CRYSTAL STRUCTURES

AND

METALLOGRAPHY

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Background Unit: Crystal Structures and Metallography

Introduction

One of the most important aspects of Materials Science is understanding how microscopic qualities affect macroscopic properties. In this unit we will begin by discussing how single crystals are formed and we will look at some simple crystalline configurations. We will add to that by examining polycrystalline structures that are of uniform composition, and then continue by examining materials that are non-uniform.

This unit also introduces you to one of the materials engineer's handiest tools-- the metallurgical microscope, a microscope equipped with a special light source to view the structure of opaque materials. Discussions will include how to prepare and effectively observe important features on metallurgical specimens, how to determine magnification, resolving power, and some important equations in quantitative metallography.

Objectives

After studying this unit and completing the lab assignment you should be able to perform the following tasks:

1. Explain the importance of microscopic structures including crystal structure, grain size, phase size, and phase distribution to macroscopic physical properties.
2. Define coordination number and atomic packing factor.
3. Determine the atomic packing factor for BCC and FCC materials.
4. Explain the meaning of the equation \( Pp = L_L = A_A = V_v \). Your explanation should tell what each term means and describe how to use \( Pp \) and \( L_L \) to determine the volume fraction of each phase in a two phase alloy. You should also be able to determine \( Pp \) and \( L_L \) from a photomicrograph of a two phase alloy.

Crystals, Crystallography and Grain Structure of Metals

A crystal is defined as a three dimensional repetitive arrangement of atoms, ions or molecules in a solid. The particles making up the crystal are arranged in a regular pattern or array. There are a variety of patterns called lattices. Crystallography is the study of crystal structures.

Minerals, snowflakes, grains of salt or sugar are all crystalline. We know these crystal's beautiful, symmetric shapes reflect an inner regular arrangement of the atoms, ions, or molecules. Metals also have crystalline structures. The shape of a specimen doesn't tell us whether the material it is made from is crystalline or non-crystalline. We can make a crystal of metal in the shape of a round or square bar, a flat sheet, a sphere, or even a complex shape like a jet engine turbine blade.

The crystal structures of salt, sugar, or ice usually involve more elements and are generally more complicated than metal crystals. We will concentrate on the simpler metal crystals.

For study purposes we assume that atoms are like hard-ball spheres. Some schematics of two dimensional arrays, or lattices, with atoms represented by circles are shown in Fig. 1.
Although it is not shown on the schematic drawings, in real crystals the atoms actually touch in certain directions. The actual size of the crystal lattice is determined by the size of the atoms in the structure.

Notice that the regular arrangement of atoms extends throughout the entire structure. This repetitive arrangement is called long range order. Long range order exists when the atom spacing and pattern repeats over many atom spacings. Short range order exists when only the atom's nearest neighbor atoms are specified, but a regular pattern does not necessarily exist throughout the structure. Crystals have long range order. A schematic of a three dimensional array is shown in Fig. 2.

Because the crystal structure is regular we can determine the important properties of a crystal (e.g. atom spacing) by examining a small arrangement of atoms called a unit cell. A unit cell is defined as a small geometric entity that completely describes the crystal symmetry. Fig. 3 shows a unit cell as part of a lattice structure and removed from the structure. A crystal is composed of many unit cells. The unit cells are like building blocks for the crystal structure. Notice that the atoms are shared by more than one unit cell.

It is important to remember that all the atoms are identical and that as long as the orientation of the unit cell is coincident with the crystal symmetry the unit cell corners can be on any atom. In the structures we will study no atoms are specifically "comer" or "inside" atoms. Since each atom site is identical each atom in the crystal has the same environment. The coordination number, CN, for a crystal system is defined as the number of nearest neighbor atoms to any other atom in the system. Every atom in the crystal will have the same coordination number.
Unit cells can be a variety of shapes. The simplest crystal systems are cubic; the unit cell is a cube. Each edge of the cube has the same length. This length is called the lattice dimension or lattice constant, \( a \). We will concentrate on two of the simplest crystal lattices. The first is body centered cubic or BCC. The unit cell is cubic, or cube shaped, and has atoms on each of its corners. It also has an atom located in the center of the cube (Fig. 4). A metal crystal with the body centered cubic structure is composed of BCC unit cells as "building blocks". Note, again, that atoms are shared between unit cells. Fig. 5 shows a partial schematic of a BCC crystal. The atom at the center of the unit cell is touched by all eight corner atoms, but the corner atoms do not touch along the unit cell edge.

Since for BCC the atoms touch along a diagonal drawn through the body of the unit cell it can be shown that for BCC systems

\[
a = \frac{4R}{\sqrt{2}}
\]

where:
- \( R \) = atom radius
- \( a \) = lattice constant

In a BCC system only the body center atom is uniquely associated with any particular unit cell, while all eight corner atoms are shared equally by eight unit cells. The atomic packing factor, APF or PF; is defined as the fraction of volume in a crystal occupied by hard ball sphere atoms.

\[
APF = \frac{\text{volume of hard ball sphere atoms}}{\text{total volume of crystal}}
\]

Since the unit cell completely describes the crystal symmetry the APF can be determined by examining the unit cell. So for BCC systems

\[
APF = \frac{\left(2 \text{ atoms/ unit cell}\right) \left(\frac{4}{3}\pi R^3 \text{ / atom}\right)}{\left(\frac{4R}{\sqrt{2}}\right)^3 / \text{ unit cell}} = 0.68
\]
The other metal crystal, or lattice, we will study is called face centered cubic or FCC. The unit cell is cubic with atoms on each corner and an atom in the center of each cube face (Fig. 7). FCC metals are "built" from FCC unit cells. Fig. 8 is a two dimensional schematic representation of a FCC crystal.

![Figure 7](image1.png) ![Figure 8](image2.png)

As you might imagine, the atoms in these structures actually touch each other. If one face of an FCC unit cell is examined, it becomes apparent that the atoms touch along the diagonal through the square that is the cube face (Fig. 9). For FCC systems

\[ a = \frac{4R}{\sqrt{2}} \]

And the packing factor is 0.74.

![Figure 9](image3.png)

So far a brief description of single crystals has been provided. But most metal structures are polycrystalline, composed of more than one single crystal. When a liquid metal solidifies tiny crystal nuclei form in a variety of locations throughout the melt. Although each of these crystals is identical in terms of atom arrangement the actual orientation of the crystals may be very different (Fig. 10). The single crystals are called grains.

![Figure 10](image4.png)
The area where the crystals grow together after the metal has completely solidified is called a grain boundary. A grain boundary is defined as the region of atomic mismatch between adjacent single crystals in a polycrystalline material. The grains are irregular polygons (Fig. 11) that butt against each other at planes called grain boundaries (Fig. 12). Fig. 13 shows a schematic of the area around a grain boundary. Notice the disruption in the individual lattices at the grain boundary surface.

Metallographic examination of specimens involves observing a plane of the sample and utilizing the data taken from the two dimensional representation to qualities of the three dimensional object. We assume, therefore, that we are observing a section of our specimen that is representative of the whole. To prepare a specimen for viewing it is polished to a mirror-like finish then etched by exposing it to a corrosive agent that chemically removes atoms from the material. The etching process exposes the metallographic features of interest.

Clearly when observing a polycrystalline metal you can see the individual atoms. The grain boundaries are crystal surfaces, however, and the atoms at the surfaces are at a higher energy than the atoms in the grain interior (which is the lowest energy site) because the surface atoms don't have their full complement of nearest neighbor atoms at the appropriate spacing. Consequently if a polished metal is etched, atoms will be removed from the higher energy grain boundary sites preferentially and the grain boundary regions can be readily observed with the aid of a microscope. The grain boundary area appears darker since light isn't fully reflected back to the viewer (Fig. 14).
When we cut through a piece of metal, our plane of cutting will randomly cross the grains within the piece. When we polish and etch the exposed surface, the intersection between the cutting plane and the planes of grain boundaries will be revealed as a network of lines which are the grain boundaries (Fig. 15). Fig. 15 shows a schematic of a magnified, etched metallographic specimen, a micrograph. The features we observe in this planar representation of our specimen must then be related to the three dimensional specimen. Because we are interested in the arrangement of the single crystals in our system and how much of the material is associated with the higher energy grain boundaries we evaluate the typical size of the grains using a standard method. Grain size can easily be measured and represented by an index. N, the ASTM grain size number:

\[ n = 2^{N-1} \]

where:

\( n \) = number of grains per square inch of a photomicrograph at 100X magnification.

\( N \) = ASTM grain size number (rounded to the nearest whole number).

The above equation is used only for relatively fine-grained material—those materials whose grains are less than 0.5 mm diameter. ASTM Standard E 112 describes another system to use with coarse-grained material (macro-grain size numbers). (ASTM stands for American Society for Testing and Materials.) The ASTM grain size number represents the typical grain size. We have to make sure we observe a large enough piece of our sample to ensure that we have viewed a representative portion and we need to remember that what appears to be small grains are only a plane sliced through the grain and may not describe the largest portion of that particular grain (Fig. 16).

At temperatures below about half the melting point of the metal the grain boundaries help strengthen the material. Deformation that occurs in metals as a response to an applied load occurs when parallel planes of atoms effectively slip over one another. Any barrier to the planes slipping, a grain boundary for instance, will cause the material to require a larger applied load to result in a unit amount of deformation. Usually we want a fine grain material because that will mean higher yield strength, better toughness, and better surface finish on machined and stamped pieces. Since electrical and thermal energy is carried through metal
samples by electrons their motion is easiest when it is through a uniform crystalline structure; disruptions in uniformity, i.e. grain boundaries, will make it more difficult to transfer energy and increase the resistance of the specimen.

At higher temperatures grain boundaries are a source of mechanical weakness because of a slow deformation process called creep. If the material is being used at high temperatures (e.g. a jet engine blade), we may want very large grains or even a single crystal. Also, the magnetic steels used in transformers give lower losses of electrical energy when their grain sizes are large.

Grain size number can also be found by using an intercept method. One or more straight lines of random length and orientation are laid on the image (lines can be drawn on the photomicrograph or a ruler can be laid on the image). The line or lines must intercept at least 50 grains total. Grains touched by the end of a line count as only half grains. If L is the total line length and G is the total number of grains crossed at total magnification M, then:

\[
\frac{L}{G} = \text{the apparent grain intercept distance (length/ grain)}
\]

and

\[
\frac{L}{(GM)} = \text{the actual grain intercept distance (units of length)}
\]

A table in ASTM Standard E 112 can then be used to find the grain diameter (Appendix A).

The intercept method can also be used directly on the microscope without the need to take a photomicrograph and make measurements on it.

Single crystals are often studied as though they are perfect throughout. There are, however, a variety of defects that occur in crystalline lattices. Point defects are about the size of an atom. Two examples of point defects are a vacancy, which is an atom missing from a lattice site (Fig. 17) and an interstitial, which is an atom located in a "hole" of the parent lattice (Fig. 18). Obviously these cannot be observed with an optical microscope. Line defects involve rows of atoms and area defects, or surface defects, involve planes of atoms. A grain boundary is an area defect. Another type of area defect is called a twin boundary. A twin boundary arises when the lattice shifts slightly to form mirror images on either side of the boundary. Fig. 19 shows a schematic of a twin boundary. When observing the grain structure of a metal a twin boundary will appear as a straight line within a grain. You shouldn’t have any trouble confusing twin boundaries with grain boundaries because the former are straight lines and the latter are usually more random.
To this point we have looked at polycrystalline metal structures in which the only visible features will be grain boundaries and perhaps twin boundaries. Metals have the simplest crystal structures in general. Ceramics and crystalline polymers tend to be more complicated.

Materials systems become even more complicated as different structures are combined into one system. A phase is defined as a, physically homogeneous part of a materials system. Many common engineering materials have more than one phase. Of course if a system is multi-phased it must have phase boundaries. Phase boundaries are like grain boundaries but they involve more than one phase. A multiphased material may have both phase boundaries and grain boundaries (Fig. 20).

Now it is important to consider not only the individual phase sizes, but also the amount of each phase, the shape, the location, and distribution. A constituent (sometimes called a microconstituent) is defined as that part of the microstructure which appears distinct at low to moderate magnifications. A constituent can be a single phase or a mixture of phases.

Steel (mostly iron and carbon) is an important engineering material that is usually multiphased (almost pure iron and iron carbide, Fe₃C). Because it is so widely used it has been a much studied material, so we know what behaviors can be predicted by the presence of particular constituents in the microstructure. Pearlite is formed of layers of iron carbide in a matrix of essentially pure iron. Pearlite is a constituent that is composed of two phases (Fig. 21). At low magnifications pearlite looks gray and the two phases cannot be distinguished.

We can control the grain size, grain shape, phase amount, phase shape, and phase distribution by controlling the chemical composition and how we treat the material. We are interested in controlling these aspects because of their impact on the macroscopic physical properties of the material. Often, for instance, a second phase is added to a material to provide strengthening; systems of relatively soft, easily deformable material can be strengthened by adding a hard phase that will provide not only phase boundaries to interfere with slip, but regions of second phase material that do not allow easy deformation.

**Quantitative Metallography**

Whenever you are examining the microstructure of a solid material you always need to remember that you are seeing a 2-D plane that is a slice through a 3-D object. Are round particles in a photomicrograph sections of spheres or rods? Are lines sections of planes or needle-shaped particles? There is a quantitative relationship between what is seen in a 2-D plane and what is really present in the 3-D object. This is called quantitative microscopy or stereology. We'll introduce it to you here by considering the situation where we have one
type of material dispersed as separated particles in a matrix of another type of material. Our example will be a ductile cast iron which has spherical particles of graphite dispersed in a matrix of almost pure iron. In this sample there are two distinctly different types of material differing in structure or composition; there are two different phases. The phases present in this material are graphite (present as separate particles, the discontinuous phase) and iron (present as the matrix material, the continuous phase). Phase boundaries occur between the iron and graphite particles, and there will also be grain boundaries observable within the iron matrix.

Because we are assuming that we are viewing a representative portion of our specimen we can use the relationship:

$$V_v = A_A = L_L = P_p$$

This means that the volume fraction, $V_v$, of any phase is equal to the area fraction, $A_A$, the line fraction, $L_L$, and the point fraction, $P_p$, on a single plane. Fig. 22 is a sketch of the microstructure of ductile iron after polishing but before etching (the iron grain boundaries haven’t been revealed). The black spots are sections through spheres of graphite; all the graphite particles are about the same size but only a few of them are cut on diametral planes (right through the center of the particle). In the above relation, let $V_v$ represent the volume fraction of graphite in the cast iron:

$$V_y \frac{V_{Graphite}}{V_{Total}} = \frac{V_G}{V_T}$$

where: $V_I = \text{cm}^3$ of iron in a sample piece of ductile iron

$V_G = \text{cm}^3$ of graphite in a sample piece of ductile iron

$V_{Total} = \text{total volume of the sample} = (V_I + V_G)$

You could experimentally determine $V_v$ by etching the iron away from the graphite particles and measuring the volume of graphite spheres left. But it would be difficult. Instead you can relatively easily find $V_v$ from a photomicrograph.
If $A_A = \text{area fraction of graphite in the photomicrograph (Fig. 23 b)}$

then

$$A_A = \frac{A_G}{A_{\text{Total}}}$$

where:

$A_G = \text{cm}^2 \text{ of graphite in a sample piece of ductile iron}$

$A_I = \text{cm}^2 \text{ of iron in a sample piece of ductile iron}$

$A_{\text{Total}} = \text{total area of the sample} = (A_I + A_G)$
Similarly, if $L_L = \text{fraction of length of lines randomly projected onto the photomicrograph which lie within graphite particles (Fig. 23 c)}$

then

$$L_L = \frac{L_G}{L_{\text{Total}}}$$

where:

$L_G = \text{length of line (cm) lying within graphite in a sample piece of ductile iron}$

$L_I = \text{length of line (cm) lying within iron in a sample piece of ductile iron}$

$L_{\text{Total}} = \text{total length of lines projected onto the sample} = (L_I + L_G)$

And if, $P_p = \text{fraction of the points on a grid of intersecting lines which lie on the graphite particles. (Fig. 23 d)}$

then

$$P_p = \frac{P_G}{P_{\text{Total}}}$$

where:

$P_G = \text{number of points on grid falling on graphite particles}$

$P_I = \text{number of points on grid falling on the iron}$

$P_{\text{Total}} = \text{total number of points on the grid} = (P_I + P_G)$

**Bibliography**

Laboratory Unit: Crystal Structures and Metallography

Experimental Procedures

Crystal Structures

In this part of the experiment you will be constructing BCC and FCC unit cells to examine the spatial relationship of the atoms.

**BCC**

Using the clay spheres provided by your lab instructor construct the layers shown in Fig. 24.

![Figure 24](image)

Place the first layer, a, flat on the desk. Place the second layer, b, on the first. Then add tile third layer, c, such that the spheres in this layer are directly over those in tile first. This is a BCC unit cell.

What is the coordination number for this type of crystal?
Where do the atoms touch in the unit cell?

**FCC**

In a manner similar to that used to construct the BCC unit cell construct the layers shown in Fig. 25.

![Figure 25](image)

Place the first layer, a, flat on the desk. Place the second layer, b, directly on the first such that the spheres rest in the spaces between the corner spheres of the first layer. Then add the third layer, c, such that its spheres are directly over those in the first layer. This is an FCC unit cell.

What is the coordination number for this type of crystal?
Why is this structure called face centered cubic?

Metallography

For this part of the experiment your instructor will give each group five pre-polished and etched metallographic specimens and/or micrographs.
The metallographic specimens are:

Specimen # 1: A sample of an elemental body centered cubic (BCC) material (e.g. iron, molybdenum, tungsten). This specimen represents the simplest possible microstructure for a polycrystalline material.

Specimen #2: A sample of a pure metal (e.g. nickel) or an alloy (e.g. 70-30 brass or 18-8 stainless steel) which is a single phase face centered cubic (FCC) material.

Specimen #3: A sample of a two phase alloy which is composed of particles of graphite in a matrix of nearly pure iron.

Specimen #4: A sample or micrograph that is essentially 100% of a two phased layered constituent.

Specimen #5: A sample or micrograph of steel that has two constituents, essentially pure iron and pearlite, a two phases layered constituent of a-iron and Fe₃C, iron carbide.

YOU MUST RETURN THE SAMPLES TO YOUR INSTRUCTOR AT THE END OF THE CLASS PERIOD.

The Metallurgical Microscope

To effectively use a materials microscope you must know:

1. Something about the preparation of specimens for examination—otherwise you will probably observe a false ("artifact") structure.
2. Something about the technique of microscope operation—so you can use the microscope in an efficient manner without damaging it or your specimen.
3. Something about the optics of microscopes so you can calculate the magnification, check to see if the microscope's resolving power is fine enough to do what you want, and use the microscope to measure fine details such as the size of particles in metals or the features of an integrated circuit.

Sample Preparation. A sample of a metal or ceramic will give little or no useful information when viewed through a metallurgical microscope unless it has been properly prepared. The usual steps in preparation are:

1. Cut a section from the material to be studied, using an appropriate saw.
2. Mount the section in plastic leaving only the face to be examined exposed.
3. Grind the exposed face to provide a flat, uniformly scratched surface to begin polishing.
4. Polish to a mirror-like finish.
5. Etch (controlled removal of atoms) with an appropriate chemical (etchants vary with material to be viewed) to reveal the structure of the material, the microstructure. The microstructure is defined as the material's structure of grains and phases; it generally requires magnification for observation.
Metallurgical Microscope Use.

The total magnification of a specimen viewed through a microscope is:

\[ \text{Total Magnification} = M_o \cdot M_e \cdot \text{T.F.} \]

where:   
\( M_o \) = objective magnification  
\( M_e \) = eyepiece magnification  
T.F. = tube factor

For the microscopes you will be using the tube factor is 1.0, so:

\[ \text{Total Magnification} = M_o \cdot M_e \]

The magnification just described has the conventional meaning, i.e. a magnification of 100X means the image is one hundred times longer than the object. Of course, the area of the image would be \( 100 \cdot 100 = 10,000 \) times larger than the area of the object.

Although it is tempting to want to view a more magnified image there is a limit to the amount of useful information that can be obtained even at very high magnifications. The smallest spacing between parallel lines which can be resolved by a microscope is its resolving power. Resolving power is primarily determined by the objective lens magnification. The idea of "empty magnification" is closely related to resolving power. We can continue to design objectives with higher and higher magnifications or use a given objective with eyepieces of higher and higher magnification, and the image we see will continue to get larger and larger but beyond a certain total magnification the resolving power won't continue to improve even though the image is larger. Magnification beyond the maximum usable magnification is called "empty magnification." The maximum usable magnification depends on the type of objective lens and its numerical aperture (N.A.). (An aperture is an opening through which light travels). In general we can say:

\[ \text{maximum usable magnification} = 1000 \times \text{N.A.} \]

For very high quality objectives the usable magnification will be about twice as large as this formula above indicates.

For any microscope system the resolving power can be determined by:

\[ \text{Resolving Power} = R = \frac{\lambda}{2(N.A.)} \]

where:   
\( \lambda \) = wavelength of the light (microns)  
N.A. = numerical aperture  
R = resolving power (microns)
Microscopic Examination

Examine your specimen at several magnifications, including high powers. Determine the grain size using the linear reticle and the intercept method or the grain size comparator (both described below).

The intercept method for determining ASTM grain size can be used directly on the microscope without the need to take a photomicrograph and make measurements on it. A transparent disc with a 1 cm long scale engraved on it (called a linear reticle) can be inserted behind the microscope eyepiece. The 1 cm scale is divided into 100 equal lengths (each division has a length of 0.1 mm). Compared to the scale, the specimen is magnified only by the objective and tube factor (since the reticle is designed to fit directly into the 10X power eyepiece it will not be necessary to include M_o in the calculations because both the reticle and the specimen are magnified by the eyepiece). The length of the reticle scale on the surface of the specimen is:

\[
\frac{1 \cdot M_e}{T.F \cdot M_o \cdot M_e} \text{ (cm)}
\]

and the distance on the surface of the specimen between two divisions on the reticle scale will be:

\[
\frac{0.1 \cdot M_e}{T.F \cdot M_o \cdot M_e} \text{ (mm)}
\]

The intercept distance (mm/ grain) can be calculated by counting the number of grains crossed by the reticle scale (grains touched by the end of the scale are counted as half grains) and dividing that number into the actual intercept distance on the surface of the sample. In most cases a number of counts should be made, repositioning the specimen or reticle between counts.

For example, assume eight different counts were made on a sample, with a total of 118 grains being crossed in the eight counts. A microscope with a T.F. of 1.35, an objective magnification of 8.5X, and an eyepiece with a magnification of 13 X were used. The reticle scale had an actual length of 10 mm. Therefore the actual length on the specimen surface crossed by 1 scale length is:

\[
\frac{10 \text{ mm}}{1.35(8.5)} = 0.87 \text{ mm}
\]

So the total scan length was

\[8 (0.87) = 6.97 \text{ mm}\]

and the intercept distance was

\[
\frac{6.97 \text{ mm}}{118 \text{ grains}} = 0.059 \text{ mm/grain} \quad (59 \text{ micron/ grain})
\]

Comparing with the table in Appendix A (from ASTM Standard E112) indicates a grain size number of 5. (ASTM grain size numbers are usually reported to the nearest whole number.)
With the linear scale reticle installed and using a total magnification of 100X or less, count the number of grains intercepted by the 100 unit scale. The grain at each end of the scale counts as 1/2.

Note on using the reticles: the WFH 10XR eyepieces are threaded (to accept reticle disks) on the end which fits into the microscope tube. Each of the linear reticle disks has a line with 100 graduations spaced 0.1 mm apart. The distance between two graduations when viewed against the surface of the sample is

\[
\text{distance on surface of sample} = \frac{0.1 \text{ mm} \cdot M_e}{M_o \cdot M_e}
\]

where: 
- \(M_o\) = objective magnification
- \(M_e\) = eyepiece magnification

Repeat this measurement on five different locations of this sample recording your results in the space provided in the data sheet.

**Microscope Magnifications**

<table>
<thead>
<tr>
<th>Objective Magnification</th>
<th>Spacing Between Linear Reticle Graduations (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5X</td>
<td>0.02</td>
</tr>
<tr>
<td>10X</td>
<td>0.01</td>
</tr>
<tr>
<td>40X</td>
<td>0.0025</td>
</tr>
<tr>
<td>100X</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Grain size can also be determined directly by observation. Replace the linear reticle in the eyepiece with the “grain size” reticle. The grain size reticle has regions indicating different grain sizes scribed around the outer portion of the disc. This reticle can only be used if the objective magnification times the tube factor equals 10X (for Unitron use 10X objective). Visually match the grain size of the reticle with that of the sample and record your results.

**BCC specimen (transformer iron)**

If possible, start work with this specimen. Examine the specimen at several magnifications. Measure the grain size using the intercept method.
FCC specimen (70-30 brass)

This specimen should also be examined under the microscope at a series of magnifications. The microstructure should again reveal grains. But FCC materials usually show a complication: "annealing twins". Annealing twins are a special planar boundary subdividing grains into regions in which the atom packing is the same except for orientation (Fig. 19). But unlike grain boundaries, where the regions on the two sides are randomly oriented, the regions on the two sides of a twin boundary are oriented relative to each other by a simple rotation of the lattice. The annealing twins aren’t grain boundaries; look carefully to determine if a line is a twin or a grain boundary. Some annealing twins are marked with a small t on the photomicrograph (Fig. 26).

Measure the grain size of the FCC material using the comparator reticle.

Two-phase specimen (ferritic nodular cast iron)

Examine this specimen under the microscope and sketch the microstructure. Estimate the dimensions of a typical graphite particle by using the linear reticle. Install the square grid reticle in the eyepiece. At a magnification of about 200X count the number of grid intersections (test points) falling in the dark regions. Moving to different areas on this sample, repeat 5 times. Record your counts in the spaces provided. Use the grain size reticle to measure the grain size of the iron matrix.

Two phase, single constituent

Sketch the microstructure of this two phase constituent paying particular attention to the amount and distribution of the two phases.

Two phase, two constituent steel

Sketch the microstructure of this alloy. Note both constituents and clearly identify the amount and distribution of the phases throughout the microstructure.

Physical Properties

We are always interested in predicting as much as possible about the macroscopic behavior of materials by studying the microscopic structure.

Examine the schematic crystal systems shown to determine the effect of grain boundaries.