EEE-2103: Electronic Devices and Circuits

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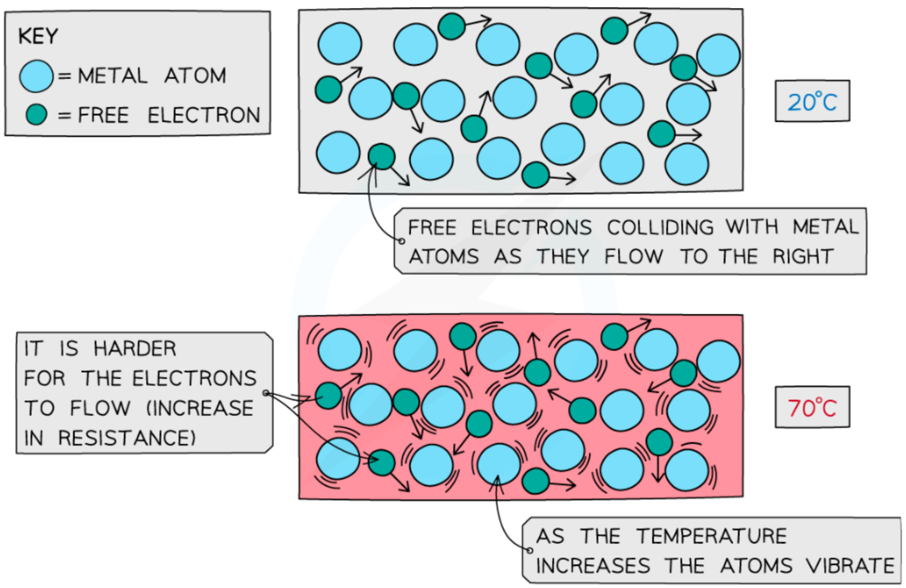
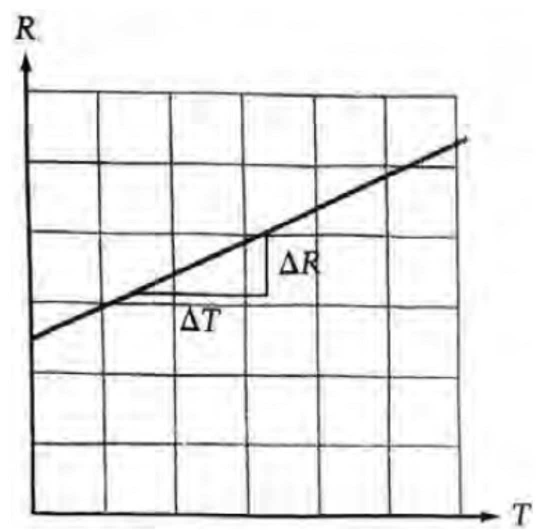
n-Type and *p*-Type Semiconductors

Effects of heat:

Conductor is heated → atoms tend to vibrate
reduces electrons movement
current flow reduces = resistance increases
positive temperature coefficient (PTC) of resistance





n-Type and *p*-Type Semiconductors

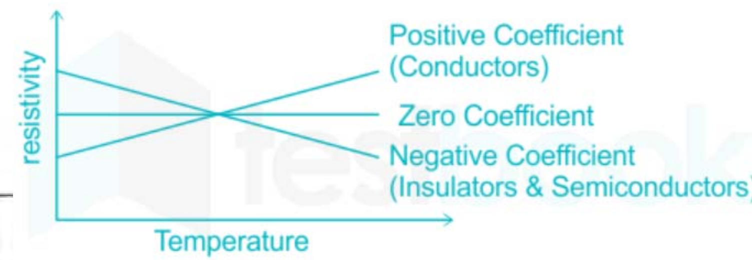
Effects of heat:

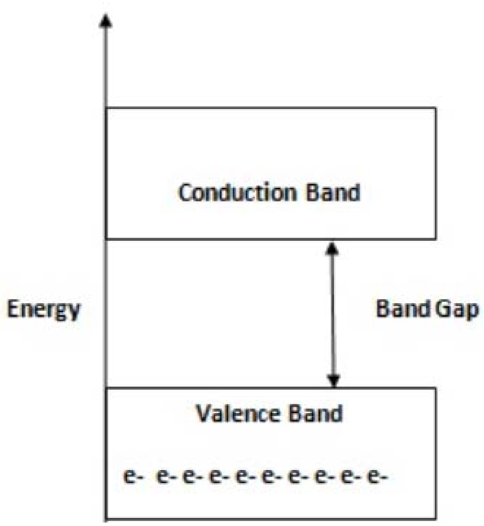
Undoped semiconductor material at absolute zero temperature (-273^{0}C) →

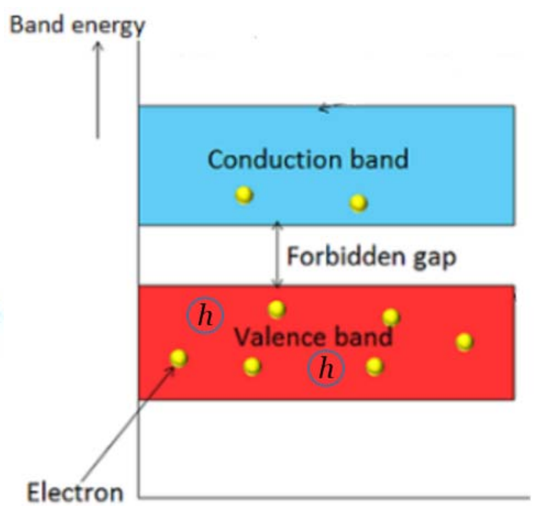
no electrons in conduction band + no holes in valence band = insulator

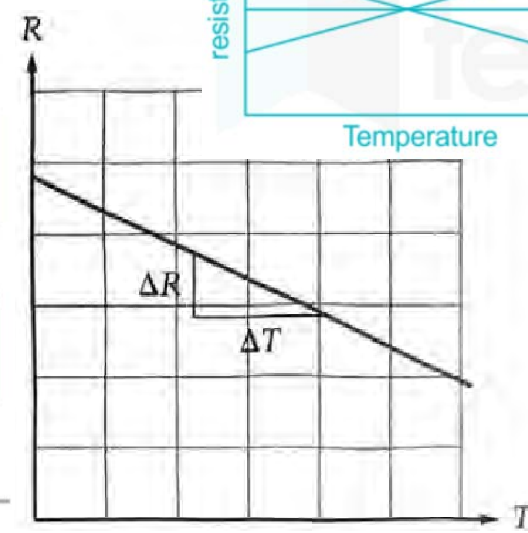
Semiconductor is heated →

electrons in conduction band + holes in valence band + thermal vibration of atoms
few electrons to be impeded + *e*-*h* pairs generation dominates =
current flow increases = resistance decreases
negative temperature coefficient (NTC) of resistance







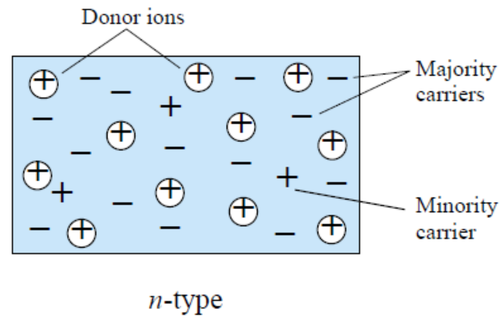


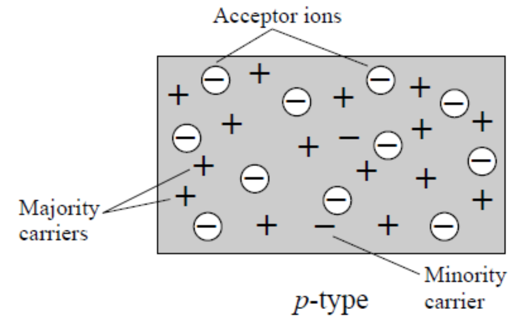
***pn*-Junction**

Junction of *p*-type and *n*-type:

p-type → holes are uniformly distributed

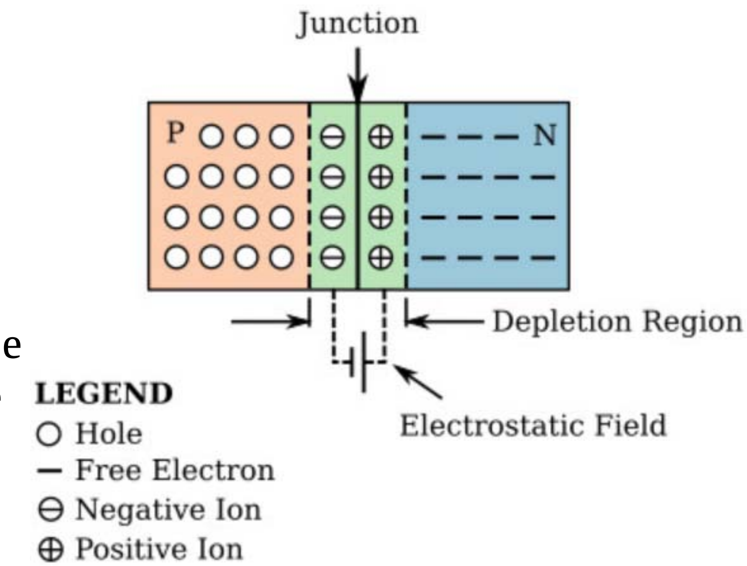
n-type → electrons are uniformly distributed





pn-junction →

- electrons and holes diffuse across junction
- free electrons fill adjacent holes on *p*-side →
    - create negative ions
    - electrons leave positive ions on *n*-side
- close to junction →
    - positive ions create positive voltage on *n*-side
    - negative ions create negative voltage on *p*-side
- negative voltage repels electrons crossing from *n*-side
- positive voltage repels holes movement from *n*-side
- creates barrier voltage
- Ge = 0.3 V, Si = 0.7 V
- barrier voltage → opposes flow of majority carriers
    assists flow of minority carriers



pn-Junction

<u>Depletion region:</u>

n-side → donor impurity atoms

lost free electrons = becomes positively charged ions

p-side → acceptor impurity atoms

lost holes = becomes negatively charged ions

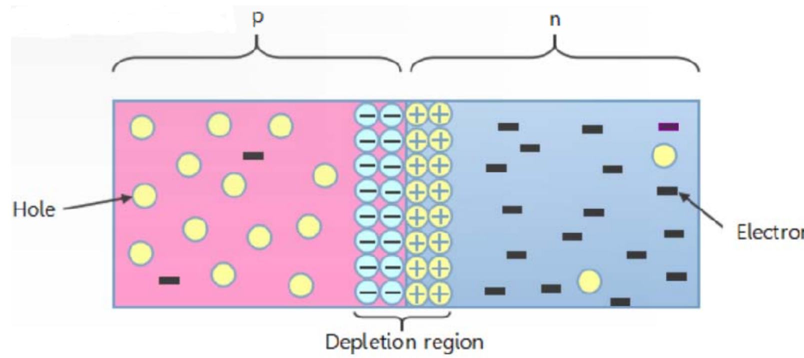
Equal number of impurity atoms involved

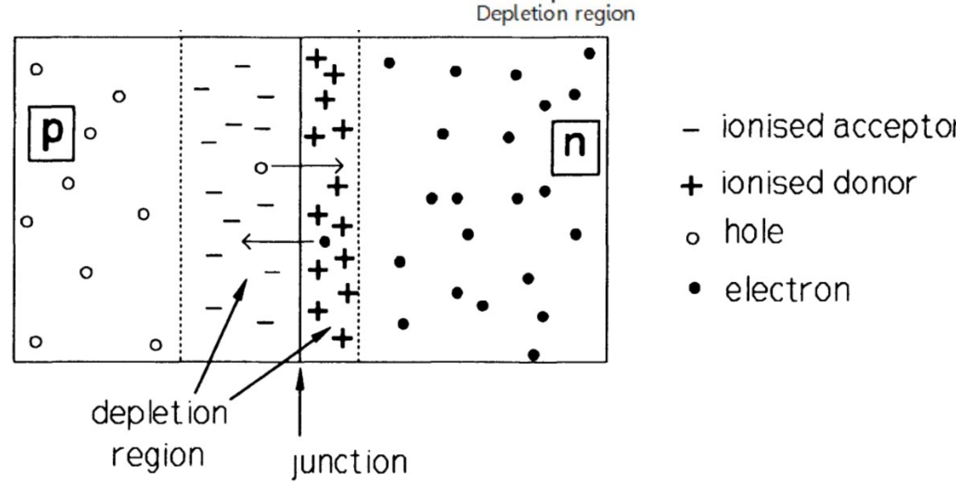
Equal doping densities → equal widths on each side

Unequal doping densities →

depletion region penetrates deeper

into lightly doped side





Biased Junction

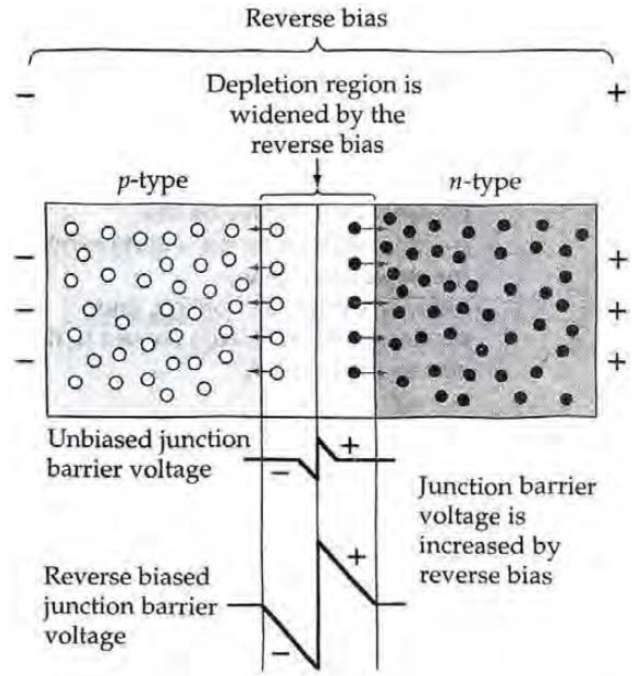
Reverse-biased junction:

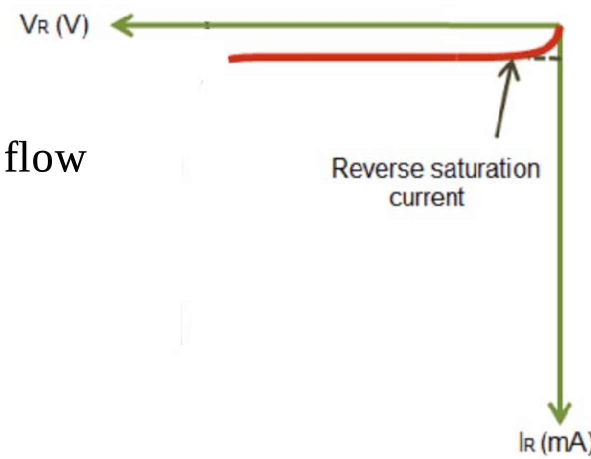
External reverse bias voltage = positive to *n*-side
negative to *p*-side

Holes on *p*-side are attracted away from junction
Electrons on *n*-side are attracted away from junction
= Depletion region widens + Barrier voltage increases

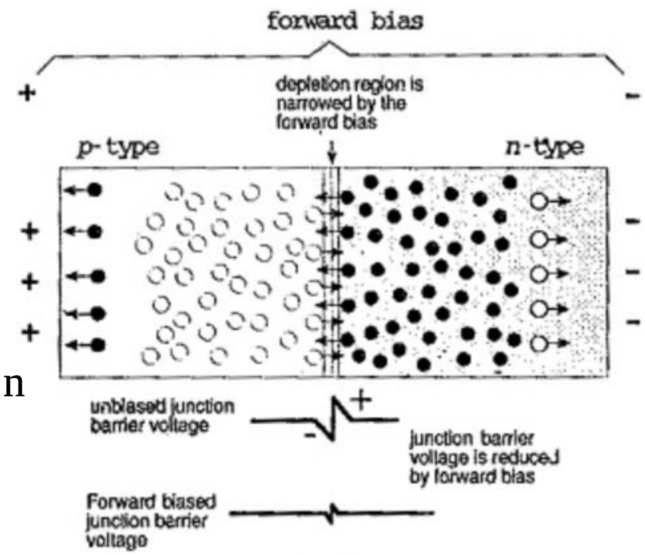
Majority charge carrier current flow stops
Minority carriers on each side can cross junction =
Very small reverse current flows
Nanoamps to microamps current flows

Very small reverse bias voltage is necessary for all minority carriers flow
Equivalent current = Reverse saturation current





Biased Junction



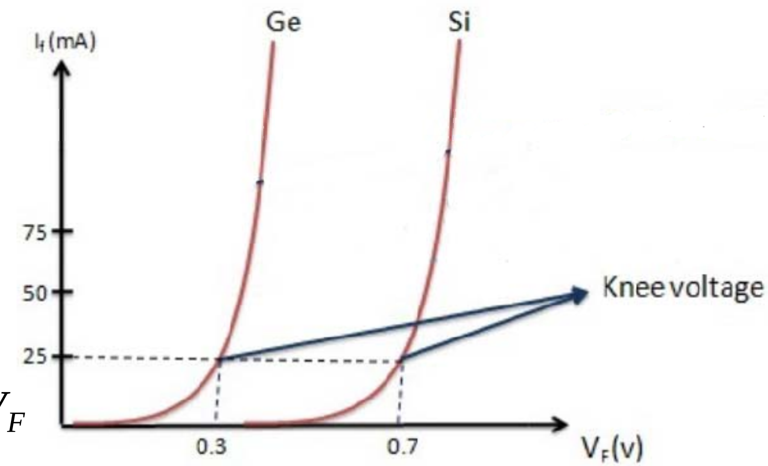
Forward-biased junction:

External forward bias voltage = positive to *p*-side
negative to *n*-side

Holes on *p*-side are repelled from +ve terminal toward junction
Electrons on *n*-side are repelled from -ve terminal toward junction
= Depletion region reduced + Barrier voltage decreases

High applied bias voltage →
barrier voltage disappears
e from *n*-side attracted to +ve bias terminal
h from *p*-side attracted to -ve bias terminal
majority charge carrier current flows easily

Very little forward current flows until
V_F > junction barrier voltage
Above knee voltage, I_F increases linearly with increase in V_F



Junction Current and Voltage

Shockley equation:

Relating *pn*-junction current and voltage levels.

Also known as diode equation.

$I_D = I_0\left[e^{V_D/nV_T} - 1\right]$ (1.1)

I_D = junction current

I_0 = reverse saturation current

V_D = junction voltage

n = 1 for Ge, 2 for Si

$V_T = kT/q$ = thermal voltage (1.2)

k = Boltzmann's constant = 1.38×10^{-23} J/K [$m^2kgs^{-2}K^{-1}$]

T = absolute temperature

q = electric charge = 1.6×10^{-19} C

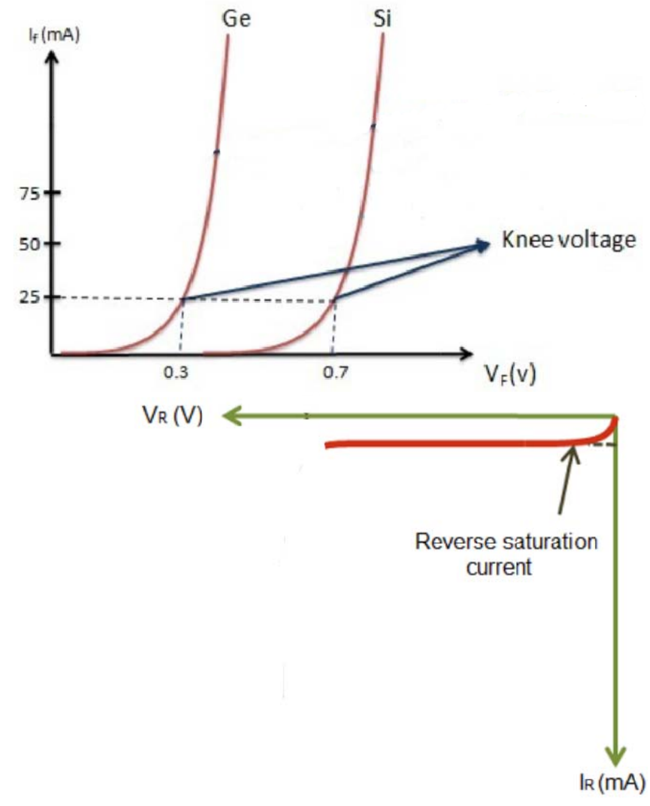
Junction voltage for a given forward current →

$V_D = (nV_T)\ln(I_D/I_0)$ (1.3) [assumption: $I_D >> I_0$]

Junction Current and Voltage

Problem-1:

A silicon pn-junction has a reverse saturation current I_0 = 30 nA at a temperature of 300 K. Calculate the junction current when the applied voltage is (a) 0.7 V forward bias, (b) 10 V reverse bias. Assume V_T = 26 mV at T = 300 K.



(a) 0.7 V forward bias

V_D/nV_T = 0.7/(2×26×10^{-3}) = 13.46

$I_D = I_0\left[e^{V_D/nV_T} - 1\right]$ = 30×10^{-9}[e$^{13.46}$ – 1] = 21 mA

(b) 10 V reverse bias

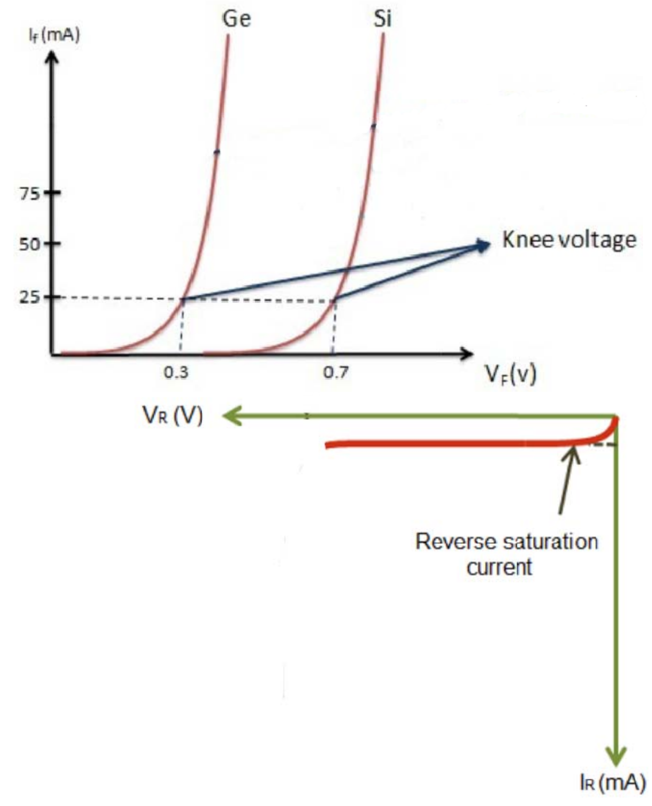
V_D/nV_T = -10/(2×26×10^{-3}) = -192

$I_D = I_0\left[e^{V_D/nV_T} - 1\right]$ = 30×10^{-9}[e^{-192} – 1] = -30 nA

Junction Current and Voltage

Problem-2:

A silicon *pn*-junction has a reverse saturation current I_0 = 30 nA at a temperature of 300 K. Calculate the junction forward bias voltage required to produce a current of (a) 0.1 mA, (b) 10 mA. Assume V_T = 26 mV at T = 300 K.



(a) I_D = 0.1 mA

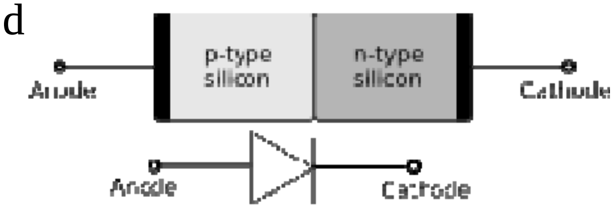
$$V_D = (nV_T)\ln(I_D/I_0)$$
$$= 2\times26\times10^{-3}\times\ln(0.1\times10^{-3}/30\times10^{-9})$$
$$= 422 \text{ mV}$$

(b) I_D = 10 mA

$$V_D = (nV_T)\ln(I_D/I_0)$$
$$= 2\times26\times10^{-3}\times\ln(10\times10^{-3}/30\times10^{-9})$$
$$= 661 \text{ mV}$$

***pn*-Junction Diode**

Diode → *pn*-junction + connecting leads
one-way device = low resistance when forward biased
open switch when reverse biased
constant forward voltage drop
constant reverse saturation current



Diode is destroyed if →
high forward current overheats device
large reverse voltage causes junction to break down = reverse breakdown

Typical forward and reverse characteristics of diode →