# Structure of Metals

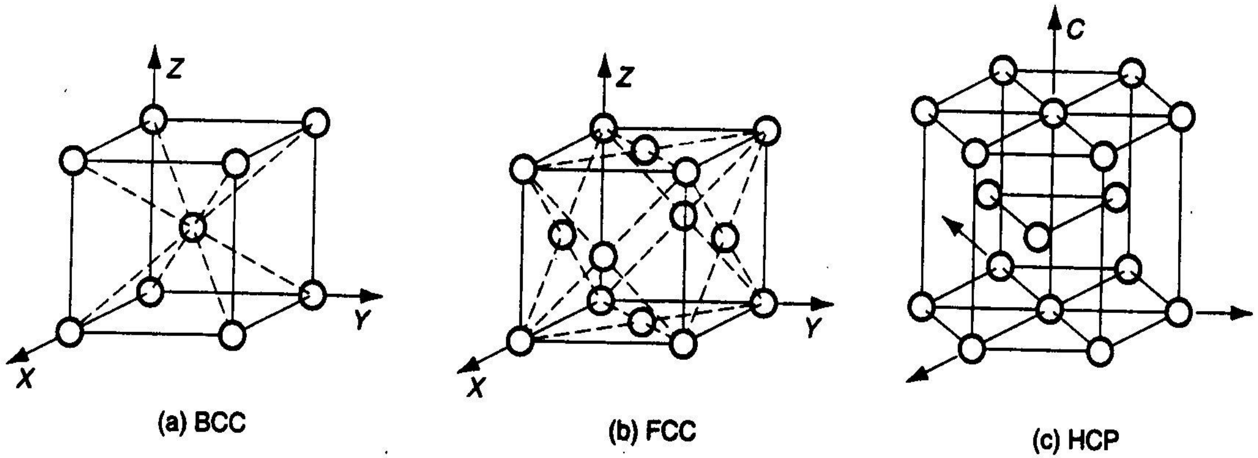
# Metals – Basic Structure (Review)

## Property

High stiffness, better toughness, good electrical conductivity, good thermal conductivity

## Why metals have these nice properties

- structures at atomic level



## Ways to change the structure

temperature, alloying, chemistry, mechanical

## Pure metals and their Alloys

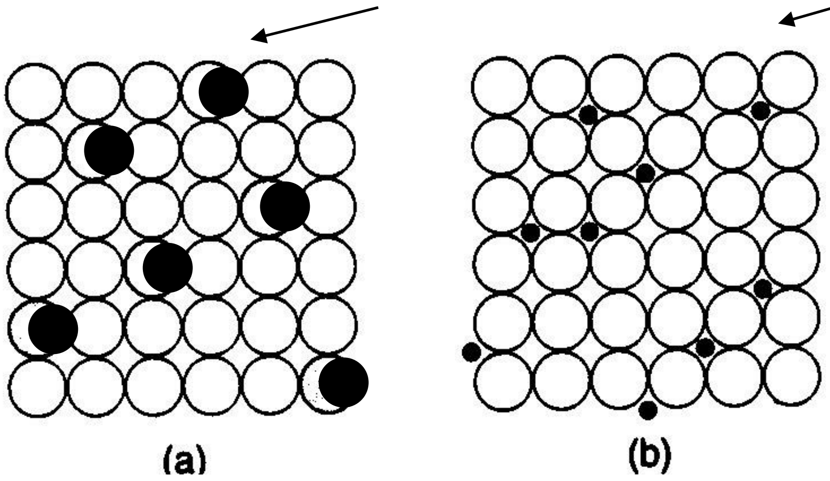
- Gold, silver, and copper may exist in applications as their pure form, but most of metals are alloyed.

- An alloy is a metal comprised of **two or more elements, at least one of which is metallic**. Two main categories of alloys are: (1) **solid solutions** and (2) **intermediate phase**.

**Solid solutions**: one element dissolved in another to form single-*phase* solution

*Phase*-Any homogeneous mass, metal with grains having same lattice structure

Types: **Substitutional and Interstitial**




- Solid solution alloy structure **stronger and harder**

**Conditions** for **substitutional** solid solutions possible:

(1) The **atomic radii** of the **two** elements **similar**

(2) Their **lattice types** must be the **same**

(3) The **lower valency** metal becomes the solvent

(4) Their **chemical affinity (similarity)** is small

Example: **BRASS** (ZINC in COPPER)

## Interstitial solid solution:

Atoms of **dissolving element** fit into **vacant spaces** between base metal atoms in **lattice structure**

- Solute atoms **small** compared to Solvent atoms

Example:

**Carbon** dissolved in **Iron** to form **STEEL**

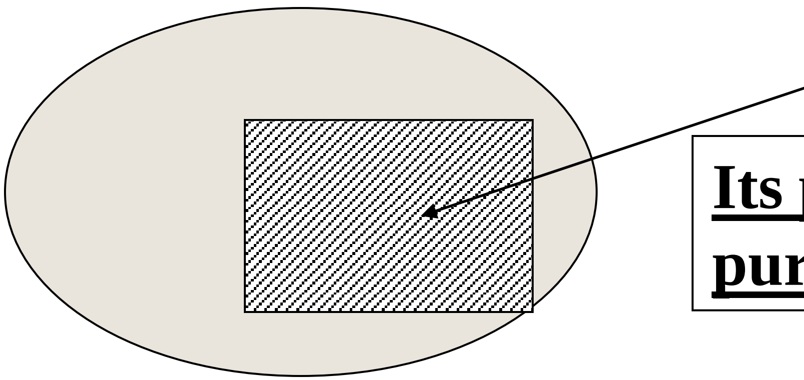
## Intermediate phases:

- Every element has a **limit** for its solubility of another element
- When element **A** completely dissolved into another element **B**, the whole system is one phase of that solid solution.

## Intermediate phases:

- When the amount of the **dissolving element** in the **alloy** exceeds the **solid solubility limit of the base metal**, a second phase forms in the alloy.

**Intermediate phase**



**Its properties are between two pure elements**

Here, the system has two elements (A,B) and two phases: intermediate phase and solid solution (A,B)

# METALLIC CRYSTALS

- tend to be **densely packed**
- have several reasons for dense packing:

  - Typically, only one element is present, so all atomic radii are the same.

  -Metallic bonding is not directional.

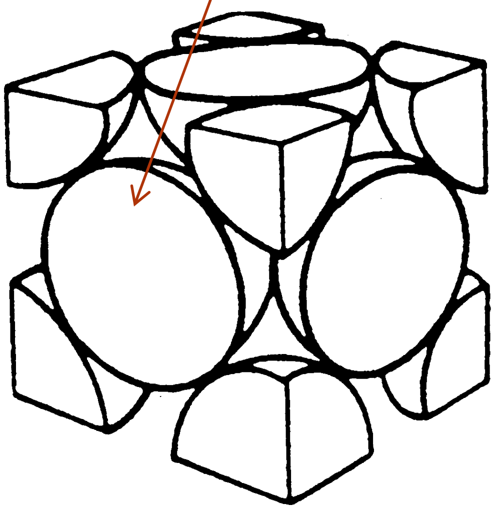
  -Nearest neighbor distances tend to be small in order to lower bond energy.
- have the simplest crystal structures.

**Three structures are found, we will look at three such structures...**

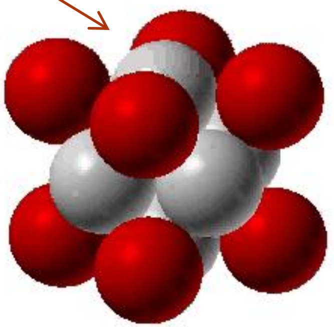
# 1. Face-Centered Cubic (FCC)

- This structure is found in many metals with atoms centered at each of the corners and center of all cube faces. eg: Cu, Al, silver, gold
- For this structure, each corner atom is shared among eight unit cells, whereas a face centered atom belongs to only two.
- Two characteristics are: **Coordination number** and **Atomic Packing factor (APF)**

**Coordination # = 12**



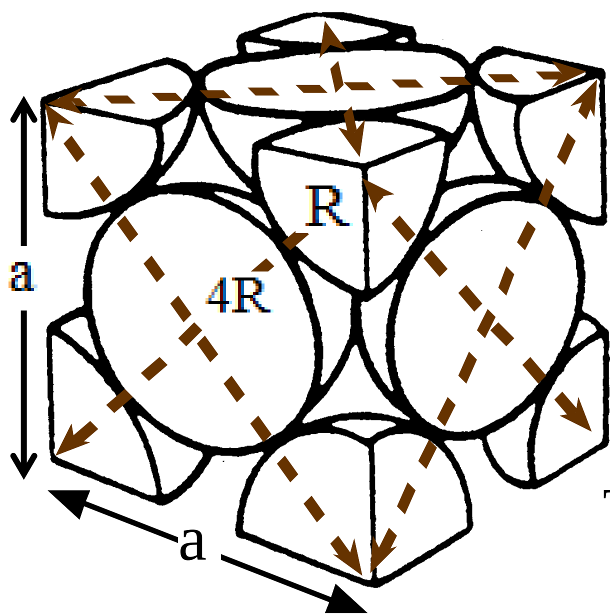
--Note: All atoms are identical; the face-centered atoms are shaded differently only for ease of viewing.



$$\text{APF} = \frac{\text{Volume of atoms in unit cell*}}{\text{Volume of unit cell}}$$

*assume hard spheres

- APF for a face-centered cubic structure = 0.74 (how?)




$$a^2 + a^2 = (4R)^2$$

$$2a^2 = 16R^2$$

$$a^2 = 8R^2$$

$$\boxed{a = 2R\sqrt{2}}$$

The FCC unit cell volume **Vc** may be computed from

$$V_c = a^3 = \left(2R\sqrt{2}\right)^3 = 16R^3\sqrt{2}$$

Volume for a sphere is $= \frac{4}{3}\pi R^3$

Unit cell contains:

6 x 1/2 + 8 x 1/8

= 4 atoms/unit cell

$$V_s = (4)\frac{4}{3}\pi R^3 = \frac{16}{3}\pi R^3$$

and

$$V_c = 16R^3\sqrt{2}$$

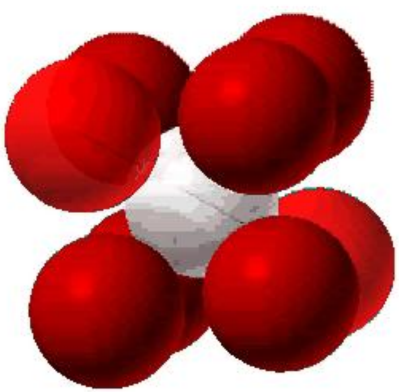
Total sphere volume

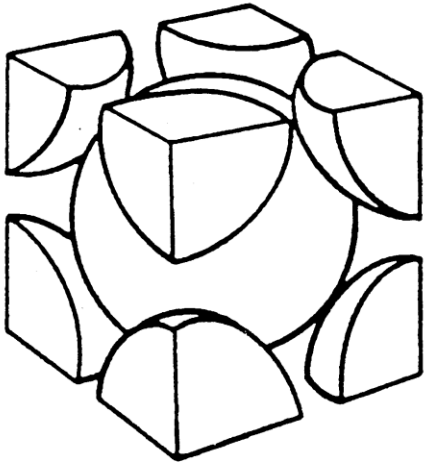
$$APF = \frac{V_s}{V_c} = \frac{\left(\frac{16}{3}\right)\pi R^3}{16R^3\sqrt{2}} = \boxed{0.74}$$

Total Unit cell volume

# 2. Body-Centered Cubic (BCC)

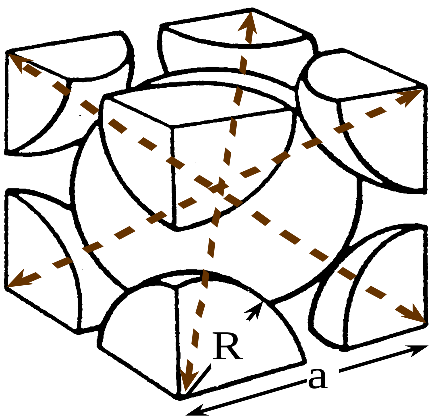
- Close packed directions are cube diagonals
- --Note:  All atoms are identical; the center atom is shaded differently only for ease of viewing. eg: Cr, Iron (alpha), Molybdenum





Coordination # = 8

# APF for a body-centered cubic structure = 0.68




Close-packed directions:

length = 4R

$= \sqrt{3}\, a$

Unit cell contains:

1 + 8 x 1/8

= 2 atoms/unit cell

atoms / unit cell

volume / atom

$$APF = \frac{2 \cdot \frac{4}{3}\pi\left(\sqrt{3}a/4\right)^3}{a^3}$$

volume / unit cell

Show that the atomic packing factor for BCC is 0.68?

Solution:

$$\text{APF} = \frac{V_S}{V_C}$$

Since there are two spheres associated with each unit cell for BCC

$$V_S = 2\,(\text{sphere volume}) = 2\left(\frac{4\pi R^3}{3}\right) = \frac{8\pi R^3}{3}$$

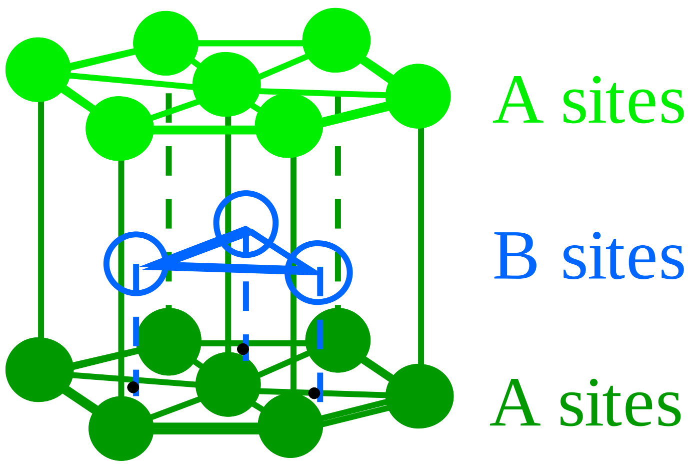
Also, the unit cell has cubic symmetry, that is $V_C = a^3$. But $a$ depends on $R$ according to Equation 3.3.

$$V_C = \left(\frac{4R}{\sqrt{3}}\right)^3 = \frac{64\,R^3}{3\sqrt{3}}$$

$$\text{APF} = \frac{V_S}{V_C} = \frac{8\pi\,R^3/3}{64\,R^3/3\sqrt{3}} = 0.68$$

# 3. Hexagonal Closed Packed Structure (HCP)

- 3D Projection

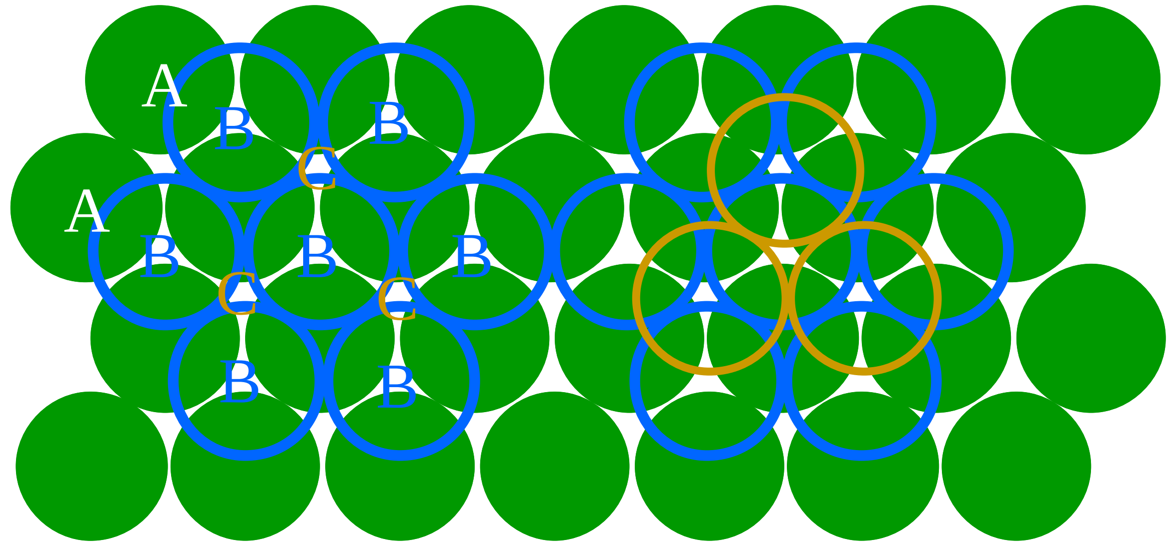



- Coordination # = 12
- APF = 0.74
- 2D Projection


- ABAB... Stacking Sequence

# Stacking Sequence: FCC

- ABCABC... Stacking Sequence
- 2D Projection

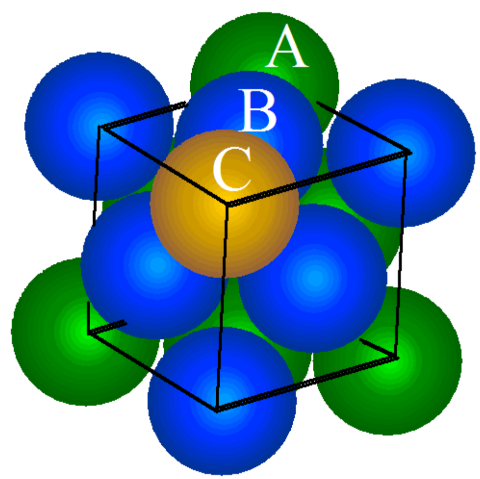



A sites

B sites

C sites

- FCC Unit Cell



# Density Computations-Metals

# atoms/unit cell

Atomic weight (g/mol)

$$\rho = \frac{n\,A}{V_c N_A}$$

Volume/unit cell
(cm $^3$/unit cell)

Avogadro's number
(6.023 x $10^{23}$ atoms/mol)

# Example

Copper has an atomic radius of 0.128nm, an FCC crystal structure, and an atomic weight of 63.5 g/mol. Compute its theoretical density and compare the answer with its measured density.

Solution:

Data from Table inside front cover of Callister (see next slide):

- crystal structure = FCC: 4 atoms/unit cell
- atomic weight = 63.55 g/mol (1 amu = 1 g/mol)
- atomic radius R = 0.128 nm (1 nm = 10 cm)

$V_c = a^3$ ; For FCC, $a = 4R/\ 2$ ; $V_c = 4.75 \times 10^{-23}\ cm^3$

**Actual= 8.94 g/cm3**

$$\rho = \frac{nA}{V_c N_A} = \frac{4 \times 63.5}{4.75 \times 10^{-23} \times 6.02 \times 10^{23}} = 8.89 g/cm^3$$

# Welding Processes

# Weldability of a Metal

- Metallurgical Capacity
  - **Parent metal** will join with the weld metal without formation of deleterious constituents or alloys.

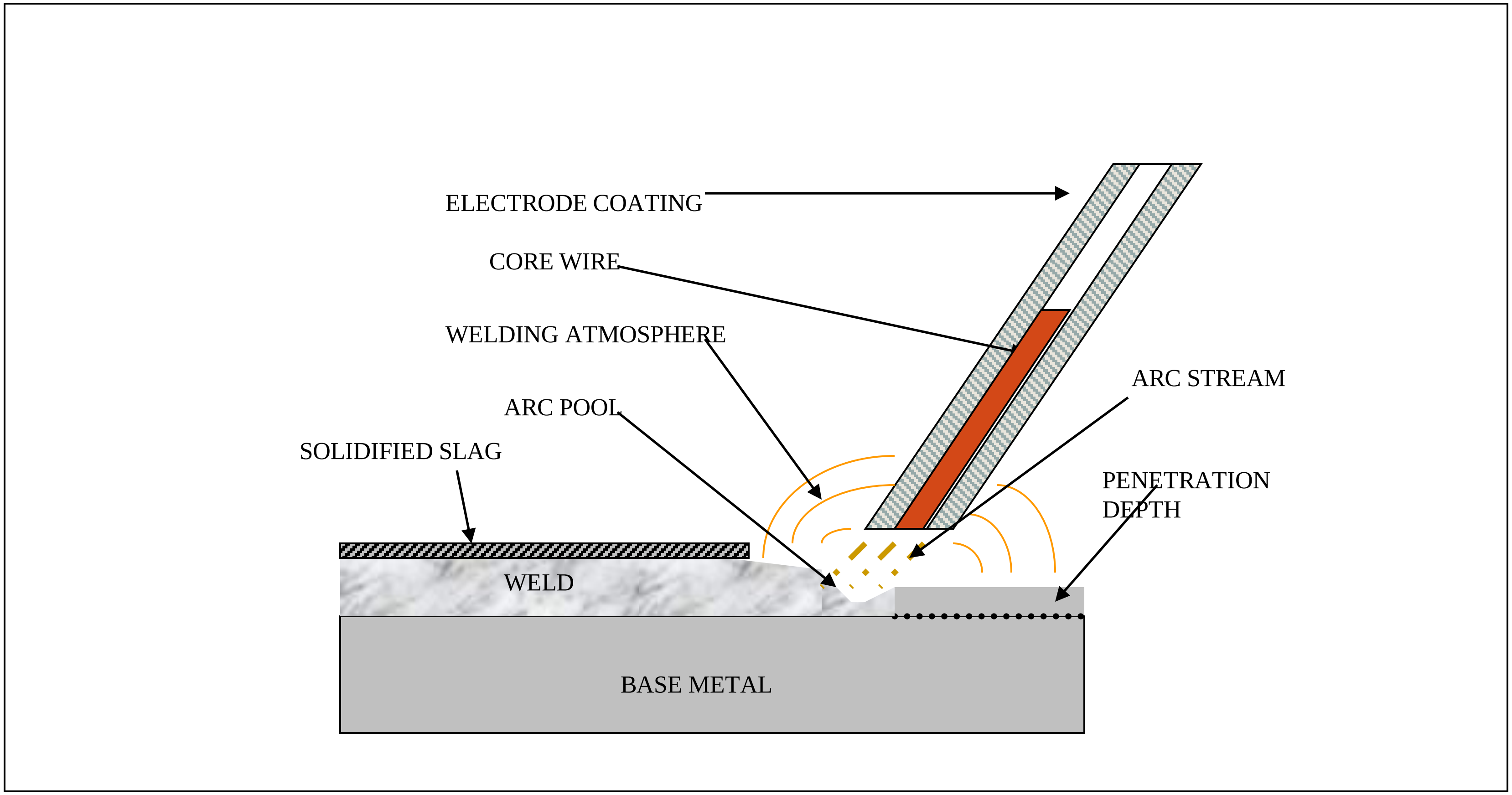
- Mechanical Soundness
  - Joint will be **free from discontinuities**, gas porosity, shrinkage, slag, or cracks

- Serviceability
  - Weld is able to perform under varying conditions or service (e.g., **extreme temperatures, corrosive environments, fatigue, high pressures**, etc.)

# Fusion Welding Principles

- **Base metal** is melted
- **Filler metal** may be added
- Heat is supplied by various means
  - Oxyacetylene gas
  - Electric Arc
  - Plasma Arc
  - Laser

# Fusion Welding



# Weld Metal Protection

- During fusion welding, the molten metal in the weld “**puddle**” is susceptible to oxidation
- Must protect weld puddle (arc pool) from the atmosphere
- **Methods**
  - **Weld fluxes**
  - **Inert Gases**
  - **Vacuum**

# Weld Fluxes

- Typical fluxes (**fluxes** facilitate soldering)
  - **$SiO_2$, $TiO_2$, FeO, MgO, $Al_2O_3$**
  - Produces a **gaseous shield** to prevent contamination
  - Act as **scavengers** (like hunter) to reduce oxides
  - Add **alloying elements** to the weld
  - Influence shape of weld bead during solidification

# Inert Gases

- **Argon, helium, nitrogen, and carbon dioxide**
- Form a protective **envelope** around the weld area
- Used in
  - MIG
  - TIG
  - Shield Metal Arc

# Vacuum

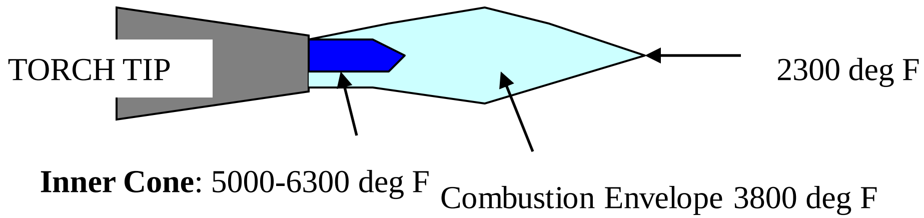
- Produce high-quality welds
- Used in **electron beam welding**
- Nuclear/special metal applications
    - Zr, Hf, Ti
- Reduces **impurities by a factor of 20** versus other methods
- **Expensive** and time-consuming

# Types of Fusion Welding

- **Oxyacetylene** Cutting/Welding
- Shielded Metal Arc (“**Stick**”)
- Metal Inert Gas (**MIG**)
- Tungsten Inert Gas (**TIG**)

# Oxyacetylene Welding

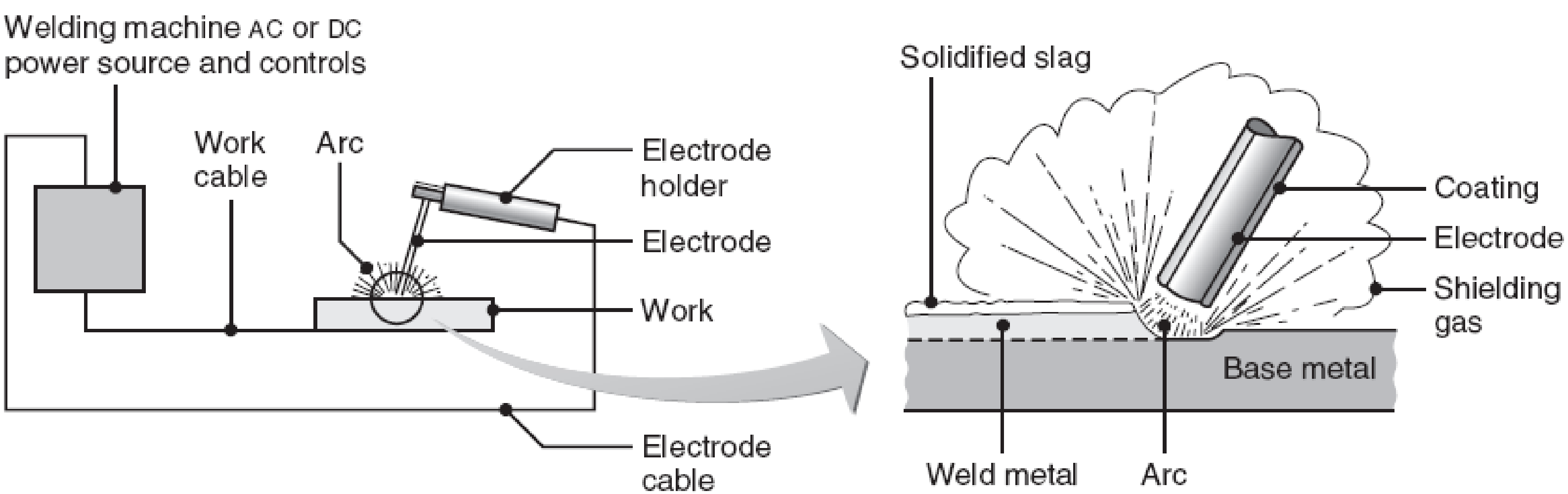
- Flame formed by burning a **mix of acetylene ($C_2H_2$) and oxygen**




- Fusion of metal is achieved by passing the **inner cone of the flame over the metal**
- Oxyacetylene can also be used for cutting metals

# Shielded Metal Arc (Stick)

- An electric arc is generated between a **coated electrode and the parent metal**
- The coated electrode carries the electric current to form the arc, produces a gas to control the atmosphere and provides filler metal for the weld bead
- Electric current may be AC or DC.  If the current is DC, the polarity will affect the **weld size** and **application**

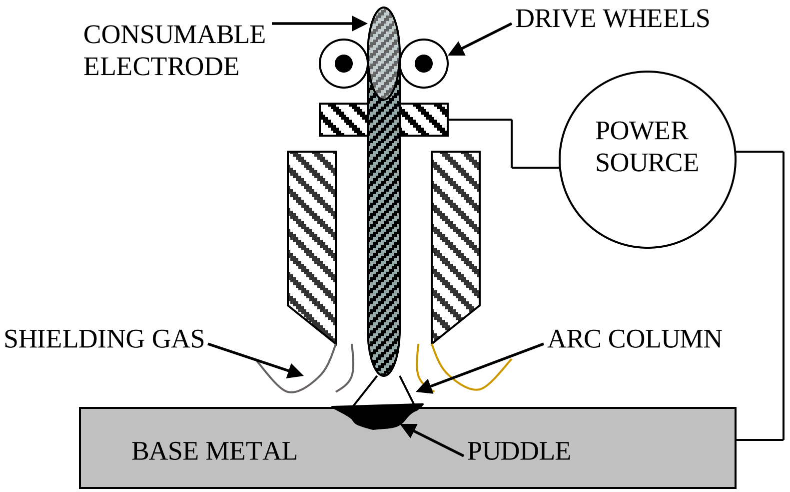


# Inert Gas Welding

- For materials such as Al or Ti which quickly form oxide layers, a method to place **an inert atmosphere around the weld puddle had to be developed**

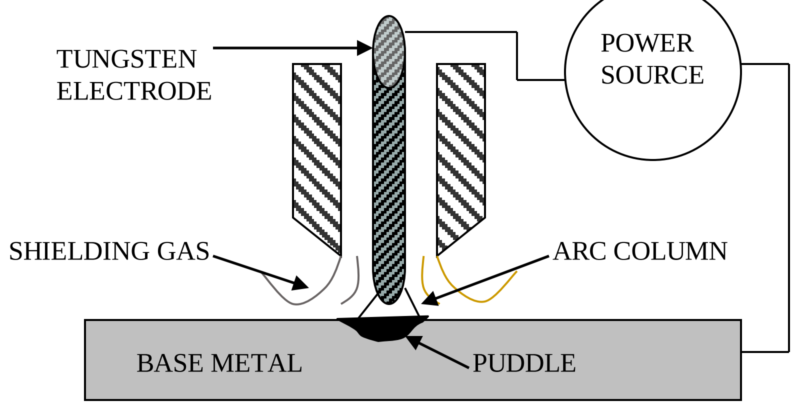
# Metal Inert Gas (MIG)

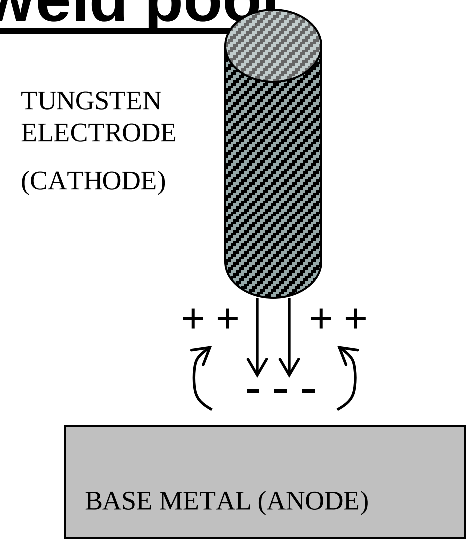
- Uses a consumable electrode (filler wire made of the base metal)
- Inert gas is typically **Argon**



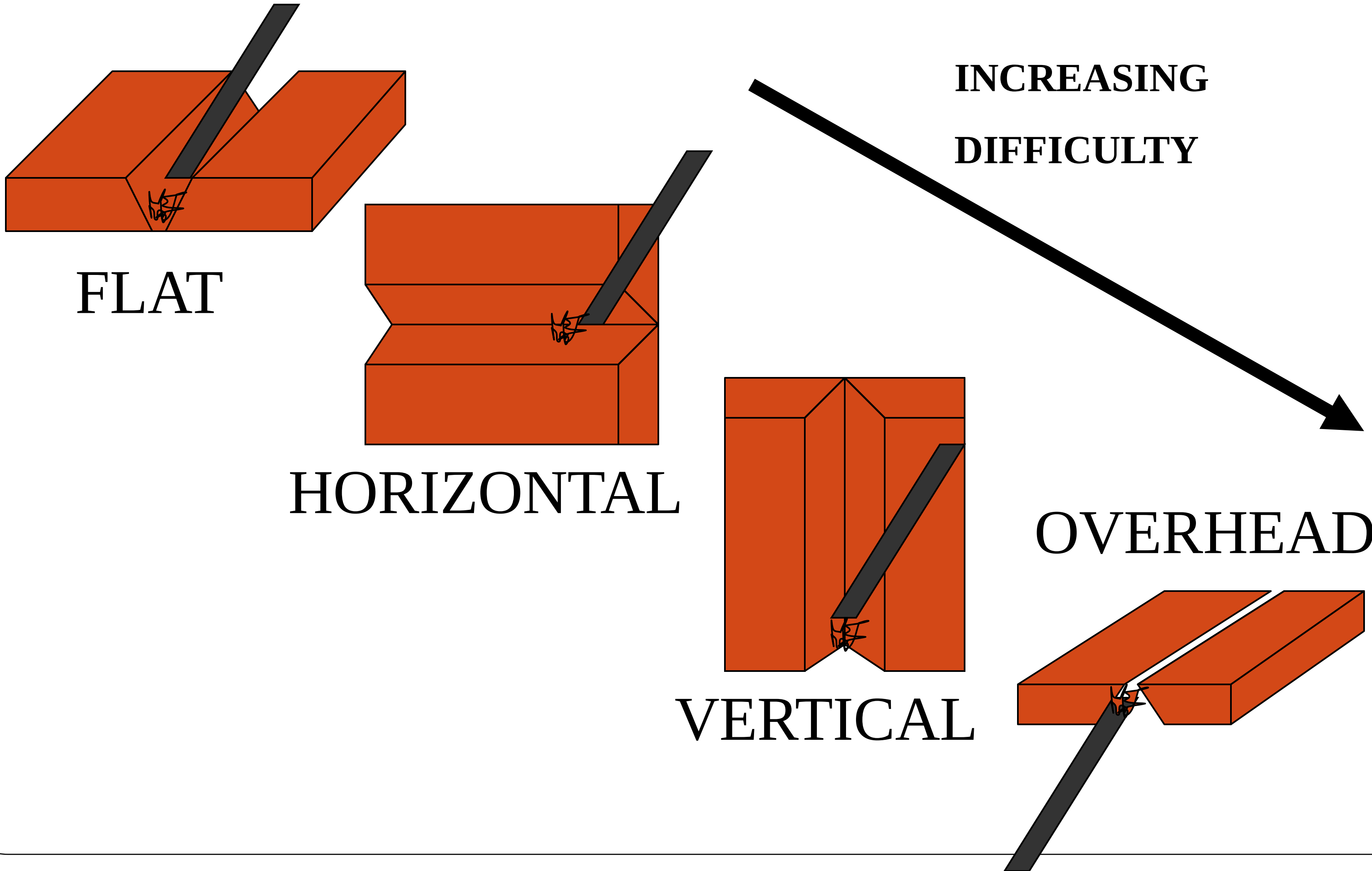
# Tungsten Inert Gas (TIG)

- Tungsten electrode acts as a **cathode**
- A **plasma** is produced between the **tungsten cathode** and the **base metal** which heats the base metal to its melting point
- Filler metal can be added to the **weld pool**



# Welding Positions



# Weld Defects

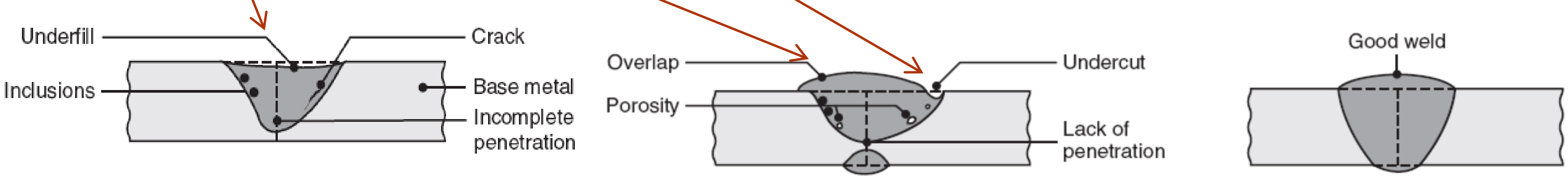
- Undercuts/Overlaps

- Grain Growth
  - A wide ΔT will exist between base metal. Preheating and cooling methods will affect the brittleness of the metal in this region
- Blowholes
  - Are cavities caused by gas entrapment during the solidification of the weld puddle. Prevented by proper weld technique (even temperature and speed)

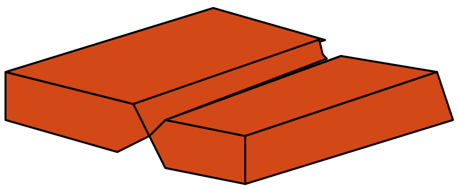
# Weld Defects

## Weld profile

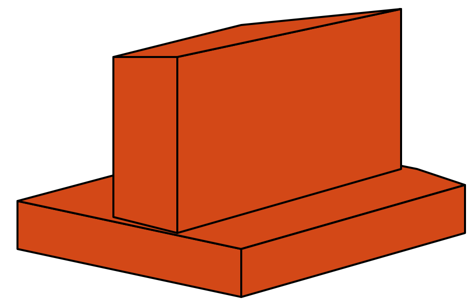
- Affects the **strength** and **appearance** of the weld.
- **Under-filling** is due to joint not filled with proper amount of weld metal.
- **Undercutting** is due to melting away of base metal.
- **Overlap** is a surface discontinuity due to poor welding practice.



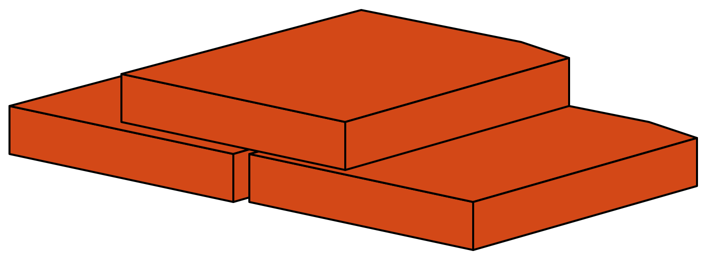
# Joint Design



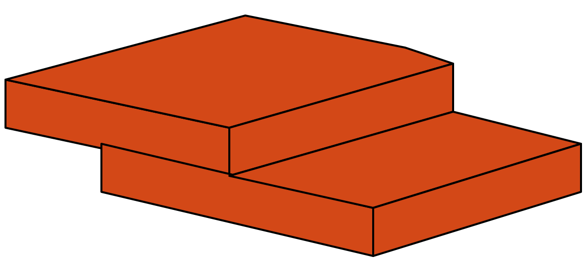
**BUTT JOINT**



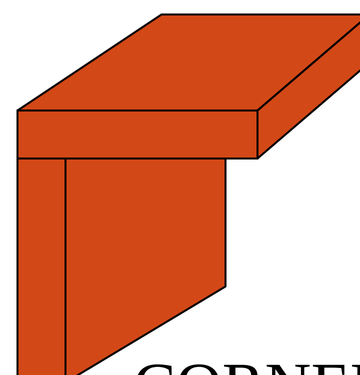
FILLET JOINT



STRAP JOINT

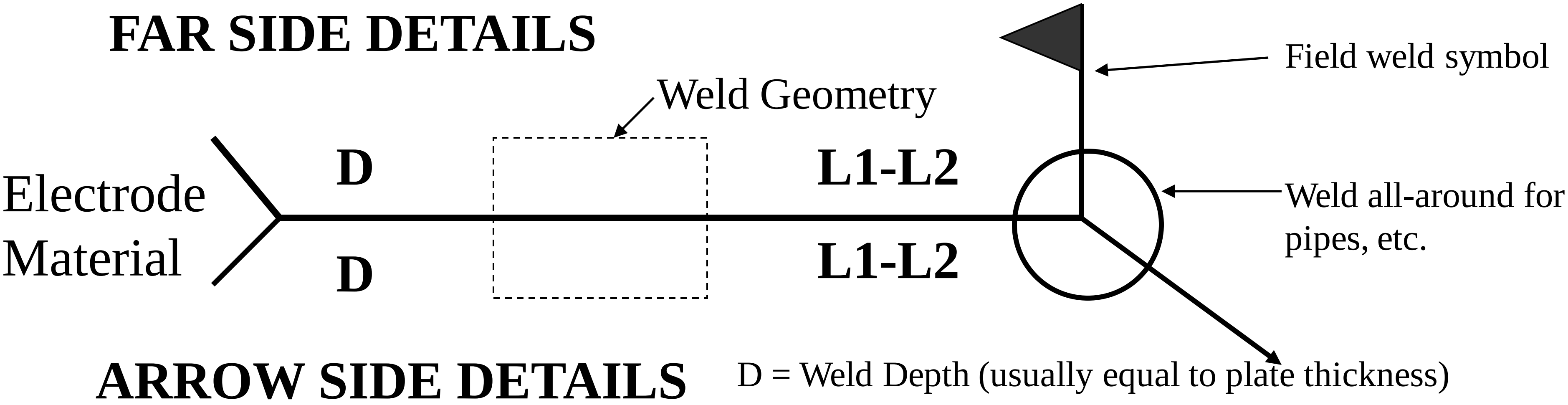


LAP JOINT



CORNER JOINT

# Generalized Welding Symbols



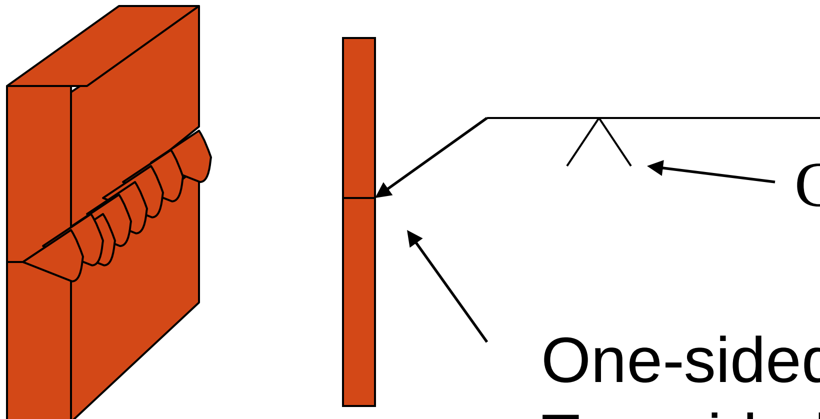

D = Weld Depth (usually equal to plate thickness)

L1 = Weld Length

L2 = Distance between centers for stitched welds

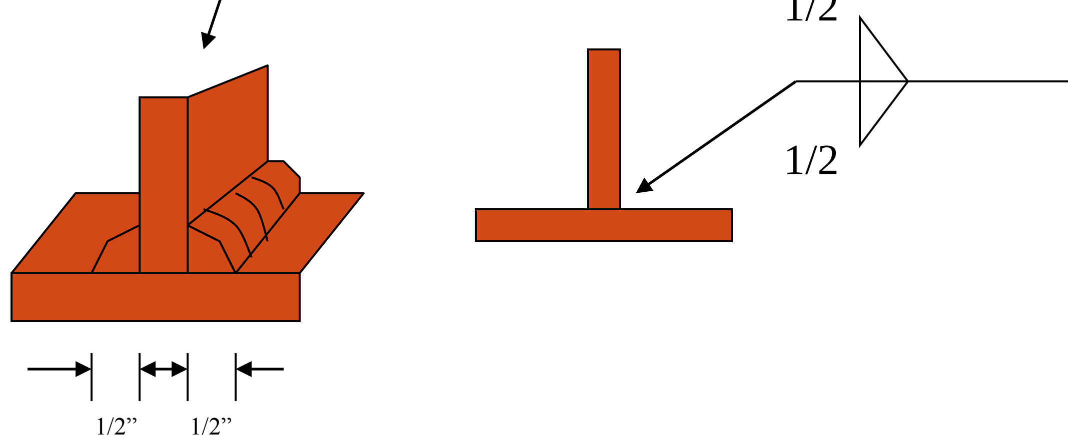
The Field Weld Symbol is a guide for installation. Shipyards normally do not use it, except in modular construction.

# Example Welding Symbol

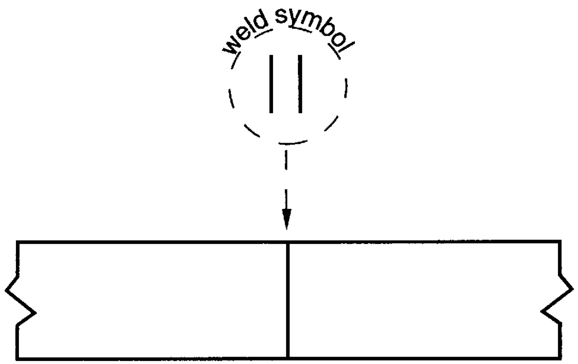


Geometry symbol for V-groove

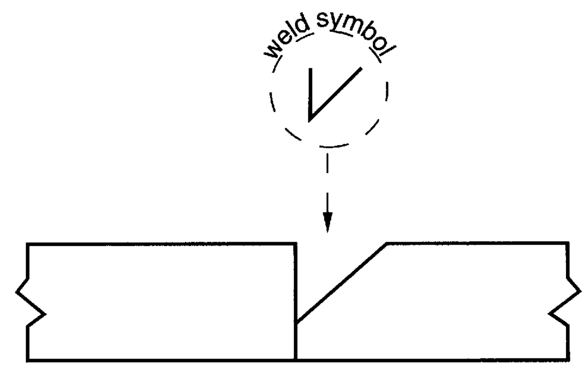
One-sided welds are max 80% efficient
Two sided are 100% efficient



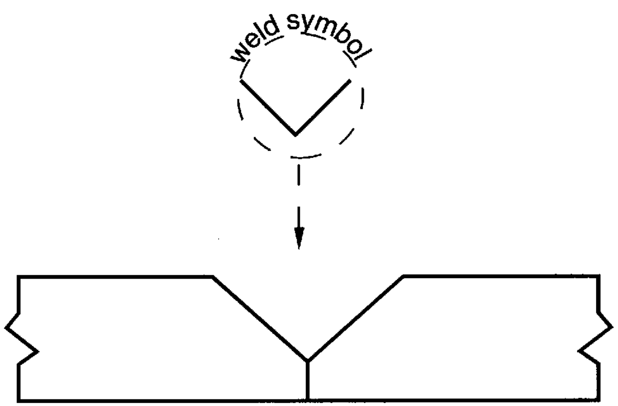
# Weld Symbols (Butt Joints)



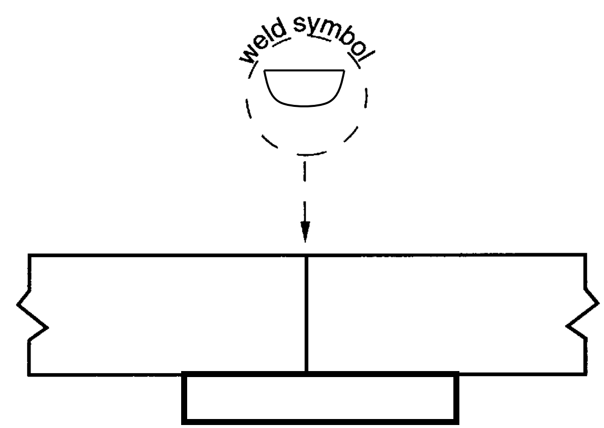

Square-Groove




Bevel-Groove

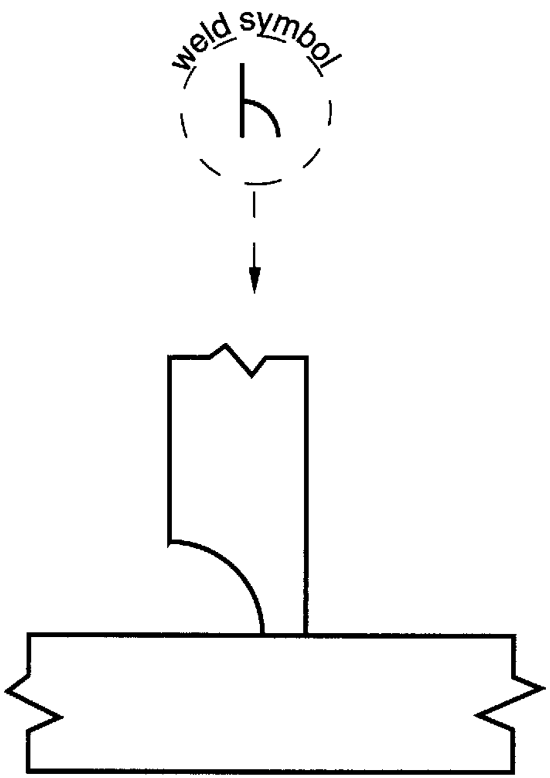



V-Groove

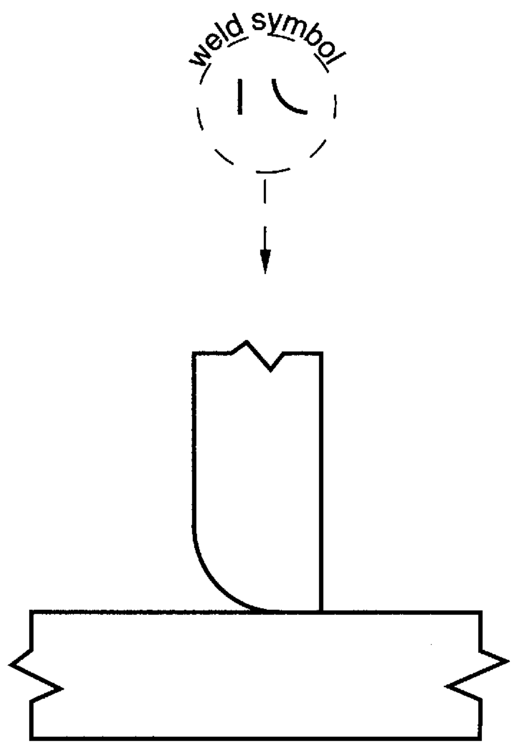



**Backing**

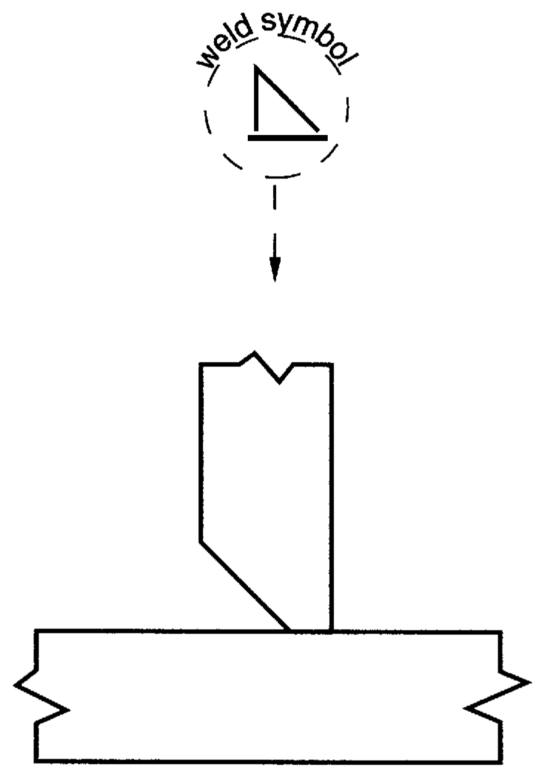
# Weld Symbol (Fillet Joints)




J-Groove

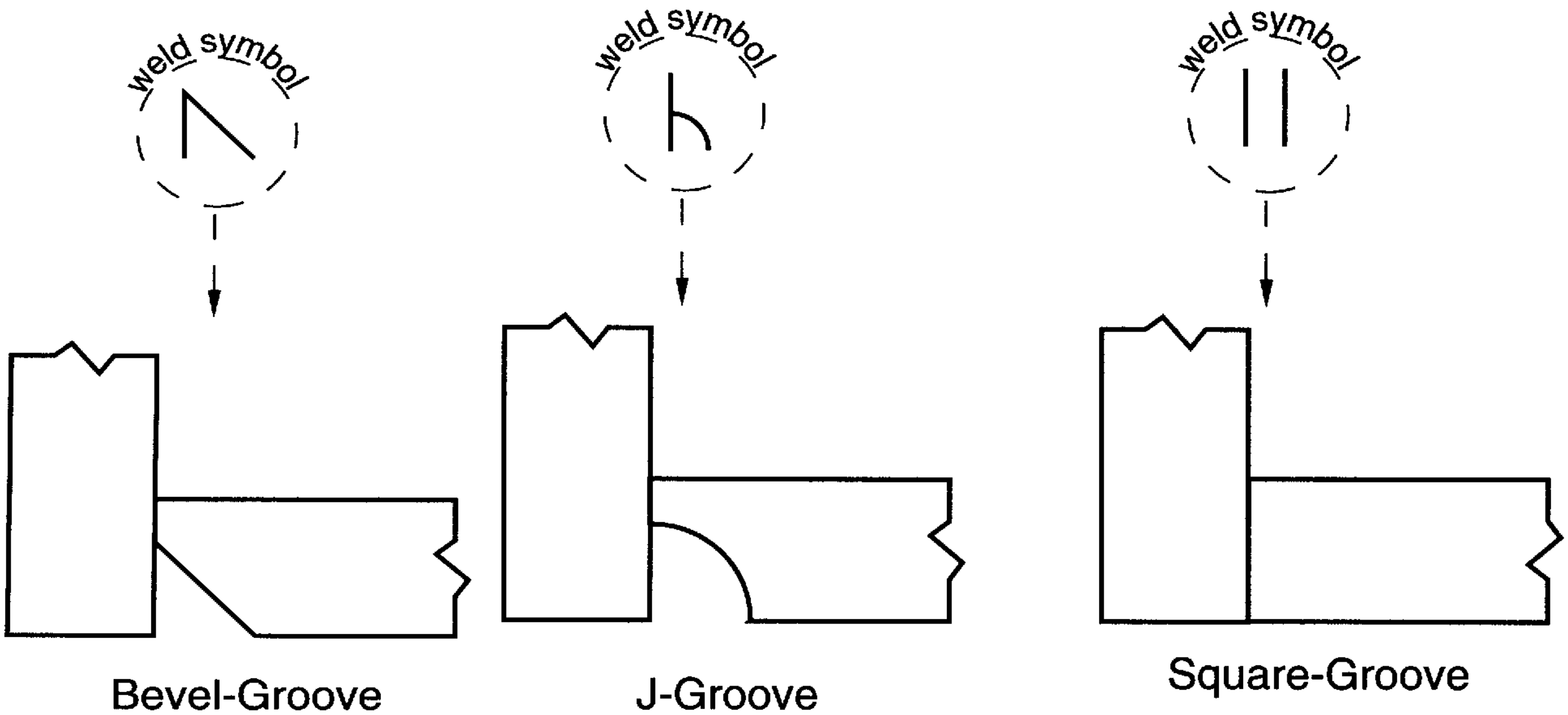



Flare-Bevel-Groove



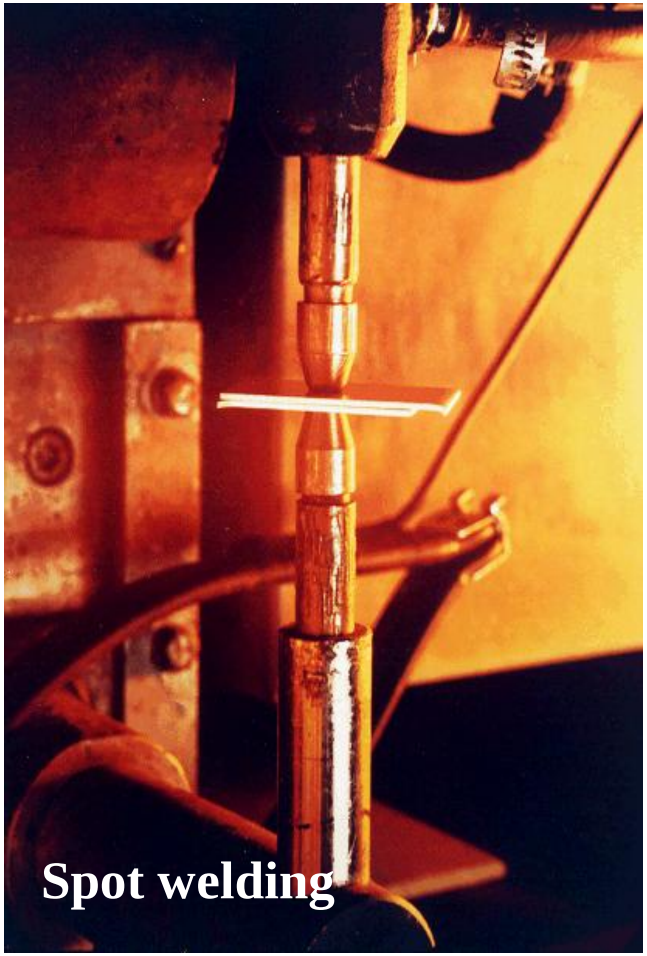

Bevel-Groove

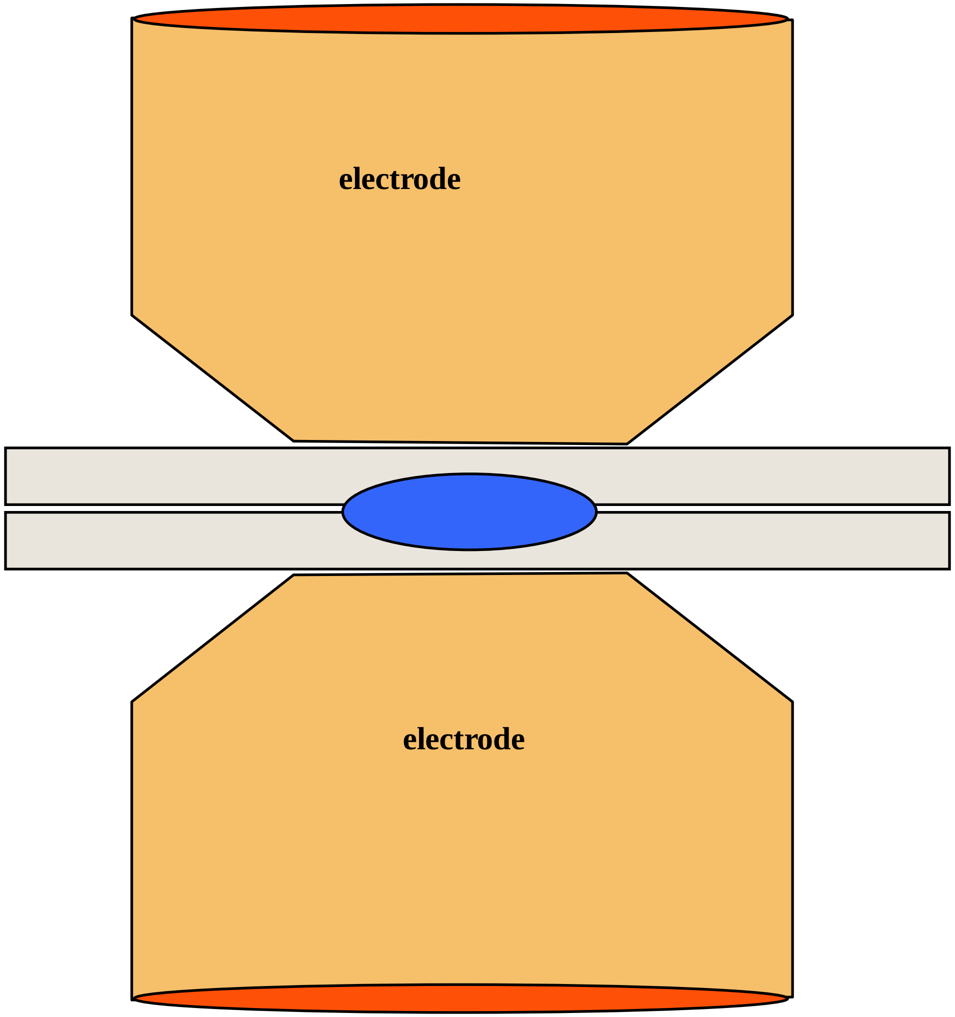
# Weld Symbol (Corner Joints)

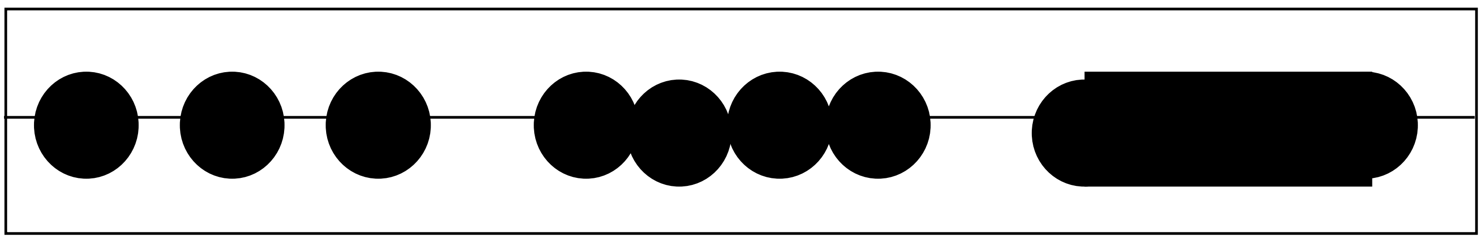


# Resistance Welding (Spot Welding)

- The resistance of metal to the localized flow of current produces heat
- Process variables
  - Current
  - Time
  - Force
- Spot and seam welding




electrode
electrode

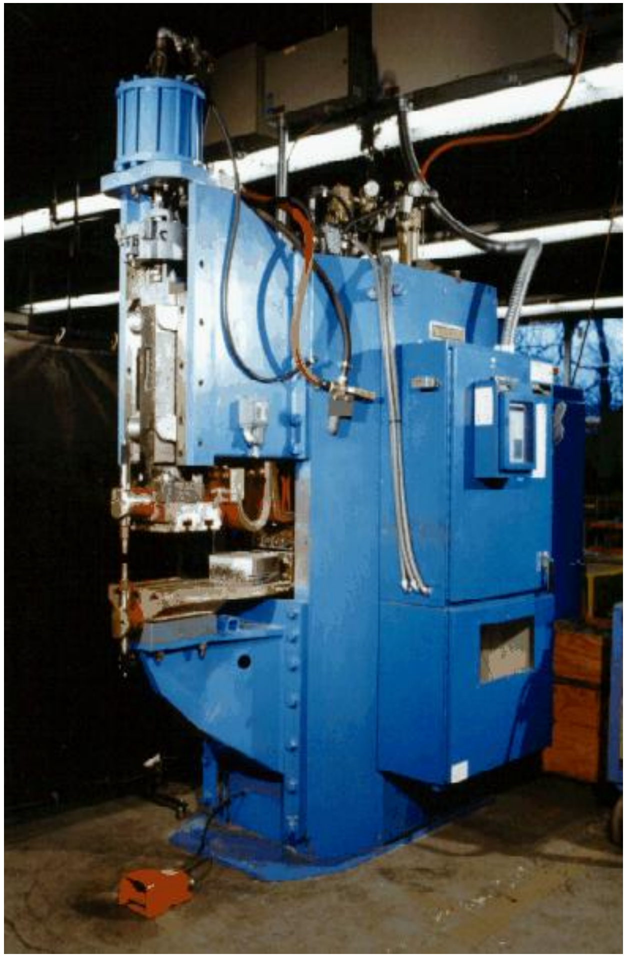


**Roll spot weld** **Overlapping seam weld** **Continuous seam weld**

# Resistance Welding Advantages

- High speed, < 0.1 seconds in automotive spot welds
- Excellent for sheet metal applications, < ¼-inch
- No filler metal

# Process Disadvantages and Limitations



- Higher equipment costs than arc welding
- Power line demands
- Nondestructive testing
- Low tensile and fatigue strength
- Not portable
- Electrode wear
- Lap joint requires additional metal

# Questions