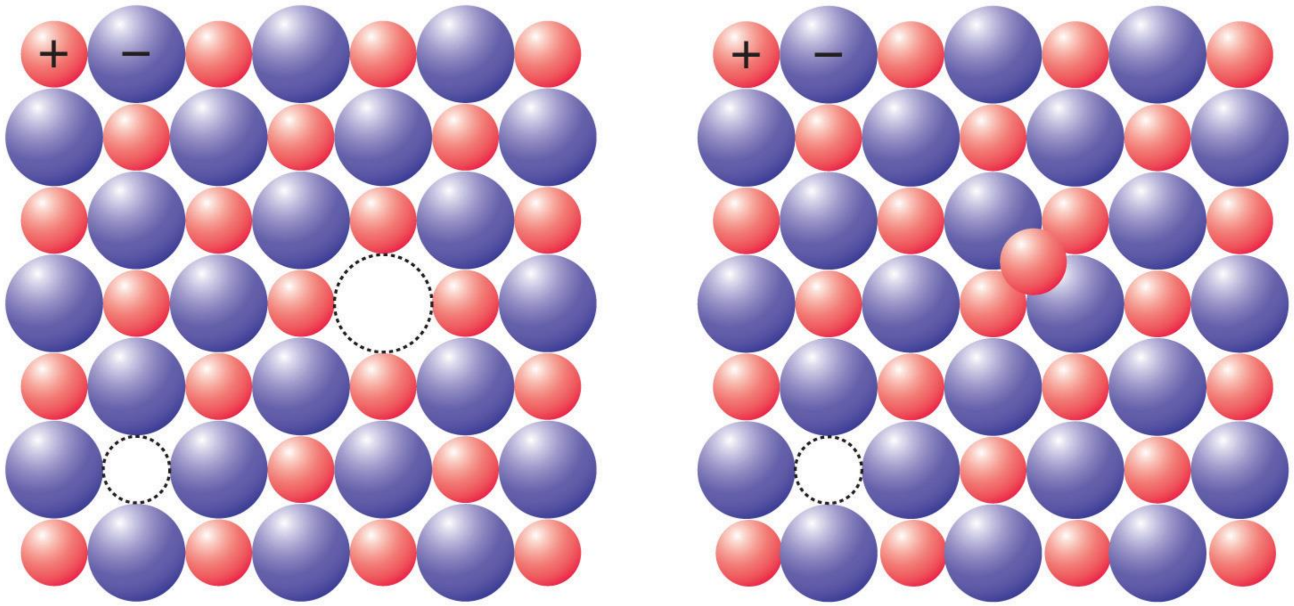
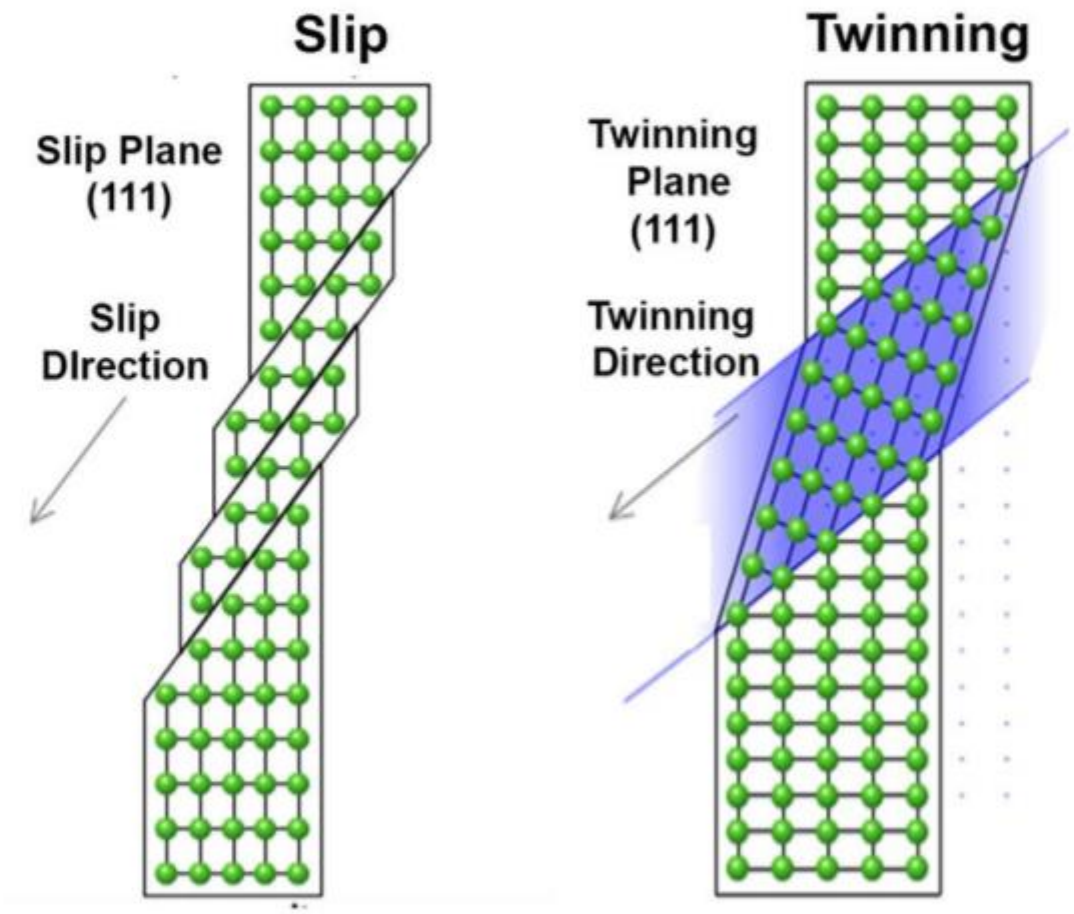
Defects in Ceramics



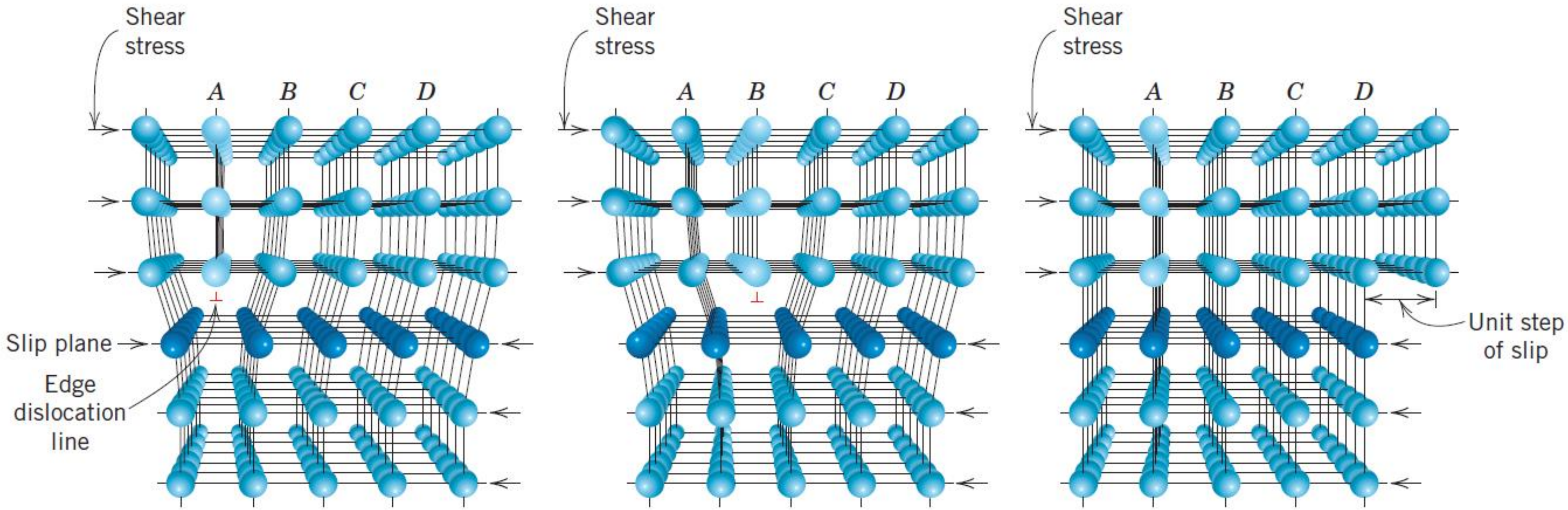
(a) Schottky defect (b) Frenkel defect

(i) Equal number of cations and anions are missing from their normal crystal sites.	Smaller ions (cation) are displaced from normal sites and occupy interstitial sites.
(ii) Density decreases.	No change in density.
(iii) Observed when cations and anions have similar size.	Observed when cations and anions differ in their size.
(iv) It is found in ionic solids having high co-ordination number.	It is found in ionic solids having low co-ordination number.

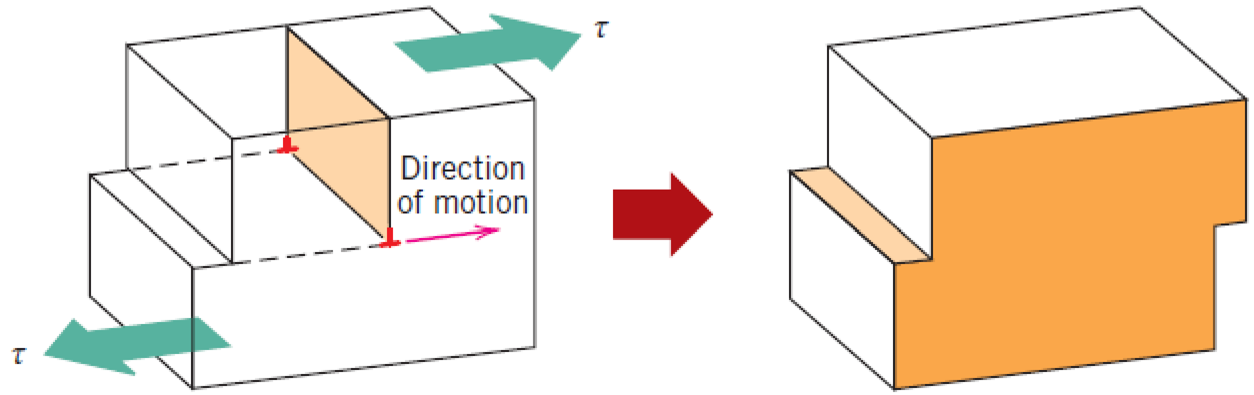
Dislocation Mechanisms and Slip systems



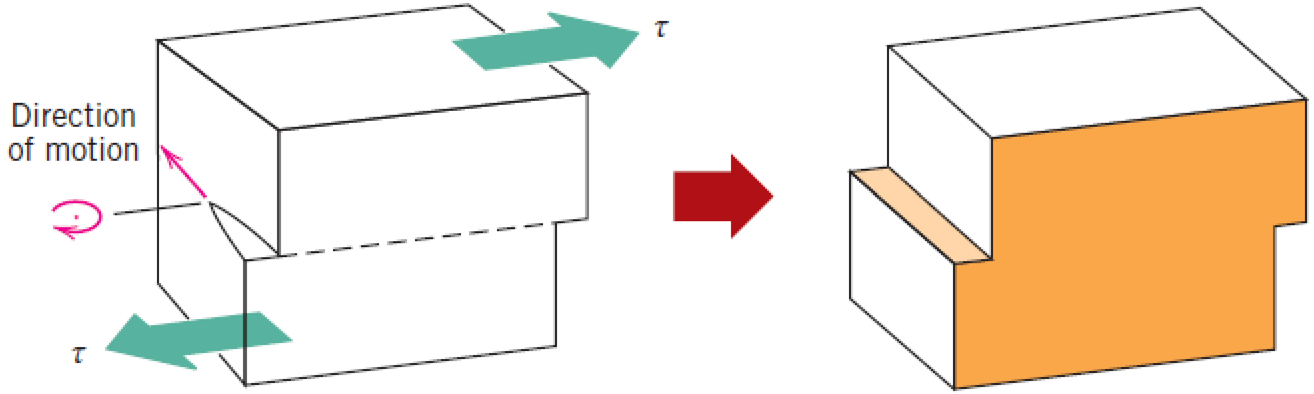
- Plastic deformation is due to movement of dislocations.
- If dislocations cannot be moved, Plastic deformation does not occur
- Dislocation motion is more prominent in metals, So metals exhibit plastic Deformation and ductility.
- Dislocation motion is difficult in Ceramics, So Ceramic does not exhibit plastic deformation and brittle.



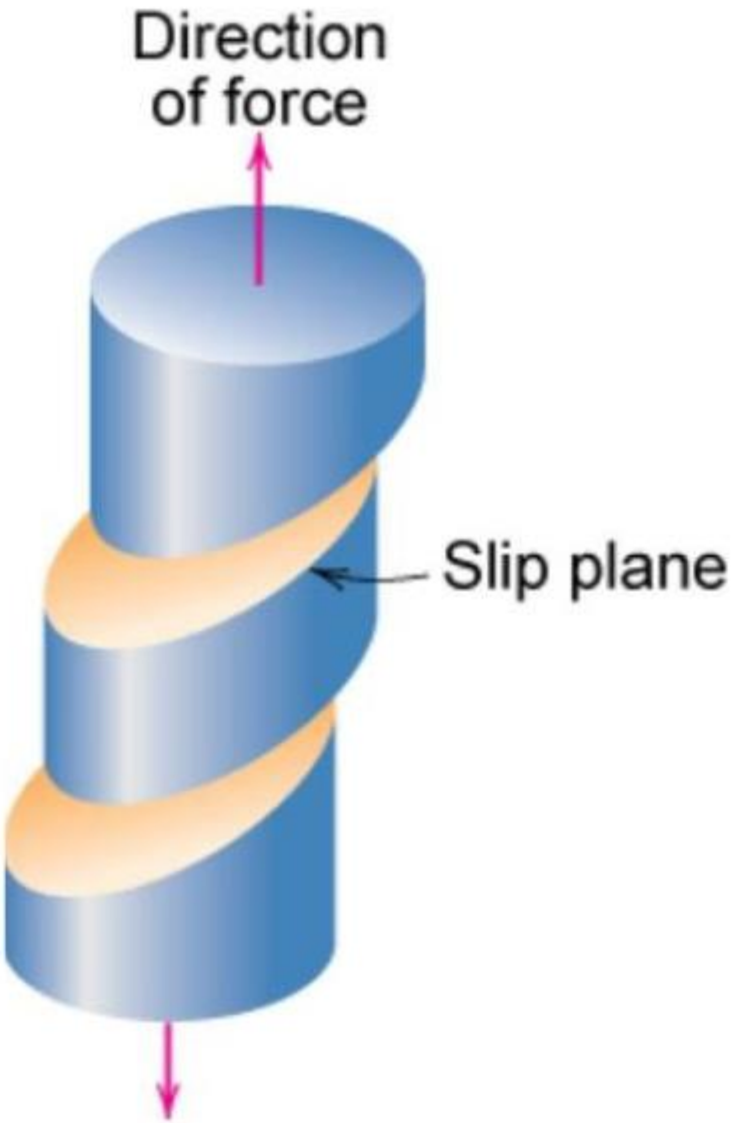
Movement of Edge and screw dislocations under shear stress



(a)



(b)

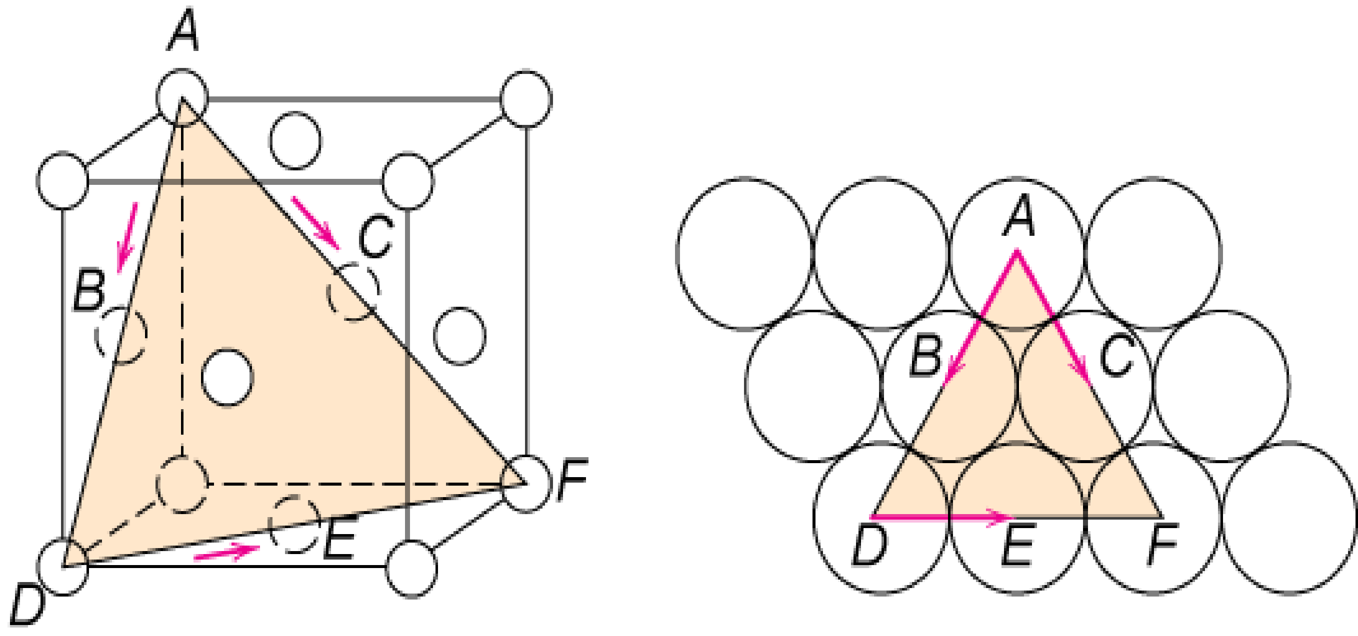

Direction
of force
Slip plane


Slip System:

Slip plane - plane on which easiest slippage occurs
Highest planar densities

Slip directions - directions of movement - Highest linear densities

FCC Slip occurs on {111} planes in <110> directions (close-packed).
Total of 12 slip systems in FCC.



(a) (b)

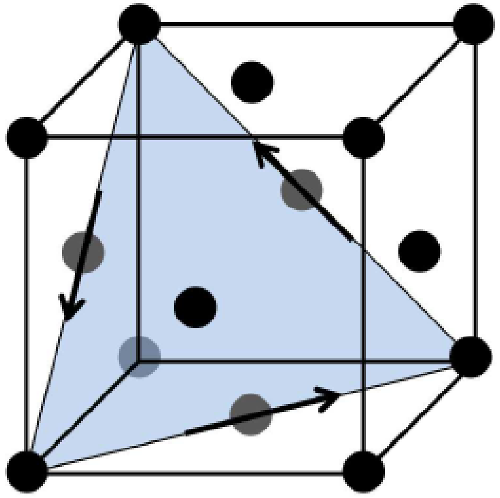
Reason

The slip planes are usually the most densely packed planes. Slip is favored on closed packed planes since a lower shear stress for atomic displacement is required than for less densely packed planes.

Slip in the closed packed direction is also favored since less energy is required to move the atoms from one position to another if the atoms are closer together.

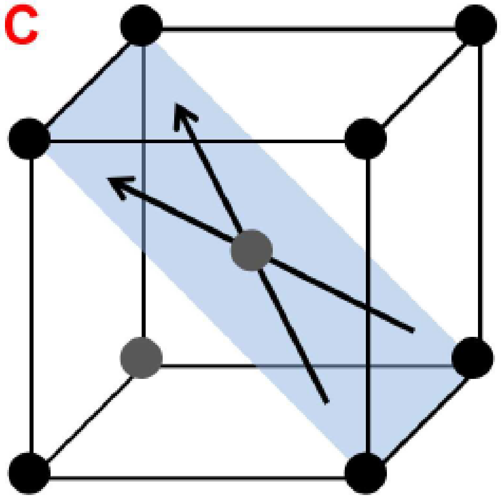
slip in FCC is much more straightforward than in BCC metals

FCC

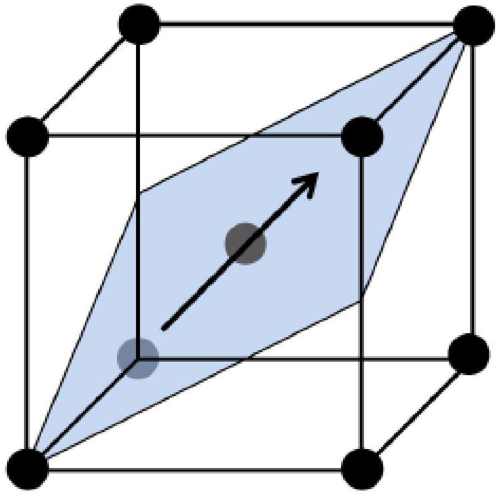


12 Slip systems:
Four {111} Planes each with three <110> Slip directions

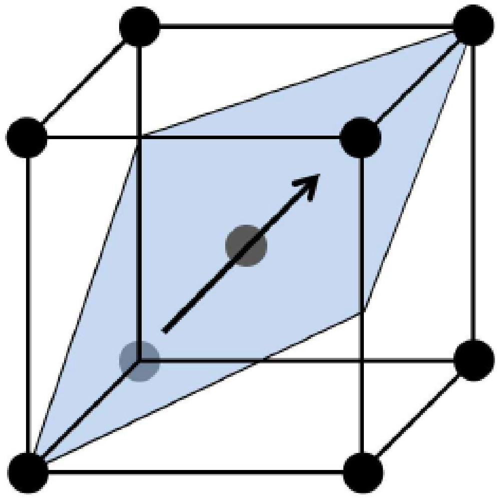
BCC



<u>12 {110} slip systems</u>
6 Planes each with two <111> Directions



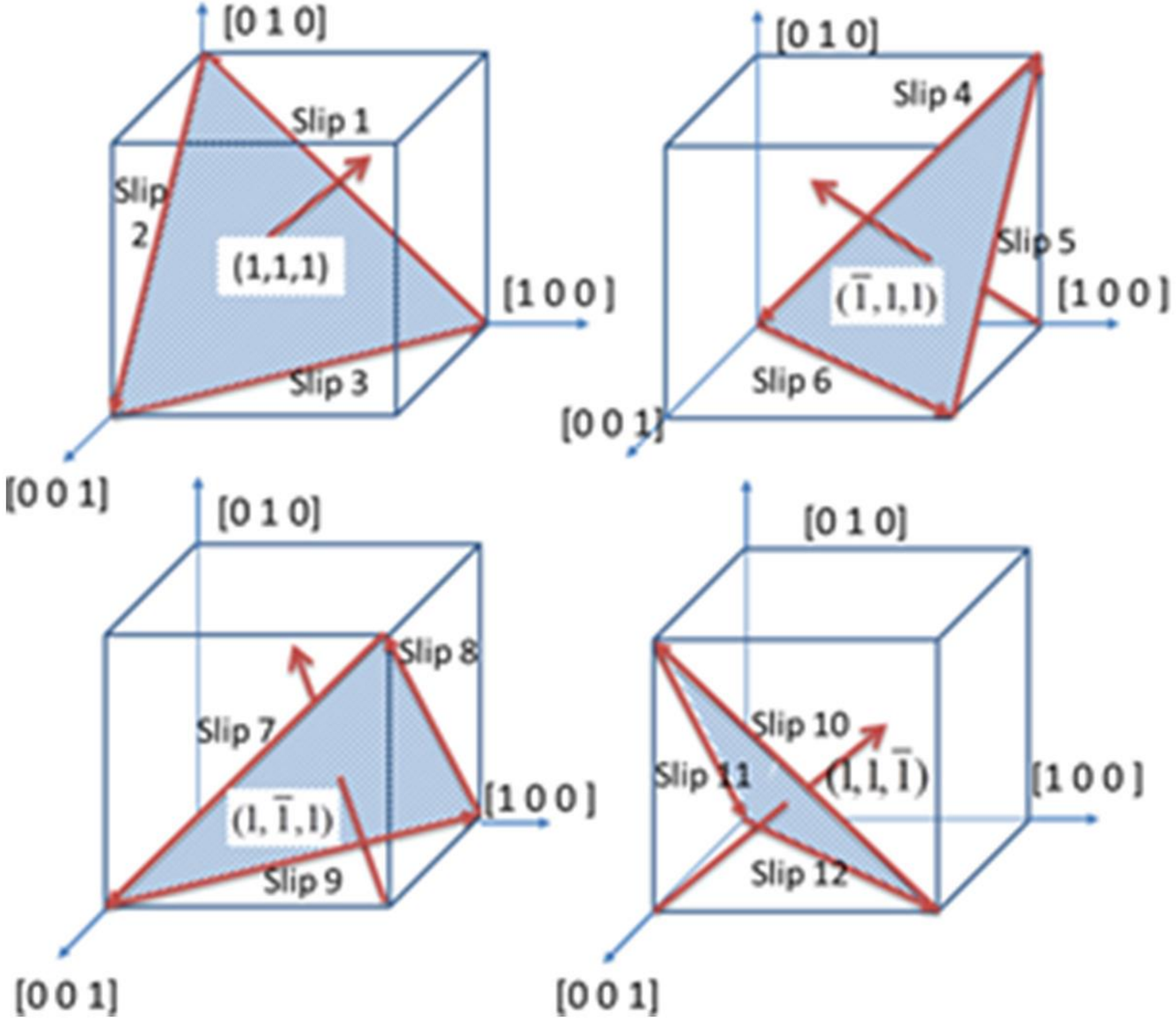
12 {112} slip systems
12 Planes each with one <111> Direction



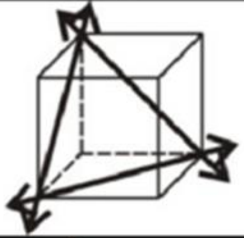
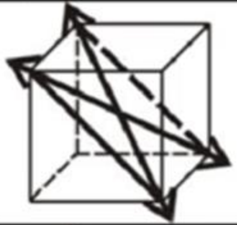
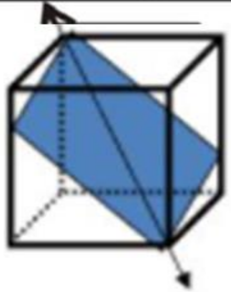
24 {123} slip systems
24 Planes each with one <111> Direction

Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	{111}	⟨110⟩	12
	Body-Centered Cubic		
α-Fe, W, Mo	{110}	⟨111⟩	12
α-Fe,W	{211}	⟨111⟩	12
α-Fe, K	{321}	⟨111⟩	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	{0001}	$\langle 11\bar{2}0\rangle$	3
Ti, Mg, Zr	$\{10\bar{1}0\}$	$\langle 11\bar{2}0\rangle$	3
Ti, Mg	$\{10\bar{1}1\}$	$\langle 11\bar{2}0\rangle$	6

FCC Slip Systems



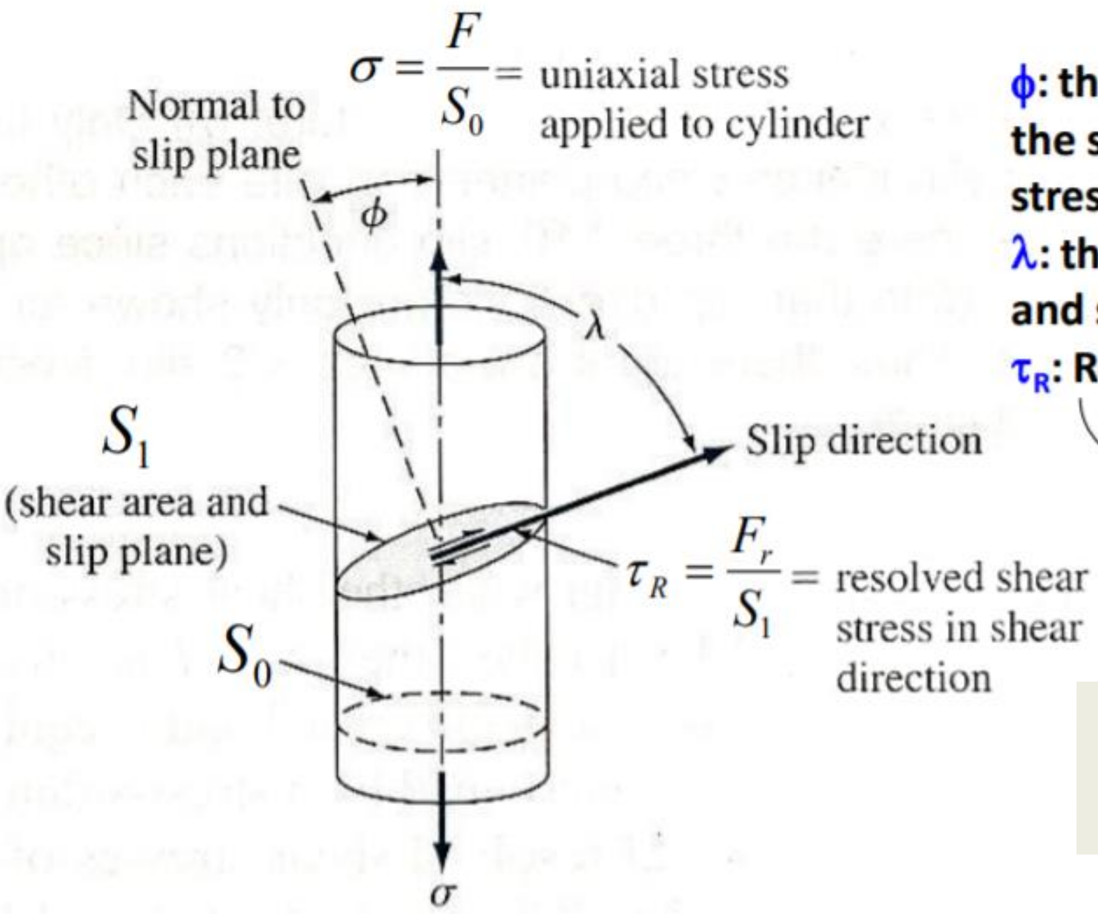
Slip system	Slip plane normal	Slip direction
1	$(1,1,1)$	$[1,\bar{1},0]$
2	$(1,1,1)$	$[0,1,\bar{1}]$
3	$(1,1,1)$	$[1,0,\bar{1}]$
4	$(\bar{1},1,1)$	$[1,1,0]$
5	$(\bar{1},1,1)$	$[0,1,\bar{1}]$
6	$(\bar{1},1,1)$	$[1,0,1]$
7	$(1,\bar{1},1)$	$[1,1,0]$
8	$(1,\bar{1},1)$	$[0,1,1]$
9	$(1,\bar{1},1)$	$[1,0,\bar{1}]$
10	$(1,1,\bar{1})$	$[1,\bar{1},0]$
11	$(1,1,\bar{1})$	$[0,1,1]$
12	$(1,1,\bar{1})$	$[1,0,1]$

Crystal structure	Slip plane	Slip direction	Slip systems	Unit cell geometry
FCC (γ-Fe, Ni, Cu, Al, Ag)	{111}	$<1\bar{1}0>$	4 x 3 = 12	
BCC (α-Fe, Mo)	{110}	$<\bar{1}11>$	6 x 2 = 12	
BCC (α-Fe, Mo)	{211}	$<\bar{1}11>$	12 x 1 = 12	
BCC (α-Fe, Mo)	{321}	$<\bar{1}11>$	24 x 1 = 24	

211, 121,112, -211, 1-21, 11-2,
21-1, 2-11, 12-1, -121, -112, 1-12

Slip in Single Crystal (Schmid's Law)

During tension, although, applied stress may be pure tensile, shear components exist in materials. These are termed resolved shear stress (τ_R)



ϕ: the angle between the normal to the slip plane and the applied stress direction

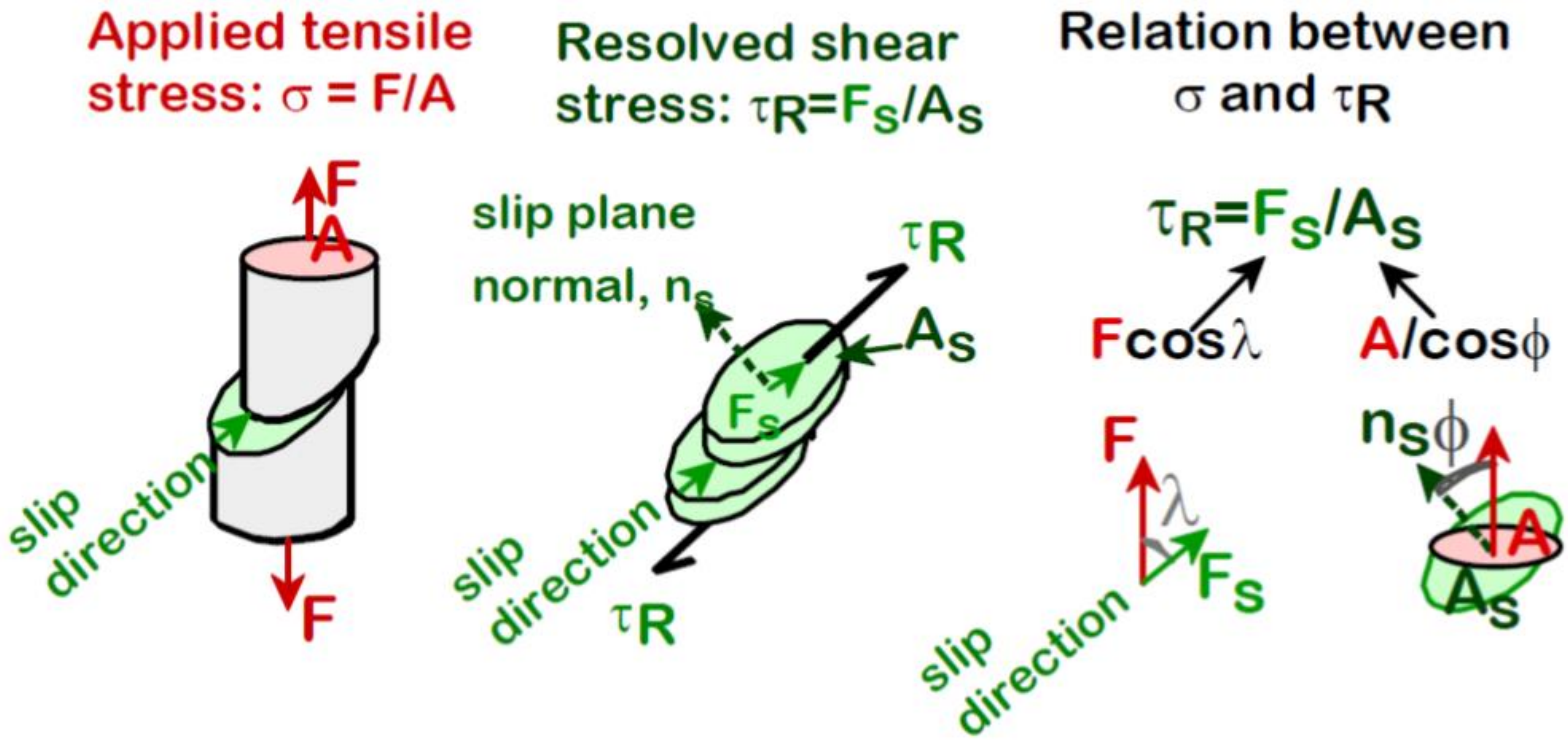
λ: the angle between applied stress and slip direction

τ_R: Resolved shear stress

Schmid's Law

$$\tau_R = \sigma \cos\phi \cos\lambda$$

- Crystal Slip is Due to resolved shear stress



$$\tau_R = \sigma \cos\lambda \cos\phi$$

Slip in a single crystal commences on the most favorably oriented slip system when the resolved shear stress reaches some critical value, termed the **critical resolved shear stress** τ_{crss}

The single crystal plastically deforms or yields when $\tau_{R(max)} = \tau_{crss}$, and the magnitude of the applied stress required to initiate yielding (i.e., the yield strength σ_y) is

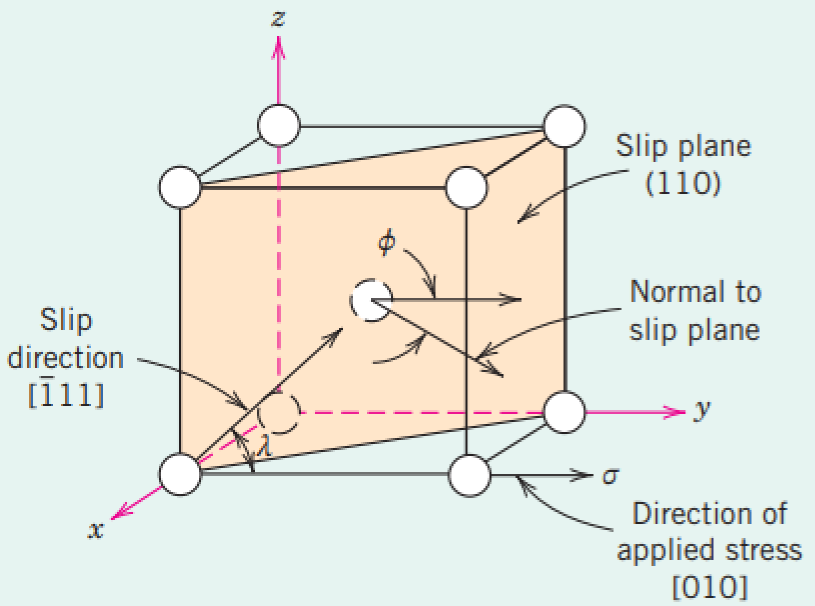
$$\sigma_y = \frac{\tau_{crss}}{(\cos\phi \cos\lambda)_{max}}$$

Resolved Shear Stress and Stress-to-Initiate-Yielding Computations

Consider a single crystal of BCC iron oriented such that a tensile stress is applied along a [010] direction.

(a) Compute the resolved shear stress along a (110) plane and in a $[\bar{1}11]$ direction when a tensile stress of 52 MPa (7500 psi) is applied.

(b) If slip occurs on a (110) plane and in a $[\bar{1}11]$ direction, and the critical resolved shear stress is 30 MPa (4350 psi), calculate the magnitude of the appli
initiate yielding.



$$\theta = \cos^{-1}\left[\frac{u_1u_2 + v_1v_2 + w_1w_2}{\sqrt{(u_1^2 + v_1^2 + w_1^2)(u_2^2 + v_2^2 + w_2^2)}}\right]$$

$$\begin{aligned}\tau_R = \sigma\cos\phi\cos\lambda &= (52\,\text{MPa})(\cos 45°)(\cos 54.7°)\\ &= (52\text{ MPa})\left(\frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{3}}\right)\\ &= 21.3\text{ MPa (3060 psi)}\end{aligned}$$

$$\sigma_y = \frac{30\text{ MPa}}{(\cos 45°)(\cos 54.7°)} = 73.4\,\text{MPa}\,(10{,}600\text{ psi})$$

Plastic deformation of Polycrystalline materials

- Plastic deformation is caused by slip of individual grains.
- Every grain has its own slip system.
- Grain boundaries generally do not break.

Deformation by Twinning

- Twinning occurs on definite plane and direction.
- ex. for BCC (112) and [111].
- Crystallographic orientation changes.
- Atomic displacement is less than interatomic spacing.
- High rates of shock loading is required to cause twinning.