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Standard Terminology Relating to Metallography[1]

This standard is issued under the fixed designation E7; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This standard covers the definition of terms, acronyms, and symbols used in ASTM documents related to the field of metallography and metallographic testing. Terms that are only relevant to a particular standard or that are adequately defined in a general dictionary are not defined in this terminology standard.

1.2 This standard includes terminology used in metallographic areas, such as, but not limited to: light microscopy, microindentation hardness testing, specimen preparation, x-ray and electron metallography, quantitative metallography, photomicrography, and determination of grain size and inclusion content.

1.3 This standard may be of use to individuals utilizing standards of Committee E04 as well as by those in need of a general reference source for terminology in the field of metallography.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E80 Recommended Practice for Dilatometric Analysis of Metallic Materials; Replaced by E 228 (Withdrawn 1986)[3]

E45 Test Methods for Determining the Inclusion Content of Steel

E80 Recommended Practice for Dilatometric Analysis of Metallic Materials; Replaced by E 228 (Withdrawn 1986)[3]

E92 Test Method for Vickers Hardness of Metallic Materials (Withdrawn 2010)[3]

E112 Test Methods for Determining Average Grain Size

E1122 Practice for Obtaining JK Inclusion Ratings Using Automatic Image Analysis (Withdrawn 2006)[3]

3. Significance and Use

3.1 Standards of Committee E-4 consist of test methods, practices, and guides developed to ensure proper and uniform testing in the field of metallography. In order for one to properly use and interpret these standards, the terminology used in these standards must be understood.

3.2 The terms used in the field of metallography have precise definitions. The terminology and its proper usage must be completely understood in order to adequately communicate in this field. In this respect, this standard is also a general source of terminology relating to the field of metallography facilitating the transfer of information within the field.

4. Terminology

absorption—the decrease in intensity which radiation undergoes during its passage through matter when the ratio of transmitted or reflected luminous flux to incident is less than 1.

absorption coefficient—specific factor characteristic of a substance on which its absorption radiation depends. The rate of decrease of the natural logarithm of the intensity of a parallel beam per unit distance traversed in a substance. For X-rays, the linear absorption coefficient is the natural logarithm of the ratio of the incident intensity of an X-ray beam incident on unit thickness of an absorbing material to the intensity of the beam transmitted. If I_e is the incident intensity of a beam of X-rays, I_t the transmitted intensity, and X the thickness of the absorbing material, then:

$$I_t = I_e exp(-\mu X) \quad (1)$$

Here μ is the linear absorption coefficient. The mass absorption coefficient is given by μ/ρ where ρ is the density.

absorption edge—an abrupt change in absorption coefficient at a particular wavelength. The absorption coefficient is always larger on the short wavelength side of the absorption edge.

absorption limit—See **absorption edge.**

accelerating potential—a relatively high voltage applied between the cathode and anode of an electron gun to accelerate electrons.

[1] This terminology is under the jurisdiction of ASTM Committee E04 on Metallography and are the direct responsibility of Subcommittee E04.02 on Terminology.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

achromatic—literally, color-free. A lens or prism is said to be achromatic when corrected for two colors. The remaining color seen in an image formed by such a lens is said to be secondary chromatic aberration. See **apochromatic objective**

achromatic objective—an objective that is corrected chromatically for two colors, and spherically for one, usually in the yellow-green part of the spectrum.

achromatic objective lens—an objective lens with longitudinal chromatic correction for green and blue, and spherical chromatic correction for green. Note—Lens should be used with a green filter.

acid extraction—See **extraction.**

air-lock—an intermediate enclosed chamber of a vacuum or pressure system through which an object may be passed without materially changing the vacuum or pressure of the system.

alignment—a mechanical or electrical adjustment of the components of an optical device in such a way that the path of the radiating beam coincides with the optical axis or other predetermined path in the system. In electron optics there are three general types:

(*1*) *magnetic alignment*—an alignment of the electron optical axis of the electron microscope such that the image rotates about a point in the center of the viewing screen when the current flowing through a lens is varied.

(*2*) *mechanical alignment*—a method of aligning the geometrical axis of the electron microscope by relative physical movement of the components, usually as a step preceding either magnetic or voltage alignment.

(*3*) *voltage alignment*—a condition of alignment of an electron microscope such that the image expands or contracts symmetrically about the center of the viewing screen when the accelerating voltage is changed.

allotriomorphic crystal—a crystal whose lattice structure is normal, but whose outward shape is imperfect since it is determined to some extent by the surroundings; the grains in a metallic aggregate are allotriomorphic crystals.

alloy system—a complete series of compositions produced by mixing in all proportions any group of two, or more, components, at least one of which is a metal.

alpha brass—a solid solution phase of one or more alloying elements in copper and having the same crystal lattice as copper.

alpha iron (Fe)—solid phase of pure iron which is stable at temperatures below 910°C and possesses the body-centered cubic lattice. It is ferro-magnetic below 768°C.

amplifier—a negative lens, used in lieu of an eyepiece, to project under magnification the image formed by an objective. The amplifier is especially designed for flatness of field and should be used with an apochromatic objective.

ampliphan eyepiece— See **amplifier.**

analyzer—an optical device, capable of producing plane polarized light, used for detecting the state of polarization.

angle of reflection: (*1*) *reflection* —the angle between the reflected beam and the normal to the reflecting surface.
(*2*) *diffraction*—the angle between the diffracted beam and the diffracting planes.

Angstrom unit (abbreviation) = A,Å , or *A. U*—a unit of length equal to 10^{-8} cm. This is the standard unit of measurement in X-ray crystallography.

angular aperture—See **aperture, optical.**

anisotropic (replaces anisotropy)—having different values for a property, in different directions.

annealing-twin bands— See **twin bands.**

anode aperture—See **aperture.**

anvil—the base on which objects for hardness test are placed.

anvil effect—the effect caused by use of too high a load or when testing the hardness of too thin a specimen, resulting in a bulge or shiny spot on the under side of the specimen.

aperture, electron:—

anode aperture— the opening in the accelerating voltage anode shield of the electron gun through which the electrons must pass to illuminate or irradiate the specimen.

condenser aperture—an opening in the condenser lens controlling the number of electrons entering the lens and the angular aperture of the illuminating beam. The angular aperture can also be controlled by the condenser lens current.

physical objective aperture—a metal diaphragm, centrally pierced with a small hole, used to limit the cone of electrons accepted by the objective lens. This improves image contrast since highly scattered electrons are prevented from arriving at the Gaussian image plane and therefore can not contribute to background fog.

aperture, optical—the working diameter of a lens or a mirror.

angular aperture— the angle between the most divergent rays which can pass through a lens to form the image of an object.

aperture diaphragm—a device to define the aperture.

apochromatic objective—an objective with longitudinal chromatic correction for red, green and blue, and spherical chromatic correction for green and blue. This is the best choice for high resolution or color photomicrography.

arcing—in electron diffraction, the production of segments of circular patterns, indicating a departure from completely random orientation of the crystals of the specimen.

arrest—that portion of a cooling curve in which temperature is invariant with time (for example, thermal or eutectic arrest).

artifact—a false microstructural feature that is not an actual characteristic of the specimen; it may be present as a result of improper or inadequate preparation, handling methods, or optical conditions for viewing.

ascending fork point—in a ternary phase diagram, the configuration at the convergence of the three bivariant curves upon each of the four phases associated in Class II univariant equilibrium; for example, the union of two ascending liquidus surface valleys to form one ascending liquidus surface valley.

aspect ratio—the length-to-width ratio of a microstructural feature in a two-dimensional plane.

asterism—a lengthening of diffraction spots usually in the radial direction.

astigmatism—a defect in a lens or optical system which causes rays in one plane parallel to the optical axis to focus at a distance different from those in the plane at right angles to it.

ASTM grain size number— See **grain size.**

athermal—not isothermal, with changing rather than constant temperature conditions.

atomic replica—See **replica.**

atomic scattering factor—the ratio of the amplitude of the wave scattered by an atom to that scattered by a single electron. Symbol = *f*.

austenite—a face-centered cubic solid solution of carbon or other elements in gamma iron.

austenite grain size—the grain size which exists or existed in austenite at a given temperature. See Test Methods E112.

autographic dilatometer—a dilatometer that automatically records instantaneous and continuous changes in dimensions and some other controlled variable such as temperature or time.

autographic pyrometer— See **pyrometer.**

automatic image analysis—the separation and quantitative evaluation of an image into its elements with or without operator interaction. It includes the enhancement, detection, and quantification of the features contained in an image through the use of optical, geometrical, and stereological parameters and a computer program. Image analysis data output can provide individual measurements on each separate feature (feature specific) or totals for all features of a particular type in the field (field specific).

automatic image analyzer—a device which can be programmed to detect and measure features of interest in an image. It may include accessories such as automatic focus and an automatic traversing stage to permit unattended operation.

average coefficient of cubical expansion— average change in unit volume of a substance per unit change in temperature over a specified range of temperature.

average coefficient of linear expansion— average change in unit length of a body per unit change in temperature over a specified range of temperature.

average coefficient of thermal expansion— general term. (See also **average coefficient of cubical expansion** and **average coefficient of linear expansion.**)

average grain diameter— See **grain size.**

axial ratio—the ratio of the length of one axis to that of another (for example, *c*/*a*) or the continued ratio of three axes (for example, *a*:*b*:*c*).

axis (crystal)—the edge of the unit cell of a space lattice. Any one axis of any one lattice is defined, in length and direction, with respect to the other axes of that lattice.

Babo's law—the vapor pressure over a liquid solvent is lowered approximately in proportion to the quantity of a nonvolatile solute dissolved in the liquid.

backing film—a film used as auxiliary support for the thin replica or specimen-supporting film.

back reflection—the diffraction of X-rays at a Bragg angle approaching 90°.

background blackening—a continuous, slowly varying blackening of photographic film which has been exposed to diffracted X-rays, on which the blackening due to diffracted spots or lines is superimposed.

bainite—upper, lower, intermediate— metastable microstructure or microstructures resulting from the transformation of austenite at temperatures between those which produce pearlite and martensite. These structures may be formed on continuous (slow) cooling if the transformation rate of austenite to pearlite is much slower than that of austenite to bainite. Ordinarily, these structures may be formed isothermally at temperatures within the above range by quenching austenite to a desired temperature and holding for a period of time necessary for transformation to occur. If the transformation temperature is just below that at which the finest pearlite is formed, the bainite (upper bainite) has a feathery appearance. If the transformation temperature is just above that at which martensite is produced, the bainite (lower bainite) is acicular, resembling slightly tempered martensite. At the higher resolution of the electron microscope, upper bainite is observed to consist of plates of cementite in a matrix of ferrite. These discontinuous carbide plates tend to have parallel orientation in the direction of the longer dimension of the bainite areas. Lower bainite consists of ferrite needles containing carbide platelets in parallel array cross-striating each needle axis at an angle of about 60°. Intermediate bainite resembles upper bainite; however, the carbides are smaller and more randomly oriented.

balanced filters (X-rays)—a pair of filters used to eliminate all but a narrow range of wavelengths. The filter materials and thicknesses are chosen so that their absorption edges lie very close together and so that they have the same absorption except for wavelengths lying in the range between their absorption edges. When these filters are used alternately, the difference in effect, if any, is due to X-rays that have wavelengths in this range. Balanced filters thus can be made to serve as a crude monochromator.

band—in electron diffraction, a broad intensity maximum with sharp edges.

banded structure (banding)—alternate bands parallel with the direction of working resulting from the elongation of segregated areas.

barrel distortion— See **distortion.**

basal plane—that plane of a hexagonal or tetragonal crystal which is perpendicular to the axis of highest symmetry. Its Miller indices are (0001) or (001), respectively.

bellows length—the distance from the eyepiece to the photosensitive material or viewing screen in a photomicrographic apparatus.

Bertrand lens—an auxiliary removable lens in the body of a microscope, used to examine images in the back focal plane of the objective, for example, interference figures with polarized light.

beta structure—structurally analogous body-centered cubic phases (similar to beta brass), or electron compounds, that have ratios of 3 valence electrons to 2 atoms.

biased gun—an electron gun in which there is a bias voltage on the cathode cap. (See also **self-biased gun.**)

bifilar eyepiece—a Filar eyepiece with motion in two mutually perpendicular directions.

binary alloy—any specific composition in a binary system.

binary system—the complete series of compositions produced by mixing a pair of components in all proportions.

binodal curve—in a two-dimensional phase diagram, a continuous line consisting of both of the pair of conjugate boundaries of a two-phase equilibrium and which join, without inflection, at a critical point. See **miscibility gap.**

birefringent—having more than one refractive index. Such materials exhibit alternately bright and dark reflections at 45° intervals during a 360° rotation with plane-polarized light. (See also **anisotropic**.)

bivariant equilibrium—a stable state among a number of phases equal to the number of components in a system and in which any two of the external variables (temperature, pressure, or concentrations) may be varied, at will, without necessarily causing a change in the number of phases; sometimes called divariant equilibrium.

blowholes—a hole produced in a casting by gas which was trapped during solidification.

body-centered—having an atom (or group of atoms) separated by a translation of ½, ½, ½ from a similar atom (or group of atoms). The number of atoms in a body-centered cell must be a multiple of two.

boiling pressure—at a specified temperature, the pressure at which a liquid and its vapor are in equilibrium.

boiling temperature—at a specified pressure, the temperature at which a liquid and its vapor are in equilibrium.

bonded abrasive disk—a rigid support surface with an abrasive, typically diamond, bonded to the surface by a ceramic, resin, or metal based material.

boundary grain—in the Jeffries' method for grain size measurement, a grain that is intersected by the boundary of the standard area and is, therefore, counted only as one-half grain. (See also **Jeffries' Method.**)

Bragg angle—the angle between the incident beam and the lattice planes considered.

Bragg equation:—

$$n\lambda = 2d\sin\theta \tag{2}$$

where:

n = order of reflection,
λ = wavelength of X-rays,
d = distance between lattice planes, and
θ = Bragg angle.

Bragg method—a method of X-ray diffraction in which a single crystal is mounted on a spectrometer with a crystal face parallel to the axis of the instrument.

Braun's law—the ratio of the solubility change with pressure, temperature being constant, $(\delta X/\delta P)T$, to the solubility change with temperature, pressure being constant, $(\delta X/\delta T)P$, is equal to the negative of the product of the absolute temperature, T, and the (fictitious) volume change (Δv) which accompanies the solution of 1 g·molecular weight of the solute in an infinitely large quantity of the saturated solution at T degrees, divided by the amount of heat, Q, developed in the process:

$$(\delta X/\delta P)T/(\delta X\,\delta T)P = -T\cdot\Delta v/Q \tag{3}$$

brightfield illumination— *for reflected light*, the illumination which causes specularly reflected surfaces normal to the axis of a microscope to appear bright. *For transmission electron microscopy*, the illumination of an object so that it appears on a bright background.

burning (burnt, burned)—a term applied to metal which has been permanently damaged by having been heated to a temperature close to or within the melting range. This results in a structure exhibiting incipient melting or intergranular oxidation.

calibration—1) the act or process of determining the relationship between a set of standard units of measure and the output of an instrument or test procedure,
2) the graphical or mathematical relationship relating the desired property (expressed in a standard unit of measure such as micrometers or Kg/mm^2) to the instrument output (instrument units such as filar divisions or pixels).

caliper diameter (Feret's diameter)—the length of a line normal to two parallel lines, tangent to opposite edges of a phase or object.

carbide—a compound of carbon with one or more elements, which, in customary formulation, are considered as being more positive than carbon.

case—*in a ferrous alloy*, the outer portion that has been made harder than the inner portion (see **core**) as a result of altered composition, or structure, or both, from treatments such as carburizing, nitriding, and induction hardening.

cassette—a light-tight film or plate holder.

cast replica—See **replica.**

cast structure—the structure, on a macroscopic or microscopic scale, of a casting.

cathode lens—a lens field terminated on one side by a surface at zero potential (cathode) normal to the optic axis. A cathode lens occurs in any system in which a cathode is imaged by its own electron emission, be it thermionic, photoelectric, secondary, or field emission.

cementite—a very hard and brittle compound of iron and carbon corresponding to the empirical formula Fe_3C. It is commonly known as iron carbide and possesses an orthorhombic lattice. In "plain-carbon steels" some of the iron atoms in the cementite lattice are replaced by manganese, and in "alloy steels" by other elements such as chromium or tungsten. Cementite will often appear as distinct lamellae or as spheroids or globules of varying size in hypo-eutectoid steels. Cementite is in metastable equilibrium and has a tendency to decompose into iron and graphite, although the reaction rate is very slow.

central pencil—a bundle of rays originating in the axis with an angular aperture equal to the effective aperture of the lens. These rays pass through the lens aperture and contribute to the formation of the image.

certified reference material—a reference material, the composition or properties of which are certified by a recognized standardizing agency or group. Typically such a material is accompanied by documentation (certificate).

characteristic curve—the curve showing the relationship between exposure and resulting density in a photographic image. It is usually plotted as the density against the log exposure. Called also the "H and D curve" and the "sensitometric curve."

characteristic radiation—X-radiation of a particular set of wavelengths, produced by and characteristic of a particular element used as a target whenever its excitation potential is exceeded.

charge neutralizer gun—an electron gun used to dissipate the charges which tend to build up on specimen surfaces, within an electron-diffraction camera, which would introduce undesired electrostatic fields.

chemical potential—(μ_i or $\bar{G}_i$) the partial molar free energy of component *i*, that is, the change in free energy of a solution upon adding one mole of component *i* to an infinite amount of solution of given composition,

$$(\delta G/\delta n_i)_{T,P,n_{1\ldots}} = \bar{G}_i = \mu_i \quad (4)$$

where:

G = Gibbs free energy, and

n_i = number of moles of the i^{th}component.

Chinese script eutectic—a configuration of eutectic constituents, found particularly in some cast alloys of aluminum containing iron and silicon and in magnesium alloys containing silicon, which resembles in appearance the characters in Chinese script.

chlorine or volatile halide extraction—See **extraction.**

chromatic aberration—a defect in a lens or lens system as a result of which the lens possesses different focal lengths for radiation of different wavelengths.

Class I quaternary equilibrium—in a four-component system, the stable univariant coexistence of five phases, one of which must disappear upon lowering the temperature or pressure; for example, the quaternary eutectic equilibrium, $L = \alpha + \beta + \gamma + \delta$.

Class I quinary equilibrium—in a five-component system, the stable univariant coexistence of six phases, one of which must disappear upon lowering the temperature or pressure; for example, the quinary eutectic equilibrium, $L = \alpha + \beta + \gamma + \sigma + \varepsilon$.

Class I ternary equilibrium—in a three-component system, the stable univariant coexistence of four phases, one of which must disappear upon lowering the temperature or pressure; for example, the ternary eutectic equilibrium, $L = \alpha + \beta + \delta$.

Class II quaternary equilibrium—in a four-component system, the stable univariant coexistence of five phases, two of which appear in each of the three associated bivariant equilibria at temperatures and pressures above, while the other three phases all occur in both of the associated bivariant equilibria below; for example, $L + \alpha = \beta + \gamma + \delta$.

Class II quinary equilibrium—in a five-component system, the stable univariant coexistence of six phases, two of which appear in each of the four associated bivariant equilibria at temperatures and pressures above, while the other four phases occur in both of the associated bivariant equilibria below; for example, $L + \alpha = \beta + \gamma + \delta + \varepsilon$.

Class II ternary equilibrium—in a three-component system, the stable univariant coexistence of four phases, two of which appear in both of the associated bivariant equilibria at higher temperature and pressure, while the other two phases occur in both bivariant equilibria below; for example, $L + \alpha = \beta + \gamma$.

Class III quaternary equilibrium—in a four-component system, the stable univariant coexistence of five phases, three of which appear in both of the associated bivariant equilibria at temperatures and pressures above, while the other two phases occur in all three of the associated bivariant equilibria below; for example, $L + \alpha + \beta = \gamma + \delta$.

Class III quinary equilibrium—in a five-component system, the stable univariant coexistence of six phases, three of which appear in all three of the associated bivariant equilibria at temperatures and pressures above, while the other three

occur in all three of the associated bivariant equilibria below; for example, $L + \alpha + \beta = \gamma + \delta + \varepsilon$.

Class III ternary equilibrium—in a three-component system, the stable univariant coexistence of four phases, one of which must disappear at higher temperature or pressure; for example, the ternary peritectic equilibrium, $L + \alpha + \beta = \gamma$.

Class IV quaternary equilibrium—in a four-component system, the stable univariant coexistence of five phases, one of which must disappear at higher temperature or pressure; for example, the quaternary peritectic equilibrium, $L + \alpha + \beta + \gamma = \delta$.

Class IV quinary equilibrium—in a five-component system, the stable univariant coexistence of six phases, four of which appear in both associated bivariant equilibria at temperatures and pressures above, while the other two occur in all four associated bivariant equilibria below; for example, $L + \alpha + \beta + \gamma = \delta + \varepsilon$.

Class V quinary equilibrium—in a five-component system, the stable univariant coexistence of six phases, one of which must disappear upon increasing the temperature or pressure; for example, the quinary peritectic equilibrium, $L + \alpha + \beta + \gamma + \delta = \varepsilon$.

Clausius-Clapeyron equation—the rate of change of the pressure of a heterogeneous equilibrium with change of temperature d*P*/d*T* is equal to the heat of transformation from the low to the high temperature state ΔHv divided by the product of the absolute temperature of the equilibrium and the volume change of the transformation $T\Delta V$:

$$dP/dT = \Delta Hv/T\Delta V \quad (5)$$

or,

$$d\ln P/dT \approx Hv/RT \quad (6)$$

where *R* is the gas constant and the equilibrium is not near a critical point.

clear cross test—an experimental method for determining which of two conceivable two-phase equilibria is real; at that composition at which the two conceivable two-phase fields cross, an alloy is brought to equilibrium and the phases identified; the same principle may be applied to higher-order equilibria in higher-order systems.

clear glass focusing screen—a glass screen polished on both sides and mounted for use in a camera, in lieu of photosensitive material, for the purpose of establishing a plane on which to focus an image prior to recording it.

cleavage planes—that family of planes of a crystal along which the crystal is easily split.

close packed—a geometric arrangement whereby a collection of equally sized spheres (atoms) may be packed together in a minimum total volume.

coefficient of thermal expansion—change in unit of length (or volume) accompanying a unit change of temperature, at a specified temperature.

coalescence—growth of grains at the expense of the remainder by absorption or the growth of a phase or particle at the expense of the remainder by absorption or by reprecipitation.

coarse grains—grains either larger than normal for the particular wrought metal or alloy, or grains of such a size that a surface roughening, popularly known as "orange peel" or "alligator skin," is produced.

coherent precipitate—a precipitated particle of a second phase, the lattice of which still maintains registry with the matrix lattice. Because the lattice spacings are usually different, strains usually exist at the interface.

coherent scattering—a kind of X-ray electron scattering in which the phase of the scattered beam has a definite (not random) relation to the phase of the incident beam. Also called unmodified scattering.

cold-cathode gun—an electron gun in which electrons produced in a gas discharge are accelerated through a small aperture in the anode.

cold junction—See **reference junction.**

cold junction correction— See **reference junction correction.**

cold worked structure—a microstructure resulting from plastic deformation of a metal or alloy below its recrystallization temperature.

collimation—the operation of controlling a beam of radiation so that its rays are as nearly parallel as possible.

collodion replica— See **replica.**

color film—a photographic film consisting of several emulsion layers, where the individual layers selectively record various wavelengths of light.

color temperature—the temperature of a blackbody in degrees Kelvin (K). In photography, the apparent temperature in K of a luminous source which may be measured by its emission ratio of blue to red light.

column, electron microscope—the assembly of gun, lenses, and specimen, viewing and plate chambers.

columnar structure—a macro- or microstructure characterized by elongated grains whose long axes are parallel, for example, to solidification direction, electroplated direction, etc.

comparison standard—a standard micrograph or a series of micrographs, usually taken at 75 or 100 diameters, or a suitable equivalent built into the eyepiece and used to determine grain size by direct comparison with the image.

compensating eyepiece—one designed for use with objectives such as apochromats, the lateral chromatic aberration of which is undercorrected.

compensating lead wires—wires leading from a thermocouple to the voltage-measuring instrument. These wires must be of such compositions that they will generate an *emf* equivalent to the *emf* generated by the reference junction of the couple.

complex silicate inclusions—a general term describing silicate inclusions containing visible constituents besides the silicate matrix. An example would be corundum or spinel crystals occurring in a silicate matrix in steel.

component—one of the independently variable substances by means of which the composition of each phase of a system of heterogeneous equilibrium may be described completely; usually an element, or a compound that remains undissociated throughout the range of temperature and pressure concerned.

composition—the quantity of each of the components of a mixture; usually expressed in terms of the weight percentage, or the atomic percentage of each of the components in the mixture.

Compton scattering—X-ray scattering by atoms in which the scattered beam has, relative to the incident beam, a longer wavelength and a random phase relationship. Also called incoherent or modified scattering.

condensed system—a pure substance, or mixture, at a pressure and temperature such that the vapor phase does not exist.

condenser—a term applied to lenses or mirrors designed to collect, control, and concentrate radiation in an illumination system.

condenser aperture— See **aperture.**

condenser lens—a device used to focus radiation in or near the plane of the object.

congruent transformation—an isothermal, or isobaric, phase change in which both of the phases concerned have the same composition throughout the process; the order of a system becomes unary at a composition of congruency.

conjugate phases—those states of matter of unique composition which coexist at equilibrium at a single point in temperature and pressure; for example, the two coexisting phases of a two-phase equilibrium.

conjugate planes—two planes of an optical system such that one is the image of the other.

constituent—a phase, or combination of phases, which occurs in a characteristic configuration in an alloy micro-structure.

constitutional diagram—graphical representation of the compositions, temperatures, pressures or combinations thereof at which the heterogeneous equilibria of an alloy system occur; also called "phase diagram," or "equilibrium diagram."

continuous phase—the phase forming the matrix or background in which other phases may be dispersed as isolated units.

continuous spectrum (X-rays)—the polychromatic radiation given off by the target of an X-ray tube, containing all wavelengths above a certain minimum value called the short wave length limit.

contrast enhancement (electron optics)— an improvement in electron image contrast by the use of an objective aperture diaphragm, shadow casting, or other means.

contrast perception—the ability to differentiate various components of the object structure by different intensity levels in the image.

contrast, photographic—the word contrast has been used in many different senses in connection with various photographic characteristics; there are different types of photographic contrast and different methods of measuring it. It is frequently used to designate the magnitude of the density difference resulting from a given exposure difference. (For another use, see **gamma**.)

conversion, hardness—the exchange of a hardness number determined by one method for an equivalent hardness number of a different scale.

cooling curve—graphical representation of the course of temperature fall of a chemical mixture as a function of time commonly exhibiting more or less abrupt changes of rate at, or near, those temperatures at which phase changes begin; used in finding the temperatures at which phase changes occur. Occasionally, some property or function other than time may be used; for example, thermal expansion.

cooling rate—the average slope of the time-temperature curve taken over a specified time and temperature interval.

core—(*1*) *case hardening*—interior portion of unaltered composition, or microstructure, or both, of a case-hardened steel article.
(*2*) *clad products*—the central portion of a multilayer composite metallic material.

coring—a variable composition between the center and outside of a unit of structure, (such as a dendrite, grain, carbide particle) resulting from non-equilibrium growth which occurs over a range of temperatures or compositions.

corona shield—a smooth, rounded metal covering placed around exposed high-voltage components to prevent electrical discharge.

counter—a device for the measurement of radiation intensity by means of an electrical triggering principle (Geiger-Müller).

coupler, color—a substance capable of reacting with the oxidation product of a color-forming developer to produce a colored dye image.

critical curve—in a binary, or higher order, phase diagram, a line along which the phases of a heterogeneous equilibrium become identical.

critical point—in a phase diagram, that specific value of composition, temperature, pressure or combinations thereof at which the phases of a heterogeneous equilibrium become identical. (See also **transformation temperature.**)

critical pressure—that pressure above which the liquid and vapor states are no longer distinguishable.

critical surface—in a ternary, or higher order, phase diagram, the area upon which the phases in equilibrium become identical.

critical temperature—that temperature above which the vapor phase cannot be condensed to liquid by an increase in pressure.

cross direction—one of three mutually perpendicular directions used to define a worked material, specifically that direction in the plane of working which is at right angles to the direction of maximum elongation.

cross grating—a two-dimensional diffraction grating, patterns from which are similar in the effects produced by diffracted electrons from thin flakes and films, and whose theory may therefore be used to explain the latter.

crystal—a solid composed of atoms, ions, or molecules arranged in a pattern which is periodic in three dimensions.

crystal analysis—a method for determining crystal structure, for example, the size and shape of the unit cell and the location of all atoms within the unit cell.

crystallite—a crystalline grain not bounded by habit planes.

crystal system—one of seven groups into which all crystals may be divided; triclinic, monoclinic, orthorhombic, hexagonal, rhombohedral, tetragonal, and cubic.

cube texture—a texture found in wrought metals in the cubic system, in which nearly all the crystal grains have a plane of the type (100) parallel or nearly parallel to the plane of working and a direction of the type [001] parallel or nearly parallel to the direction of elongation.

cubic—having three mutually perpendicular axes of equal length.

cupping—the condition sometimes occurring in heavily cold worked rods and wires, in which the outside fibers are still intact and the central zone has failed in a series of cup-and-cone fractures.

Curie point—that temperature above which a substance becomes paramagnetic.

curvature of field—a property of a lens that causes the image of a plane to be focused into a curved surface instead of a plane.

darkfield illumination—the illumination of an object such that it appears illuminated with the surrounding field dark. This results from illuminating the object with rays of sufficient obliquity so that none can enter the objective directly. As applied to electron microscopy, the image is formed using only electrons scattered by the object.

dashpot—a hydraulic cylinder device with a controlled leak designed to eliminate impact loading of mechanisms. Hardness testers may employ a dashpot to bring an indenter into contact with a specimen without impact or other disturbance.

dead-weight loading—a method of loading in which a weight is supported solely by the specimen and has no other mechanical connection to the testing machine. In hardness testing, the weight is supported by the indenter.

Debye ring—a continuous circle, concentric about the undeviated beam, produced by monochromatic X-ray diffraction from a randomly oriented crystalline powder. An analogous effect is obtained with electron diffraction.

Debye-Scherrer method—a method of X-ray diffraction employing monochromatic radiation and a polycrystalline specimen mounted on the axis of a cylindrical strip of film. (See **powder method.**)

decarburization—loss of carbon from the surface of a carbon containing alloy due to a reaction with one or more chemical substances in a medium that contacts the surface. Decarburization may be either (*1*) *partial*, that is, where carbon content is less than the unaffected interior but greater than the room temperature solubility limit of carbon in ferrite or (*2*) *complete*, that is, where carbon content is less than the solubility limit of carbon in ferrite so that only ferrite is present.

deep etching—macroetching; etching preliminary to macroexamination, intended to develop gross features such as segregation, grain flow, cracks or porosity.

define (X-rays)—limit a beam of X-rays by passage through apertures in order to obtain a parallel, divergent, or convergent beam.

definition—the clarity or sharpness of a microscopical image.

deformation bands—bands produced within individual grains during cold working which differ variably in orientation from the matrix.

deformation lines—thin bands or lines produced in grains of some metals, particularly those of face-centered cubic structure, by cold working; they are not removed by repolishing and re-etching.

degree of freedom—in heterogeneous equilibrium, an external variable that may be adjusted independently without causing a change of state; the external variables usually considered are: temperature, pressure, and concentration parameters numbering one less than the order of the system.

delta ferrite—designation commonly assigned to delta iron containing alloying elements in solid solution. Small amounts of carbon and large amounts of other alloying elements markedly affect the high-and-low-temperature limit of equilibrium.

delta iron (δ Fe)—solid phase of pure iron which is stable at temperatures between 1400 and 1539°C and possesses the body-centered cubic lattice. Strictly, there is no difference between delta and alpha iron.

denatured alcohol—ethyl alcohol containing an addition of a poisonous substance, making it unfit for human consumption.

dendrites—crystals, usually formed during solidification or sublimation, which are characterized by a tree-like pattern composed of many branches; pine-tree or fir-tree crystals.

densitometer—an instrument which measures the relationship between incident light and transmitted or reflected light and, using a logarithmic scale, gives a numerical measurement that corresponds to a material's opacity or a film's photographic density.

density (film)—transmission density is the common logarithm of the ratio of the radiant flux incident on the sample to the radiant flux transmitted by the sample, assuming no reflection.

deoxidation products—a term specifically applied to those non-metallic inclusions formed as a result of the addition of deoxidizing agents to molten metal.

depletion—selective removal of one component of an alloy, usually from the surface or preferentially from grain boundary regions.

depth of field—the depth or thickness of the object space that is simultaneously in acceptable focus.

depth of focus—the depth or thickness of the image space that is simultaneously in acceptable focus.

derived differential curve—the curve derived from the data obtained by the use of the differential method of thermal analysis. The changes in the temperature difference $\Delta(\theta - \theta')$, between a specimen and a neutral body, for a constant interval of temperature $\Delta\theta$ are plotted against the temperature. An arithmetic treatment of the differential data resulting in a plot of $\Delta(\theta - \theta')/\Delta\theta$ *versus* θ. (See **differential curve.**)

descending fork point—in a ternary phase diagram, the configuration at the convergence of the three divariant curves upon each of the three high-temperature phases associated in Class III univariant equilibrium; for example, the division of a descending liquidus surface valley into two descending liquidus-surface valleys.

detected feature—*in image analysis*, an object or constituent of interest that is isolated for measurement by adjustment of the threshold setting to its particular range of gray level.

deviation (X-ray)—the angle between the diffracted beam and the transmitted incident beam. It is equal to twice the Bragg angle θ.

devitrification—crystallization of an amorphous substance.

dezincification—a type of corrosion found with some copper-zinc alloys which occurs by solution of a small region and immediate redeposition of the copper in a spongy porous form, thus giving the impression of selective removal of zinc from the alloy.

diagonal—in hardness testing, a line joining two opposite corners of a diamond pyramid indentation.

differential curve: (*1*) *in thermal analysis*——a curve resulting from the differential method of thermal analysis when the difference in temperature $(\theta - \theta')$ between a specimen and a neutral body is plotted against the temperature of the latter.

(*2*) *in dilatometry*—a curve produced by plotting against the temperature the difference in changes of length or volume between a body of known expansivity and a body (specimen) of unknown expansivity.

differential interference contrast illumination—a microscopical technique employing a beam-splitting double-quartz prism; that is a modified Wollaston prism placed ahead of the objective with a polarizer and analyzer in the 90° crossed positions. The two light beams are made to coincide at the focal plane of the objective, thus rendering height differences visible as variations in color. The prism can be moved, shifting the interference image through the range of Newtonian colors.

differential thermocouple—two thermocouples placed in series opposition (bucking).

diffraction:—(*1*) a modification which radiation undergoes, as in passing by the edge of opaque bodies or through narrow slits, in which the rays appear to be deflected.

(*2*) coherent scattering of X-radiation by the atoms of a crystal which necessarily results in beams in characteristic directions. Sometimes called reflection.

(*3*) the scattering of electrons, by any crystalline material, through discrete angles depending only on the lattice spacings of the material and the velocity of the electrons.

diffraction grating—an artificially produced periodic array of scattering centers capable of producing a pattern of diffracted energy, such as accurately ruled lines on a plane surface.

diffraction pattern (X-rays)—the spatial arrangement and relative intensities of diffracted beams.

diffraction ring—the diffraction pattern produced by a given set of planes from randomly oriented crystalline material. (See also **Debye ring.**)

diffusion-transfer process—a rapid photographic process in which a negative image is produced at one location, with unused imaging materials then diffusing across a thin fluid layer to produce a positive image on a receptor sheet.

diffusion zone—the zone of viable composition at the junction between two different materials, such as in welds or between the surface layer and the core of clad materials or bearings, in which interdiffusion between the various components has taken place.

dilatometer—the instrument used in dilatometry for measuring lengths or volume changes.

dilatometry—the measurement of length or volume changes of a substance undergoing a change in temperature, pressure, or state. See Practice E80.

direct print—a photographic print of an original negative.

discontinuous stringer—three or more Type B or C inclusions aligned in a plane parallel to the hot working axis and offset by no more than 15 μm with a separation of less than 40 μm (0.0016 in.) between the two nearest neighbor inclusions (see Practices E45 and E1122).

disordered structure—the crystal structure of a solid solution in which the atoms of different elements are randomly distributed with respect to the available lattice sites.

dispersoid—in metallography, finely divided particles of relatively insoluble constituents which can be seen in the microstructure of certain alloys.

dissociation—as applied to heterogeneous equilibria, the transformation of one phase into two, or more, new phases, all of different composition.

dissociation pressure—at a designated temperature, the pressure at which a phase will transform into two, or more new phases, of different composition.

distortion—an aberration of lens systems where axial and marginal magnifications are unequal.

(*1*)*barrel distortion*—the distortion in the image which occurs when the magnification of the image in the center of the field is greater than in the edge of the field. This is also called negative distortion.

(*2*) *pincushion distortion*—the distortion in the image which results when the magnification in the center of the field is less than it is at the edge of the field. This is also called positive distortion.

divorced eutectic—a structure in which the components of an eutectic appear to be entirely separate.

double boiling system—a series of mixtures characterized by the vaporization of a liquid phase in one temperature (or pressure) range and the vaporization of another liquid phase within another temperature (or pressure) range; for example, a salt and water mixture which boils with the expulsion of water at moderately elevated temperature and then at higher temperature the molten salt itself boils to produce salt vapor.

double melting system—a series of mixtures which, with rising temperature, first develops a liquid phase that is totally converted to vapor before a second liquid phase appears; for example, a salt and water mixture which, upon heating, first melts to an aqueous solution of the salt, the water then boils away and the salt residue itself melts.

doublet (in characteristic X-ray spectra)— a separation of characteristic radiation into subspecies of slightly different wavelength.

drift—in electron optics, motion of the electron beam or image due to current, voltage or specimen instabilities or charging of a projection such as dirt in or near the electron beam.

dry objective—any microscopical objective designed for use without immersion liquids.

duplex microstructure—a two-phase structure.

duplex grain size—the simultaneous presence of two grain sizes, in substantial amounts, with one grain size appreciably larger than the other. (Synonymous with **mixed grain size.**)

dynamical theory—the explanation of diffraction phenomena in terms of dynamical interaction between the incident beam, all scattered waves and the crystal lattice, where the latter is treated as a triply periodic field of potential.

dystetic equilibrium—synonymous with **eutectoid equilibrium.**

Eberbach—See **micro penetration tester.**

edge angle—the included angle between two opposite edges of a hardness indenter.

elastic electron scatter—the scatter of electrons by an object without loss of energy, usually an interaction between electrons and atoms.

elastic recovery—in hardness testing, the shortening of the original dimensions of the indentation upon release of the applied load.

electrolytic extraction— See **extraction.**

electrolytic polishing—a metallographic preparation procedure where metal is preferentially dissolved from high points on an anodic surface by passage of an electric current through a conductive bath, to produce a specular reflecting surface. Used as an alternative to mechanical polishing.

electromagnetic focusing device—See **focusing device.**

electromagnetic lens—an electromagnet designed to produce a suitably shaped magnetic field for the focusing and deflection of electrons or other charged particles in electron-optical instrumentation.

electron—a subatomic particle having a negative charge of 4.8025×10^{-10} esu, and a charge-to-mass ratio or specific charge of $5.2737 \pm 0.0015 \times 10^{17}$ esu/g.

electron beam—a stream of electrons in an electron optical system.

electron diffraction—the phenomenon, or the technique of producing diffraction patterns through the incidence of electrons upon matter.

electron gun—a device for producing and accelerating a beam of electrons.

electron image—a representation of an object formed by a beam of electrons focused by an electron optical system (See **image.**)

electron lens—a device for focusing an electron beam to produce an image of an object.

electron micrograph—a reproduction of an image formed by the action of an electron beam on a photographic emulsion.

electron microscopy—the study of materials by means of the electron microscope.

electron microscopy impression—See **impression.**

electron optical axis—the path of an electron through an electron optical system along which it suffers no deflection due to lens fields. This axis does not necessarily coincide with the mechanical axis of the system.

electron optical system—a combination of parts capable of producing and controlling a beam of electrons to produce an image of an object.

electron optics—the science that deals with the propagation of electrons, as light optics deals with that of light and its phenomena.

electron probe—a narrow beam of electrons used to scan or illuminate an object or screen.

electron trajectory—the path of an electron.

electron velocity—the rate of motion of an electron.

electron wavelength—the wavelength necessary to account for the deviation of electron rays in crystals by wave diffraction theory. It is numerically equal to the quotient of Planck's constant divided by the electron momentum. This is approximately $\lambda = (12.3/V)$ *A*., where V = the accelerating potential in volts.

*electrostatic focusing device***—**See **focusing device.**

*electrostatic immersion lens***—**See **immersion objective**

electrostatic lens—a lens producing a potential field capable of deflecting electron rays to form an image of an object.

elongated grain—a grain with one principal axis significantly longer than either of the other two.

emission microscope—a type of electron microscope in which the specimen is the cathode source of the electrons. Sometimes used synonymously with shadow microscope.

enantiotropic transformation—a reversible metastable phase change; for example, the freezing of sulfur directly to the rhombic phase, or the direct melting of the latter, without passing through the stable intermediate monoclinic phase.

end-centered—having an atom (or group of atoms) separated by a translation of the type ½, ½, 0 from a similar atom (or group of atoms). The number of atoms in an end-centered cell must be a multiple of two.

epsilon (ε)—designation generally assigned to intermetallic, metal-metalloid, and metal-nonmetallic compounds found in ferrous alloy systems (for example, Fe_3Mo_2, $FeSi$, Fe_3P).

epsilon carbide—carbide with hexagonal close-packed lattice which precipitates during the first stage of tempering of primary martensite. Its composition corresponds to the empirical formula $Fe_{2.4}C$.

epsilon structure—structurally analogous close-packed phases (similar to epsilon brass), or electron compounds, that have ratios of 7 valence electrons to 4 atoms.

equiaxed grain—a polygonal crystallite, in an aggregate, whose dimensions are approximately the same in all directions.

equilibrium—a state of dynamic balance between the opposing actions, reactions, or velocities of a reversible process.

*equilibrium diagram***—** See **constitutional diagram.**

etch figures—markings formed on a crystal surface by etching or chemical solution and usually related geometrically to the crystal structure.

etching—controlled preferential attack on a metal surface for the purpose of revealing structural details.

eutectic alloy—the alloy which has the composition of the eutectic point.

eutectic arrest—in a cooling curve (or heating curve) an approximately isothermal segment, corresponding to the time interval during which the heat of transformation from the liquid phase to two or more conjugate solid phases is being evolved, (or conversely).

eutectic carbides—in hypereutectic tool steels, the skeleton-like structure of the eutectic carbide.

eutectic colony, grain—a two-phase region which solidified progressively from a simple center and, therefore, has some uniformity of structural relationship.

eutectic equilibrium—a reversible univariant transformation in which a liquid, that is stable only at superior temperature, decomposes into two or more conjugate solid phases; for example, $L = \alpha + \beta$, $L = \alpha + \beta + \gamma$, etc.

eutectic point—the composition of a liquid phase that is in univariant equilibrium with two or more solid phases; the lowest melting alloy of a composition series.

eutectic structure—the structure resulting when an alloy has passed through a eutectic equilibrium upon freezing.

eutectoid equilibrium—a reversible univariant transformation in which one solid phase, that is stable only at superior temperature, decomposes into two or more conjugate solid phases; for example, $\alpha = \beta + \gamma$, $\alpha = \beta + \gamma + \delta$, etc.

eutectoid point—the composition of a solid phase which, upon cooling, undergoes univariant transformation into two, or more, other solid phases.

*eutectoid reaction***—** See **eutectoid equilibrium.**

eutectoid structure—the microstructure resulting when an alloy has passed through an eutectoid equilibrium upon cooling.

evaporation—the vaporization of a material by heating it, usually in a vacuum. In electron microscopy this process is used for shadowing or to produce thin support films by condensation of the vapors of metals or salts.

Ewald sphere—a geometric construction, of radius equal to the reciprocal of the wavelength of the incident radiation, with its surface at the origin of the reciprocal lattice. Any crystal plane will reflect if the corresponding reciprocal lattice point lies on the surface of this sphere.

excitation potential—the applied potential on an X-ray tube required to produce characteristic radiation from the target.

exogenous inclusion—a nonmetallic constituent produced by entrapment of foreign material in the melt. (See **inclusions.**)