Electrical Conductors

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Electrical conductivity

Ohms Law

$$V = I\,R$$

voltage drop (volts = J/C)
C = Coulomb

current (amps = C/s)

resistance (Ohms)

- Resistivity, ρ:
  -- a material property that is independent of sample size and geometry

$$\rho = \frac{RA}{l}$$

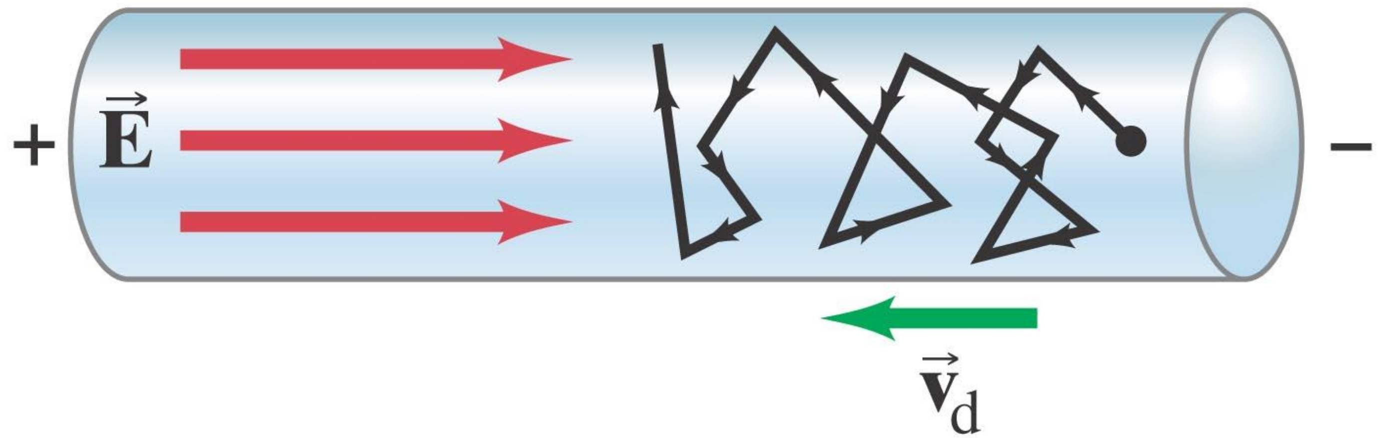
surface area of current flow

current flow path length

- Conductivity, s

$$\sigma = \frac{1}{\rho}$$

Drift Velocity

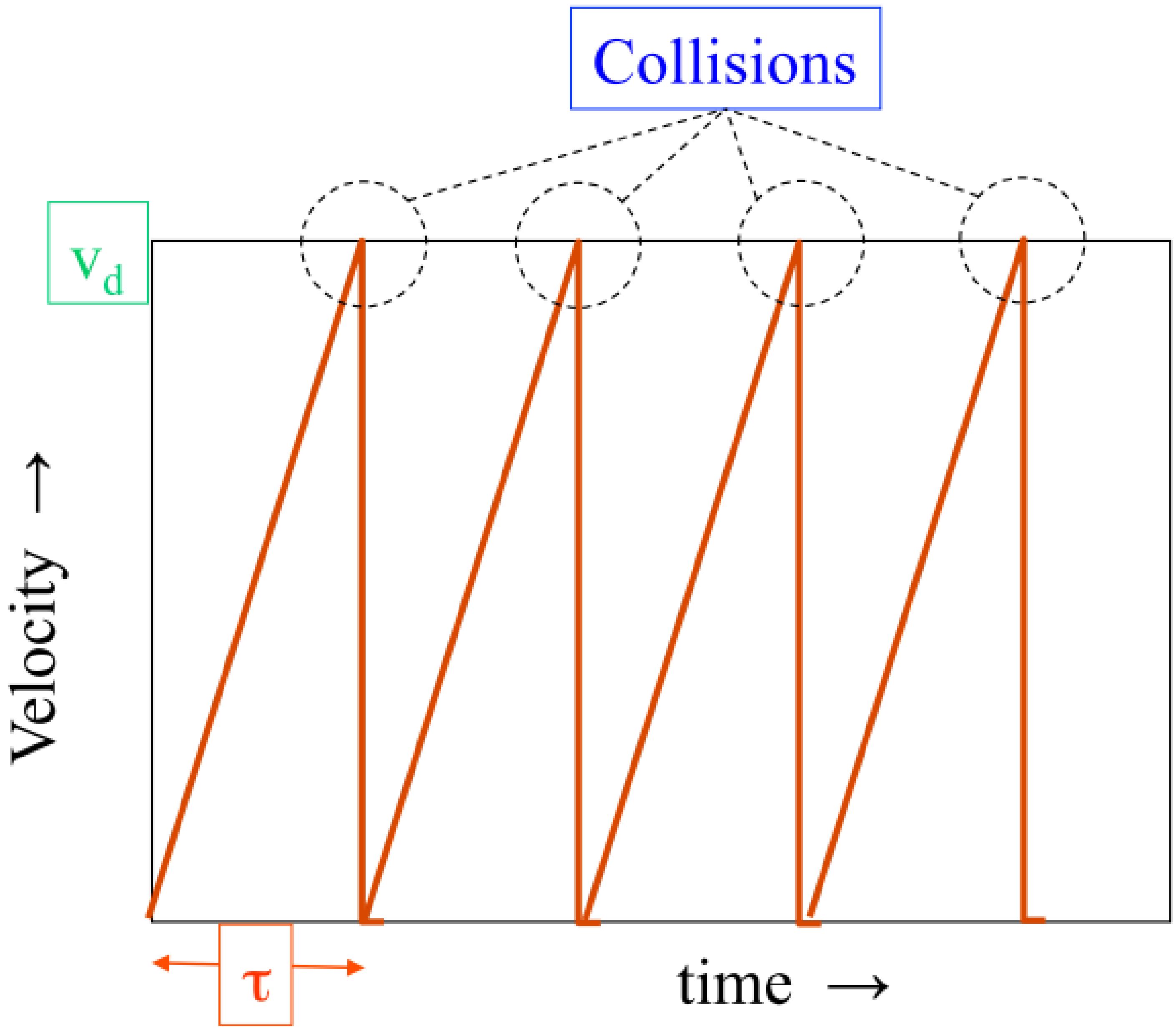


- When the E-Field is first applied, the electrons initially accelerate but soon reach a more or less steady state average velocity.

- This average velocity is in the direction opposite of the E-Field and is known ***drift velocity***

- Drift velocity is due to electrons colliding with metal atoms in the conductor

Drift velocity



Force experienced by an electron

$$F = ma = \vec{E}e$$

m → mass of an electron
E → applied electric field

$$F = m\left(\frac{V_d}{\tau}\right) = E.e$$

$$V_d = \frac{Ee\tau}{m}$$

V_d = Average drift velocity

τ = average collision time

Av. electron velocity in the direction of force imposed by the applied field.

Mobility of electron

Average electron velocity in the direction of force imposed by the applied field.

$v_d \propto E$

proportionality constant = electron mobility.

$v_d = \mu_e E$

μ_e is an indication of the frequency of the scattering events;

Its unit is $m^2/V.s$

$$\vec{J} = ne\vec{v}_d \quad \text{and} \quad \vec{J} = \sigma\vec{E} \quad \rightarrow \quad \boxed{\begin{array}{l} \sigma = ne\mu \\ \sigma = \dfrac{ne^2\tau}{m} \end{array}}$$

Mean free path of electron

Average distance between two successive collisions (With electric field)

For an ideal crystal

1. At temperature $T = 0$ K,

   mean free path = $\infty \rightarrow$ infinite conductivity

2. At temperature $T > 0$ K

- Atoms vibrate about their mean positions
- these vibrations can be thought of as elastic waves in crystals (phonons)
- these phonons interact with the motion of electrons

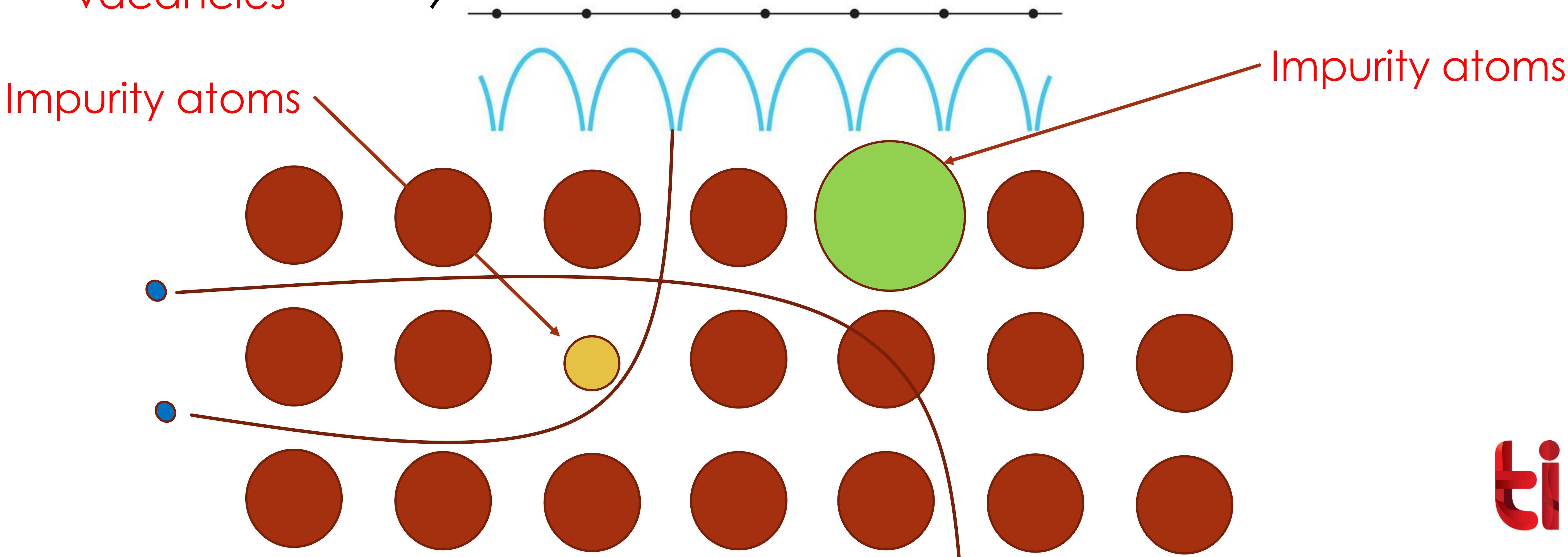
  $\rightarrow$ decrease in conductivity

Mattheissen Rule

Metals: Influence of Temperature and Impurities on Resistivity

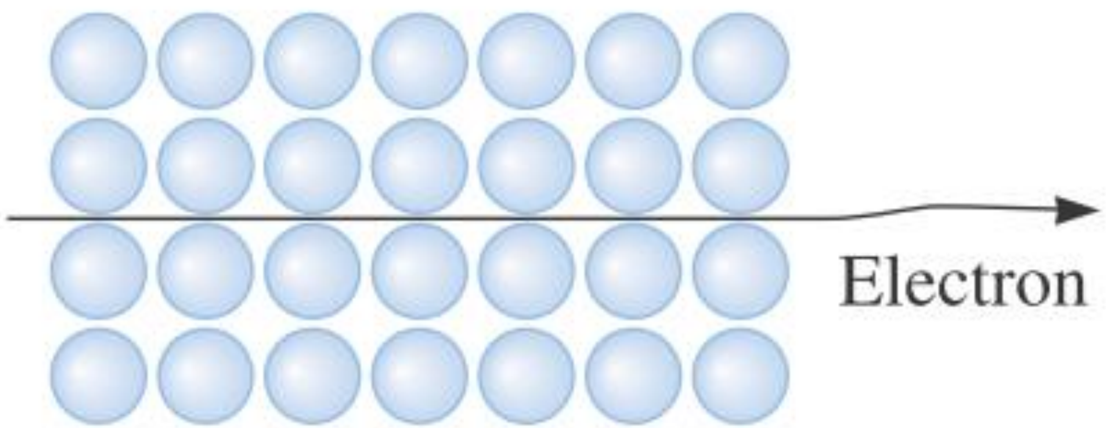
- Presence of imperfections (Scattering centers) increases resistivity
  - -- grain boundaries
  - -- dislocations
  - -- impurity atoms
  - -- vacancies

These act to scatter electrons so that they take a less direct path.



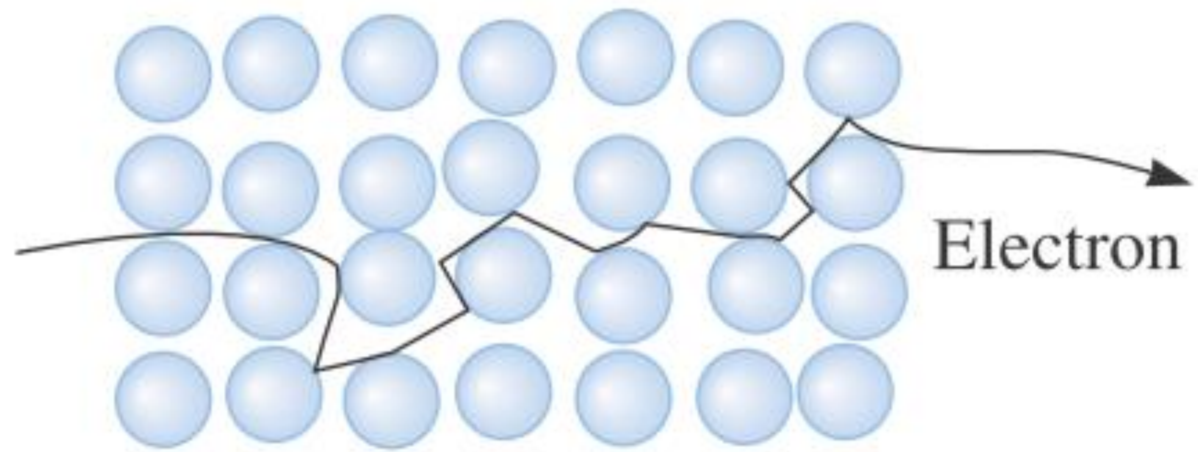
Scattering of electrons

Perfect crystal

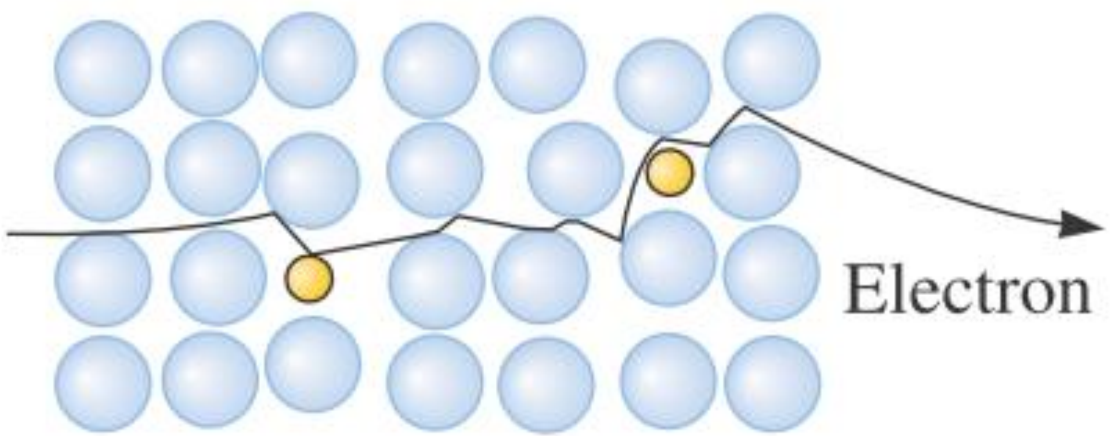


(a)

At high temperature



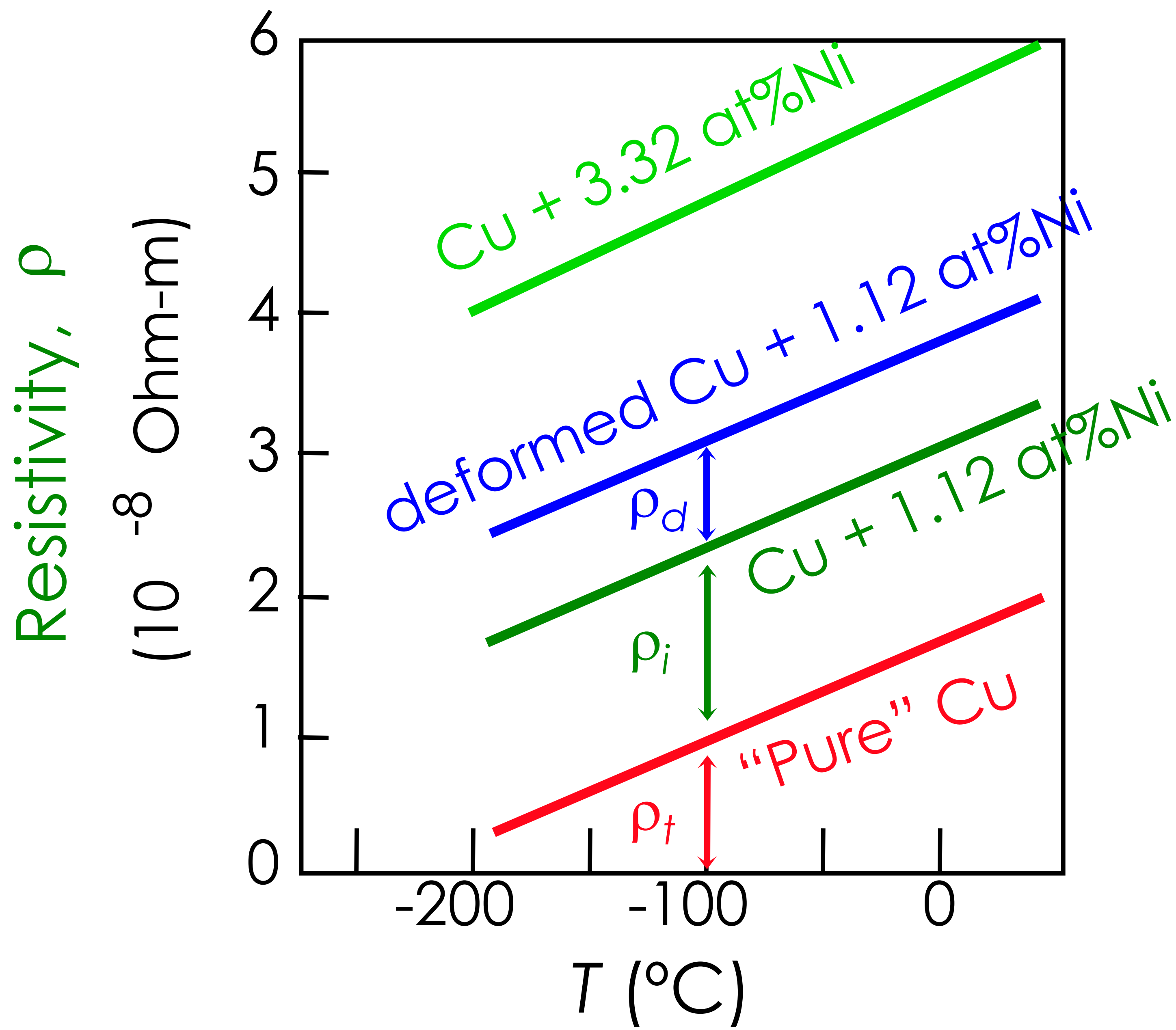
(b)



A crystal with atomic level defects

Mattheissen Rule

Metals: Influence of Temperature and Impurities on Resistivity



- Resistivity increases with:
  - -- temperature
  - -- wt% impurity
  - -- % *Deformation*

$$\rho = \rho_{thermal} + \rho_{impurity} + \rho_{deformation}$$

Applications of conductors

For electrical contacts

1. High electrical conductivity
2. High thermal conductivity – dissipate heat effectively
3. High melting point – accidental overheating does not fuse the contacts
4. High oxidation resistance – free from insulating oxides
5. High mechanical strength- For critical contacts. Al strength increases by CdO dispersion. Dislocation do not move- ductility decreases.

Ex: Al for long distance applications & Cu for switch, brushes, relays, etc.

Applications of conductors

As a conductor in transmission and distribution lines

1. Low I^2R loss (Power)
2. Copper and Al best choices.
3. Large cross section area to reduce loss.
4. Al by reinforcing steel gives better strength.

Applications of conductors

As a resistor

1. Uniform resistivity
2. Stable resistance
3. Low thermoelectric potential with Cu
4. Small temperature coefficient of resistance (α)

   ➔ (minimizes error due to fluctuations in temp)

$$\alpha = \frac{1}{R}\frac{dR}{dT}$$

For pure Cu, $\alpha = 4000 \times 10^{-6}\ K^{-1}$,

Manganin alloy (87 % Cu, 13 % Mn) $\alpha = 20 \times 10^{-6}\ K^{-1}$

E.g. Ballast Resistor: used to maintain constant current in industrial circuits.

Flow of current increases → Temp increases → Resistance increases → decreases current in the circuit → Fault.

Applications of conductors

As a heating element

1. High melting point
2. High resistivity
3. Good oxidation resistance
4. Good creep strength
5. Resistance to thermal fatigue
   - ➔ Low elastic modulus
   - ➔ Low thermal expansion

Candidates

a. Nichrome (80%NI,20%Cr)
b. Kanthal (69%Fe, 23%Cr, 6%Al, 2%Co)
c. SiC
d. $MoSi_2$
e. Graphite for inert atmosphere
f. Mo, Ta: Poor oxidation resistance
g. W: ThO_2 dispersion to improve creep resistance

Applications of conductors

As a thermometer

1. High temperature coefficient of resistance (α)
2. Should changes linearly with temperature

Candidate: Pure metal e.g. Pt

Summary

1. A velocity of electron in the presence of electric field is known as drift velocity.
2. Conductivity is directly proportional to the mobility of electrons.
3. Electrical conductivity is strongly affected by impurity, defects and grain boundaries.
4. At 0 K the ideal crystal has infinite conductivity, which decreases with increases in the temperature due to atomic vibrations.