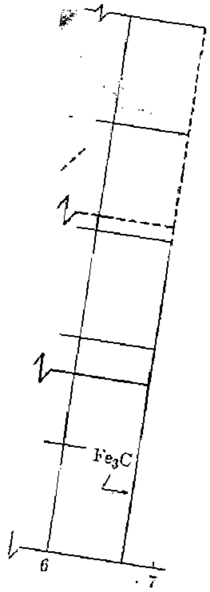


FIG. 9-21. Solubility of carbon in austenite (γ-iron).



ɜs. 9–21 and 9–24(b).

ent of iron and steel

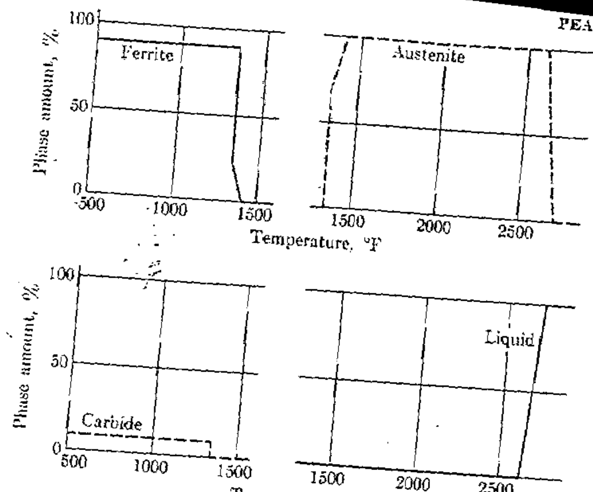


FIG. 9–27. Equilibrium amounts of phases (0.6% carbon-99.4% iron alloy). See Example 9–8.

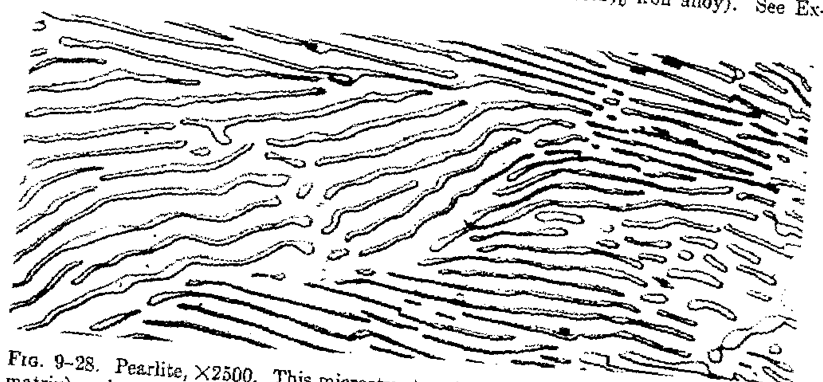
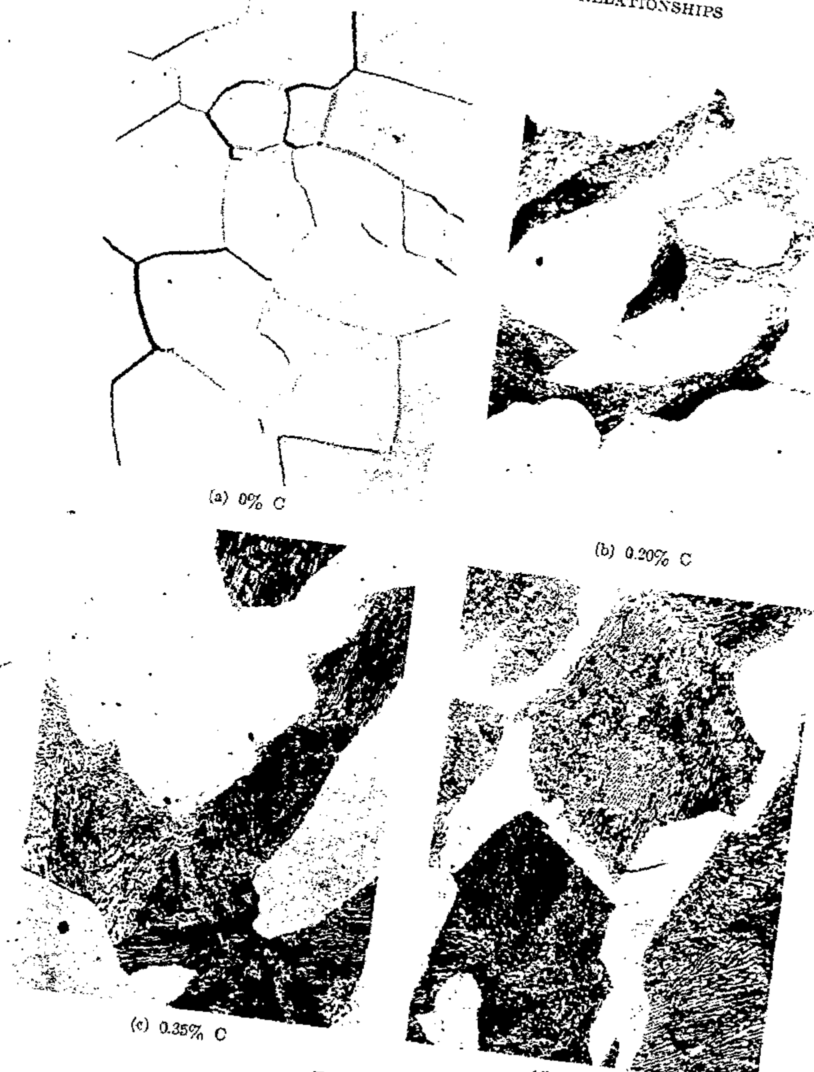


FIG. 9–28. Pearlite, ×2500. This microstructure is a lamellar mixture of ferrite (lighter matrix) and carbide (darker). Pearlite forms from austenite of eutectoid composition. Therefore the amount and composition of pearlite is the same as the amount and composition of eutectoid. (J. R. Vilella, U. S. Steel Corp.)

9–12 Pearlite. The Fe-C eutectoid reaction involves the simultaneous formation of ferrite and carbide from austenite of eutectoid composition. There is nearly 12% carbide and slightly more than 88% ferrite in the resulting mixture. Since the carbide and ferrite form simultaneously, they are intimately mixed. Characteristically, the mixture is lamellar, i.e., it is composed of alternate layers of ferrite and carbide (Fig. 9–28). The resulting microstructure, called *pearlite*, is very important in iron and steel technology, because it may be formed in almost all steels by means of suitable heat treatments.



(a) 0% C (b) 0.20% C (c) 0.35% C (d) 0.5% C

FIGURE 9–29

Pearlite is a specific mixture of two phases formed by transforming austenite of eutectoid composition to ferrite and carbide. This distinction is important, since mixtures of ferrite and carbide may be formed by other reactions as well. However, the microstructure resulting from other reactions will not be lamellar (com-

.20% C

% C

orming austenite of
is important, since
ons as well. How-
be lamellar (com-

(e) 0.7% C

(f) 0.9% C

Fig. 9-29. Photomicrographs (×500) of Fe-C alloys, (a) through (g). The amount of pearlite is directly related to the composition of the steel. (United States Steel Corp.)

(g) 1.2% C

pare Figs. 11-13 and 9-28) and consequently the properties of such mixtures will be different. (See Section 11-4.)

Since pearlite comes from austenite of eutectoid composition, the amount of pearlite present is equal to the amount of eutectoid austenite transformed (Fig. 9-29).

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perature. Basis: 100 lb

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TABLE 9–1

NOMENCLATURE FOR AISI AND SAE STEELS

AISI or SAE number	Composition
10xx	Plain carbon steels
11xx	Plain carbon (resulfurized for machinability)
13xx	Manganese (1.5-2.0%)
23xx	Nickel (3.25-3.75%)
25xx	Nickel (4.75-5.25%)
31xx	Nickel (1.10-1.40%), chromium (0.55-0.90%)
33xx	Nickel (3.25-3.75%), chromium (1.40-1.75%)
40xx	Molybdenum (0.20-0.30%)
41xx	Chromium (0.40-1.20%), molybdenum (0.08-0.25%)
43xx	Nickel (1.65-2.00%), chromium (0.40-0.90%) molybdenum (0.20-0.30%)
46xx	Nickel (1.40-2.00%), molybdenum (0.15-0.30%)
48xx	Nickel (3.25-3.75%), molybdenum (0.20-0.30%)
51xx	Chromium (0.70-1.20%)
61xx	Chromium (0.70-1.10%), vanadium (0.10%)
81xx	Nickel (0.20-0.40%), chromium (0.30-0.55%), molybdenum (0.08-0.15%)
86xx	Nickel (0.30-0.70%), chromium (0.40-0.85%), molybdenum (0.08-0.25%)
87xx	Nickel (0.40-0.70%), chromium (0.40-0.60%), molybdenum (0.20-0.30%)
92xx	Silicon (1.80-2.20%)

xx—carbon content, 0.xx%.
Mn—All steels contain 0.50% ± manganese.

B—Prefixed to show bessemer steel.
C—Prefixed to show open-hearth steel.
E—Prefixed to show electric furnace steel.

9–13 Nomenclature for steels. The importance of carbon in steel has made it desirable to indicate the carbon content in the identification scheme of steel types. A four-digit numbering scheme is used, in which the last two digits designate the number of hundredths of percent of carbon content (Table 9–1). For example, a 1040 steel has 0.40% carbon (plus or minus a small workable range). The first two digits indicate the type of alloying element that has been added to the iron and carbon. The classification (10xx) is reserved for plain carbon steels with only a minimum amount of other alloying elements.

These designations for the steels are accepted as standard by both the American Iron and Steel Institute and the Society of Automotive Engineers (AISI and SAE). Many commercial steels are not included in this classification scheme because of larger additions or more subtle variations in alloy contents. Usually, however, such steels have more specialized applications and may not be stocked as regular warehouse items.

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8

MAC–MYZ

On preceding pages:

Left. Computer-calculated perspective drawing of a geodesic projection executed with the Gerber digital plotter. (R. D. Resch, Associate Research Professor, Computer Science, University of Utah)

Right. Epitaxial layer of silicon grown in the direction of the [111] plane. (General Motors Research Laboratories)

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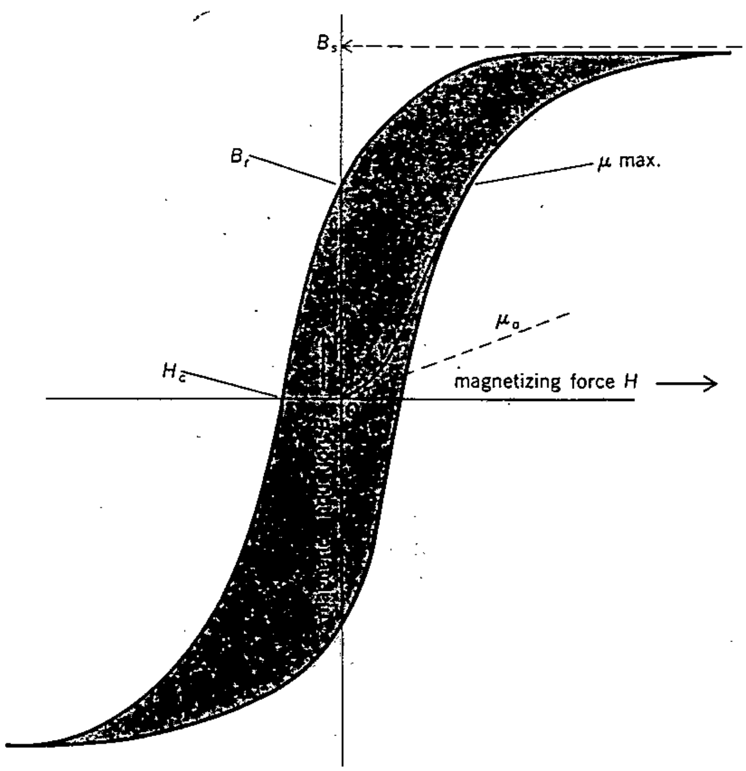
Table 2. Some properties of selected hard magnetic materials

	Material or trade name	Composition, % by weight, remainder Fe	Coercive force H_c, oersteds	Residual induction B_r, gauss	Energy product $(B \cdot H)_{max}$, gauss-oersteds
1	1% carbon steel	1 C, 0.50 Mn	51	9,000	0.18
2	5% Tungsten steel	5 W, 0.7 C	70	10,500	0.33
3	3 1/2% Chromium steel	3.5 Cr, 1 C, 0.5 Mn	66	9,500	0.29
4	9% Cobalt steel	9 Co, 0.9 C, 1.25 W, 5 Cr	122	7,800	0.41
5	40% Cobalt steel	40 Co, 0.7 C, 5 W, 4.25 Cr	242	10,000	1.03
6	Alnico 1	12 Al, 22.5 Ni, 5 Co	540	6,600	1.40
7	Alnico 2	10 Al, 18 Ni, 13 Co, 6 Cu	650	7,000	1.70
8	Alnico 3	12 Al, 26 Ni, 3 Cu	560	6,400	1.35
9	Alnico 5	8 Al, 15 Nc, 24 Co, 3 Cu	720	12,000	5.0
10	Alnico 5 DG	8 Al, 14.5 Ni, 24 Co, 3 Cu	700	13,100	6.5
11	Alnico 6	8 Al, 16 Ni, 24 Co, 3 Cu, 1 Ti	760	10,500	3.65
12	Alnico 8	7 Al, 15 Ni, 35 Co, 4 Cu, 5 Ti	1,600	10,400	5.50
13	Remalloy	12 Co, 17 Mo	250	10,500	1.1
14	Cunife	60 Cu, 20 Ni	590	5,400	1.85
15	Cunico	50 Cu, 21 Ni, 29 Co	710	3,400	0.85
16	Vicalloy 2	52 Co, 13 V	450	10,000	3.0
17	Pt-Co (Platinax II)	76.7 Pt, 23.3 Co	4,600	6,480	9.4
18	Indox, ferrimag ceramagnet	$BaO \cdot 6 Fe_2O_3$	1,700	3,800	3.0
19	Westro alpha	$Sr_x Ba_{1-x} O \cdot 6 Fe_2O_3$	2,200	4,000	3.66
20	Elongated single domain iron	61 Hg, 4 Sn	765	9,150	4.3
21	Elongated single domain cobalt	60 Hg, 4 Sn	980	10,800	6.5



Key:
O = origin V = virgin magnetization curve
$\mu = B/H$; μ max. = point of maximum permeability (permeability)
B_s = saturation magnetic induction ($H = \infty$)
B_r = residual induction ($H = 0$)
H_c = coercive force ($B = 0$)

Fig. 4. Identification of properties related to the magnetic hysteresis loop. Colored area is the magnetization energy lost every cycle (hysteresis loss).

tage of the technical fact that the easiest direction of magnetization in an iron crystal is along a cube edge (Fig. 1). In singly oriented material the cube edges lie parallel to the rolling direction of the steel (Fig. 2). This is the principal direction of magnetic flux in their use—largely in transformers. In doubly oriented material the cube face lies in the plane of the sheet and the cube edges are aligned both parallel and transverse to the direction of rolling (Fig. 3).

Many special alloys find their use in special devices designed to exploit unusual properties. These include high saturation (B_s) materials, usually Co–Fe; and high permeability alloys (high μ), most often Ni–Fe. These alloys are the mainstay of the telecommunications industry. Some of the devices require high initial permeability μ_0 (the permeability at very low fields), and others may depend on high values of μ_{max}, the maximum permeability. *See* IRON-SILICON ALLOY; PERMALLOY.

In power equipment the major consideration is the power lost in the magnetic circuit under operating conditions. The total core loss P_c, consists of the hysteresis loss P_h and the eddy current loss P_e. The hysteresis loss represents the energy lost each cycle in the magnetization process. It is proportional to the area of the hysteresis loop and is directly dependent on the frequency. The loss due to eddy currents depends on the square of the electromotive force (emf) developed in the conducting magnetic material, that is, B^2f^2, and inversely on the electrical resistivity ρ of the material. By combining geometric factors into constants, the equation below is obtained.

$$P_{c(B,f)} = P_h + P_e = \text{const} \times f + \text{const} \times \frac{B^2 f^2}{\rho}$$

The hysteresis loss may be kept low by using a material with a narrow hysteresis loop (low H_c) and minimizing mechanical strain after the final stress-

Table 2. Some properties of selected hard magnetic materials (cont.)

Preferred operating point				
H_d, oersteds	B_d, gauss	Preparation	Heat treatment*	Mechanical properties
33	6,000	Hot roll, machine, punch	Q 800	Hard, strong
47	7,000	Hot roll, machine, punch	Q 850	Hard, strong
45	6,500	Hot roll, (temper) machine	Q 830	Hard, strong
78	5,100	Hot roll, hot form, grind	Q 890	Very hard, strong
158	6,500	Hot roll, hot form, grind	Q 930	Very hard, strong
340	4,100	Cast, grind		Hard, brittle, weak
390	4,300	Cast, grind		Hard, brittle, weak
340	3,900	Cast, grind		Hard, brittle, weak
540	9,100	Cast, grind	1300, MFA 900/800, B600	Hard, brittle, weak
590	11,000	Cast, grind	1300, MFA 900/800, B560	Hard, brittle, weak
520	7,000	Cast, grind	1300, MFA 900/800, B560	Hard, brittle, weak
980	5,340	Cast, grind	MFA	Hard, brittle, weak
160	6,900	Hot roll, machine, punch	Q1200, B700	Hard, strong, malleable
450	4,200	Draw, machine, punch	Q1070, B700	Ductile, 100 kpsi
430	2,000	Cold roll, machine, punch	Q1080, B625	Ductile, 100 kpsi
365	8,200	Cold roll, draw	B600 (pptn hardening)	Brittle after heat treatment
2,700	3,500	Cast, age	Q1200, B650	Hard, strong
		Sintered, ground, or lapped		Brittle
1,700	2,150	Press, sinter, fire		Brittle
		Add Sn, press in field		
		Add Sn, press in field		

*Q = quenched from indicated temperature (°C) in water or oil; B = baked at indicated temperature; MFA = cooled in a magnetic field through the Curie temperature and below; for example, heat to 1300, cool in magnetic field between 900 and 800 is listed as 1300, MFA 900/800.

relief anneal. Eddy current loss may be reduced by breaking up eddy current paths, for example, by using laminations rather than solid cores.

Audio-frequency devices require very thin laminations or resin-bonded alloy powder cores. The very high electrical resistivity ($1-10^6$ ohm-cm) qualifies many ferrites for very high frequencies. The computer industry uses large numbers of tiny ferrite cores or very thin alloy films.

Some of the properties mentioned above are given for soft magnetic materials in Table 1. Terms used in the table are partially illustrated in Fig. 4. Many other materials are discussed in the cross references. *See* FERRITE; HYSTERESIS, MAGNETIC; INDUCTION, MAGNETIC; MAGNETIC CIRCUITS; MAGNETIZATION.

Hard materials. The bulk of commercial permanent magnets are either Alnico or the ceramic type. The needs of special applications are filled by many special-property materials of proportionately smaller commercial value and higher unit cost. Elongated single-domain particles of Fe and Co embedded in another matrix have been used to manufacture permanent magnets.

The criteria for hard materials are large coercive force H_c, high remanence B_r, and as large as possible values of the energy product $(B \cdot H)_{max}$. Some properties are shown in Table 2.

Mechanical precautions must be followed in applying almost all permanent magnet materials, since only a few are ductile. Because of their low B_r, ceramic magnets are generally used in magnetic circuits in which an iron structure helps to concentrate the flux. *See* ALNICO; IRON ALLOYS.

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Magnetic moment

The relationship between a magnetic field and the torque exerted on a magnet, a current loop, or a charge that is moving in the field.

When a magnet is placed in a magnetic field of strength H, there is a torque L exerted on the magnet by the field. The torque is a maximum when the axis of the magnet is perpendicular to the field. The ratio of the torque for this position to the strength of the field is called the magnetic moment M of the magnet, as defined in Eq. (1). *See* MAGNET.

$$M = \frac{L}{H} \qquad (1)$$

If a flat coil of wire of N turns and area A, in which there is a current I, is placed in a magnetic field of flux density B, the coil experiences a torque L given by Eq. (2), where θ is the angle between the

$$L = NIAB \sin\theta \qquad (2)$$

field and the normal to the plane of the coil. The torque is maximum when $\theta = 90°$, that is, when the plane of the coil is parallel to the field. The ratio of the maximum torque to the flux density B is the magnetic moment of the coil, as shown in Eq. (3).

$$M = \frac{L}{B} = NIA \qquad (3)$$

Alternatively, the magnetic moment of the coil may be defined as the ratio of L to H. For this definition Eq. (4) holds, since $B = \mu_0 H$ in empty

$$M = \frac{L}{H} = \mu_0 NIA \qquad (4)$$

space, μ_0 being the permeability of empty space.