

18-100 Introduction to Electrical and Computer Engineering

Lecture 04 Semiconductors, Diodes, and Light Emitting Diodes (LEDs)



Are you here?

Let us know and win prizes.

Course Syllabus

18-100: *Introduction to Electrical and Computer Engineering* **Spring 2025**

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Office Hours: Monday, 2-4pm or by appointment

Schedule (Subject to Change)

Week	Date	Day	Lecture Topic
1	13-Jan	M	L01: Intro, Physics, EM, Leveling Students
	15-Jan	W	L02: Circuits Basics
2	20-Jan	M	Martin Luther King Celebration (No Lecture)
	22-Jan	W	L03: Equivalent Circuits
3	27-Jan	M	L04: Semiconductors, Diodes, LEDs
	29-Jan	W	L05: MOSFETs to Simple Gates
4	3-Feb	M	L06: Professional Identity, Professional Responsibility, and Ethics
	5-Feb	W	Exam 1
5	10-Feb	M	L07: Capacitors, RC Time Constants, RC Circuits
	12-Feb	W	L08: Inductors, RL Time Constants, 555
6	17-Feb	M	L09: Binary, Logic Gates, Boolean Logic
	19-Feb	W	L10: Latches, Registers, RAM, Flip-Flops
7	24-Feb	M	L11: Computers
	26-Feb	W	L12: Op Amps
	3-Mar	M	SPRING BREAK
	5-Mar	W	SPRING BREAK

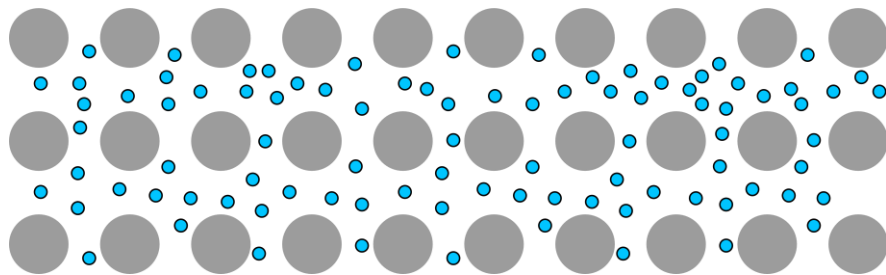
Objectives of this Lecture

- Semiconductors
- Diodes
- Light Emitting Diodes (LEDs)

Conductors vs. Insulators

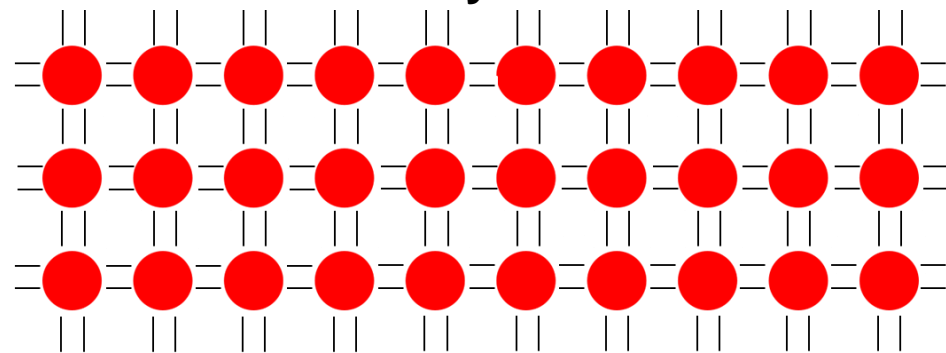
- Material **conductivity** is a material electrical property
- More free electrons, more current can flow

Conductors have many free electrons



Gold, copper, aluminum, salt water...

Insulators have very few free electrons

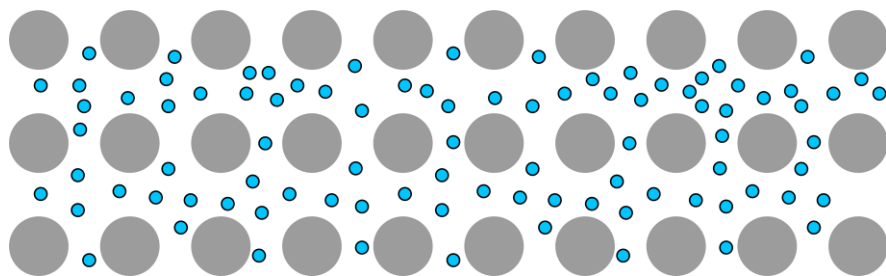


Rubber, glass, plastic, rust...

Conductors vs. Insulators vs. Semiconductors

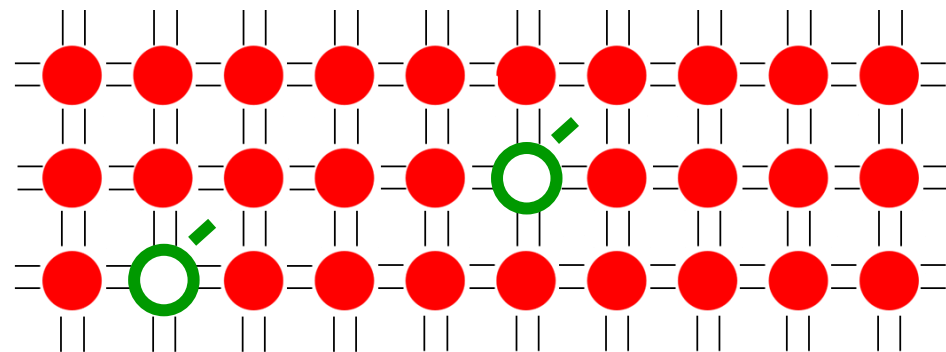
- Material **conductivity** is a material electrical property
- More free electrons, more current can flow

Conductors have many free electrons



Gold, copper, aluminum, salt water...

Semiconductors have a few free electrons



Silicon, germanium, gallium arsenide...

Start with a Block of Pure, Electrically Neutral Silicon (Or Another Semiconductor)

Column
IV

4/8 Valence Electrons

1

IA

1

H

Hydrogen

1.008

1

2

IIA

4

Be

Beryllium

9.0122

2-2

3

3

Li

Lithium

6.94

2-1

11

11

Na

Sodium

22.98976928

2-1

19

19

K

Potassium

39.0983

2-1

37

37

Rb

Rubidium

85.4678

2-1

55

55

Cs

Cesium

132.90545196

2-1

2

2

He

Helium

4.0026

2

10

10

Ne

Neon

20.180

2-8

18

18

Ar

Argon

39.948

2-8-8

36

36

Kr

Krypton

83.798

2-8-18-8

54

54

Xe

Xenon

131.29

2-8-18-18-8

86

86

Rn

Radon

(222)

2-8-18-32-18-8

13

IIIA

5

B

Boron

10.81

2-3

14

IVA

6

C

Carbon

12.011

2-4

15

VA

7

N

Nitrogen

14.007

2-5

16

VIA

8

O

Oxygen

15.999

2-6

17

VIIA

9

F

Fluorine

18.998

2-7

13

13

Al

Aluminium

26.982

2-3

14

14

Si

Silicon

28.085

2-4

15

15

P

Phosphorus

30.974

2-5

16

16

S

Sulfur

32.06

2-6

17

17

Cl

Chlorine

35.45

2-7

31

31

Ga

Gallium

69.723

2-8-3

32

32

Ge

Germanium

72.630

2-8-4

33

33

As

Arsenic

74.922

2-8-5

34

34

Se

Selenium

78.971

2-8-6

35

35

Br

Bromine

79.904

2-8-7

49

49

In

Indium

114.82

2-8-18-3

50

50

Sn

Tin

118.71

2-8-18-4

51

51

Sb

Antimony

121.76

2-8-18-5

52

52

Te

Tellurium

127.60

2-8-18-6

53

53

I

Iodine

126.90

2-8-18-7

81

81

Tl

Thallium

204.38

2-8-18-32-3

82

82

Pb

Lead

207.2

2-8-18-32-4

83

83

Bi

Bismuth

208.98

2-8-18-32-5

84

84

Po

Polonium

(209)

2-8-18-32-6

85

85

At

Astatine

(210)

2-8-18-32-7

113

113

Nh

Nihonium

284.1597

2-3

114

114

Fl

Flerovium

289.101

2-3

115

115

Mc

Moscovium

289.101

2-3

116

116

Lv

Livermorium

289.101

2-3

117

117

Ts

Tennessine

289.101

2-3

118

118

Og

Oganesson

289.101

2-3

Atomic Number →

1

← Symbol

→ Name

Hydrogen

← Atomic Weight

→ Electrons per shell

1

State of matter (color of name)

GAS LIQUID SOLID UNKNOWN

Subcategory in the metal-metalloid-nonmetal trend (color of background)

Alkali metals

Alkaline earth metals

Transition metals

Lanthanides

Actinides

Post-transition metals

Metalloids

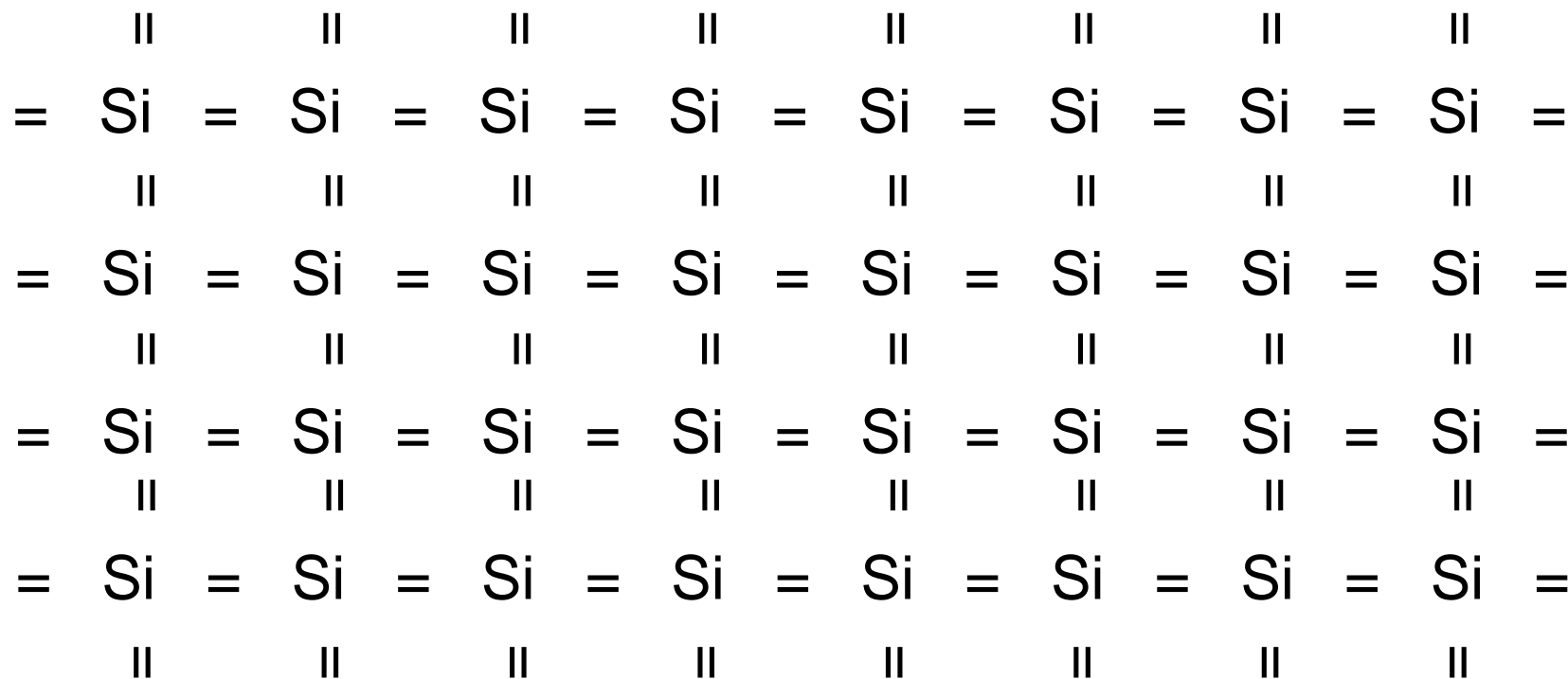
Reactive nonmetals

Noble gases

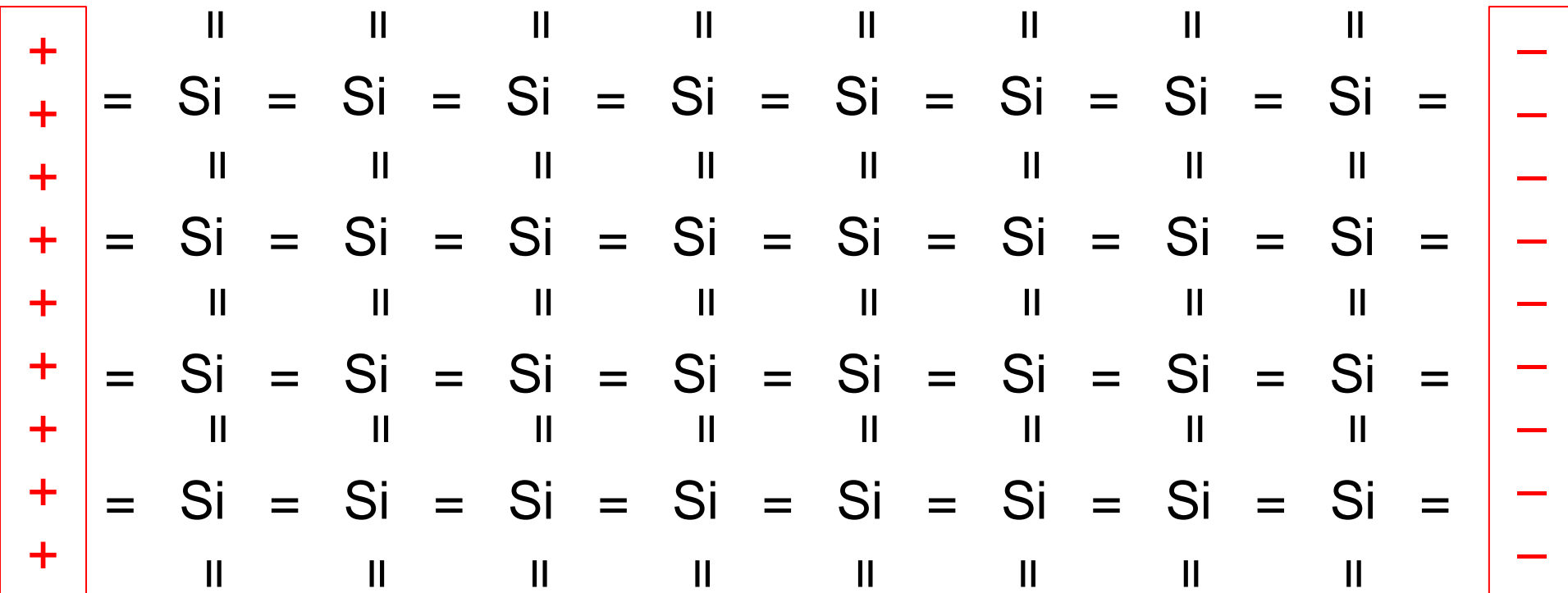
Unknown chemical properties

4/8 Valence Electrons

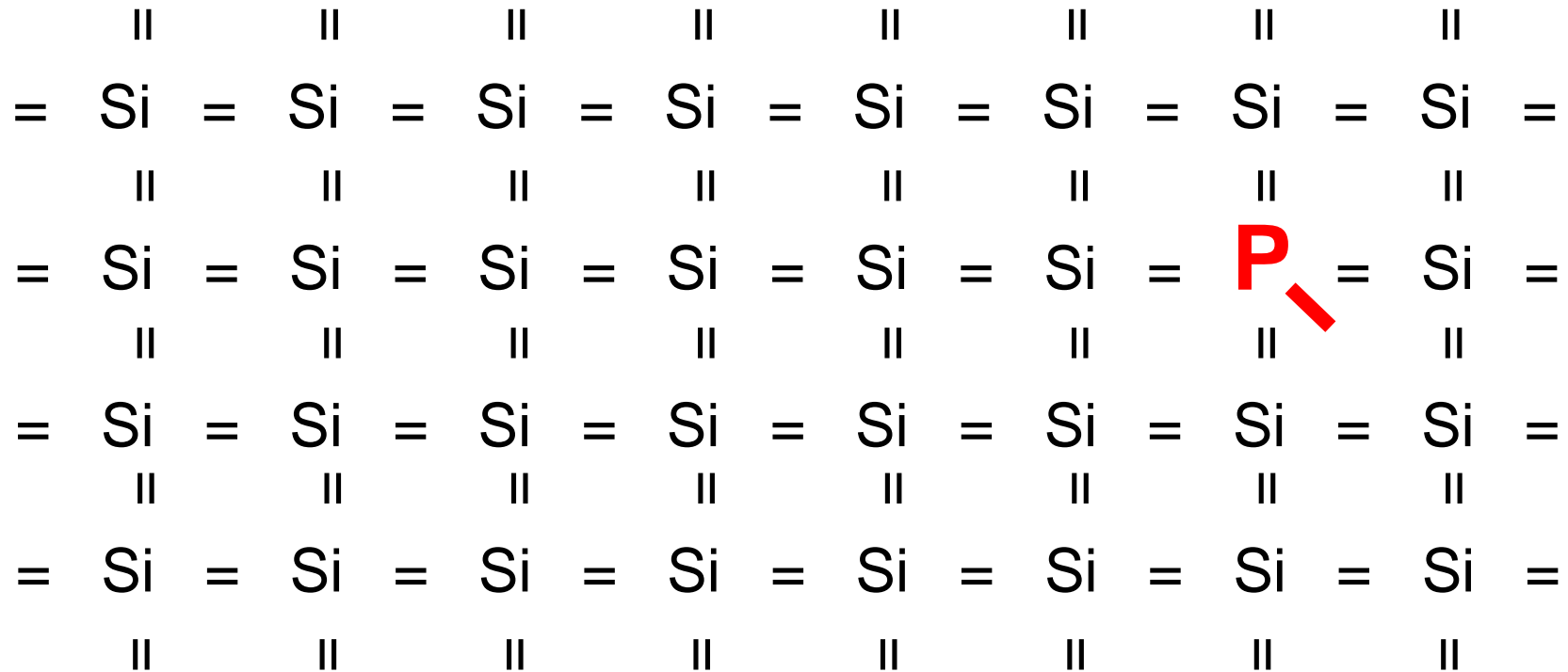
Start with a Block of Pure, Electrically Neutral Silicon:



Start with a Block of Pure, Electrically Neutral Silicon: Strong Covalent Bonds Make It an Insulator

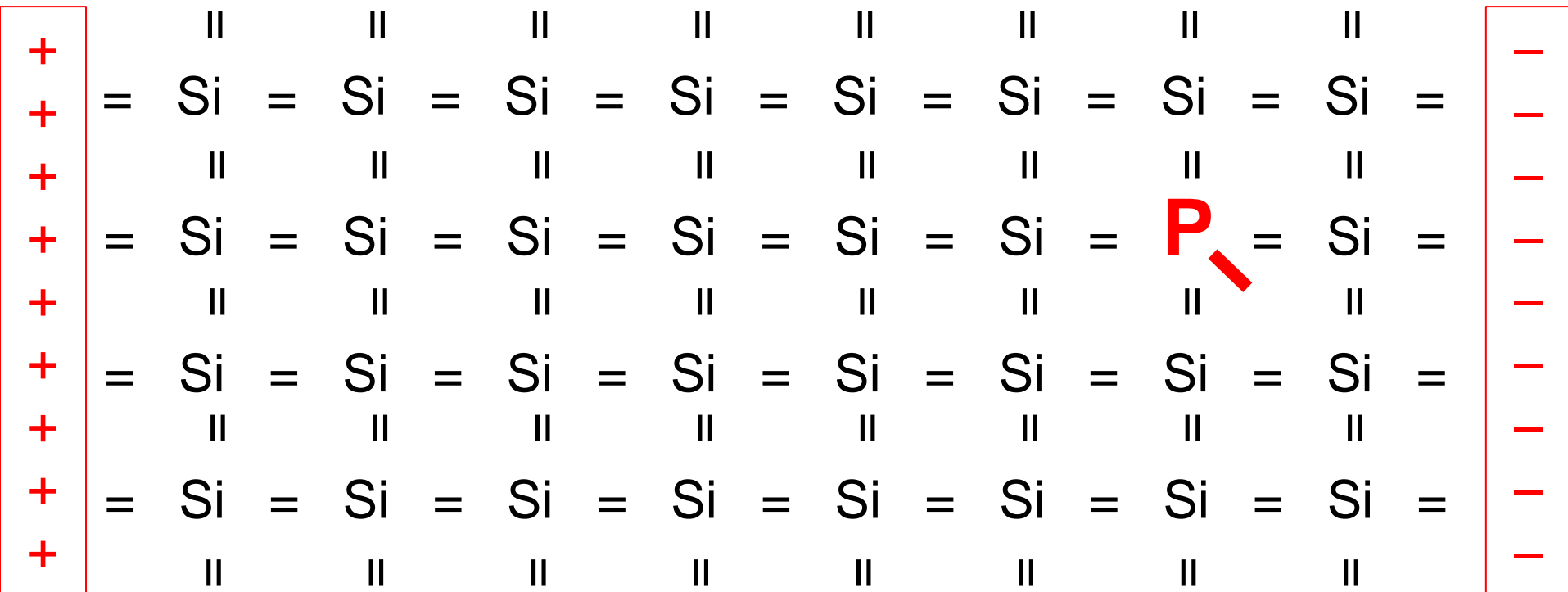


Phosphorus Has One Extra Valence Electron



Phosphorus Has One Extra Valence Electron

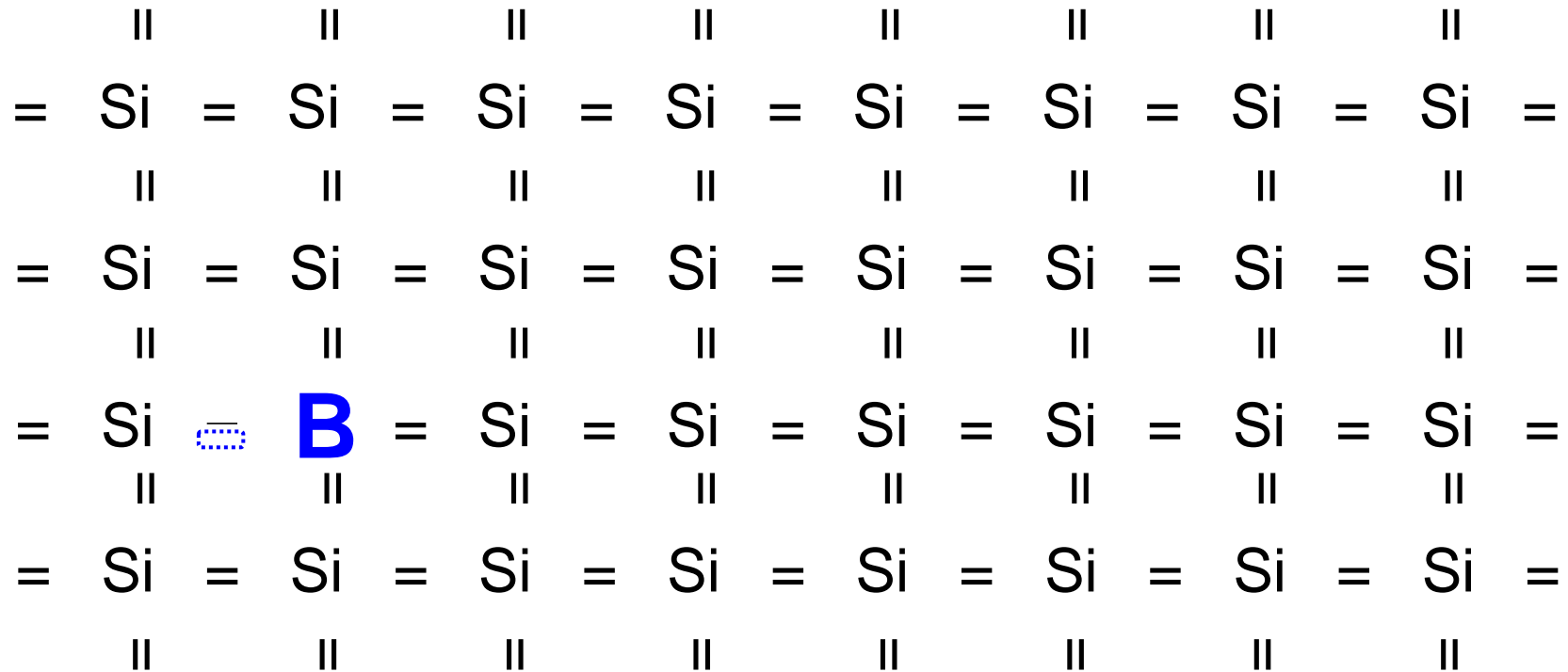
Greatly Increases Conductivity of the Semiconductor



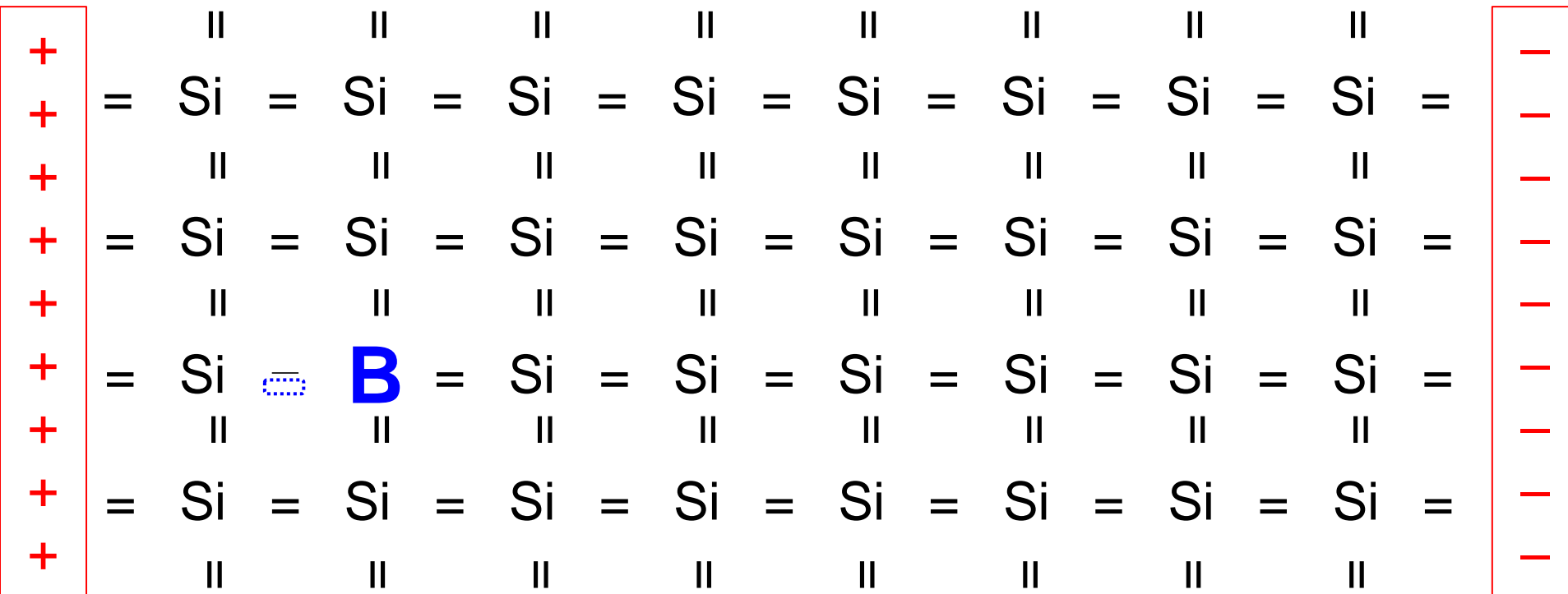
Column

2-8-13-2 2-8-14-
ENGINEERING

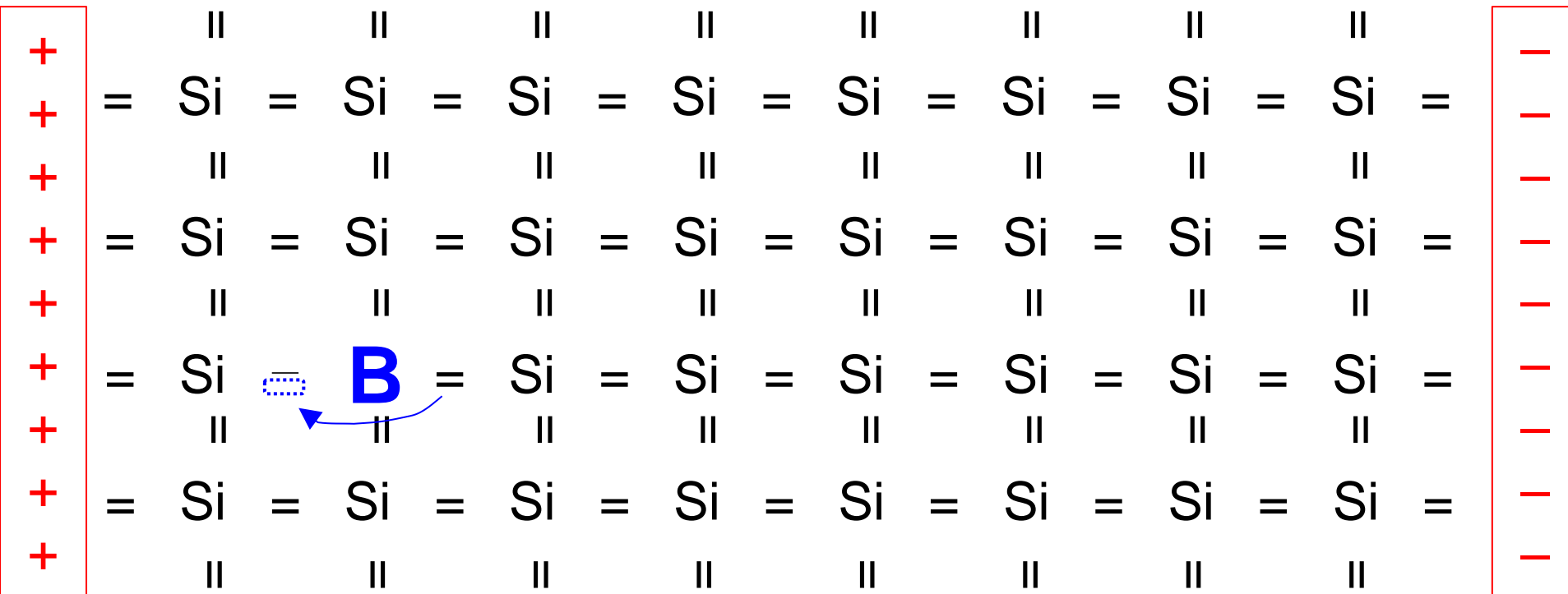
Boron Has One Fewer Valence Electron (hole, h^+)



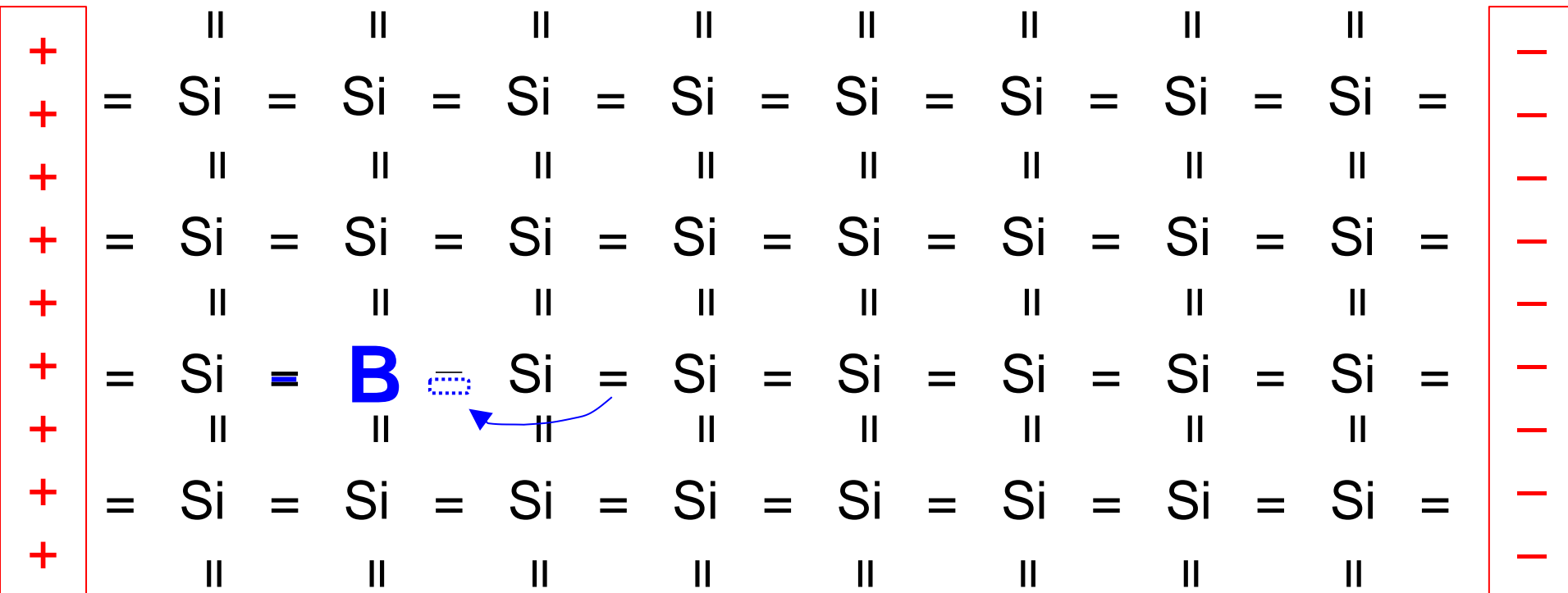
Boron Has One Fewer Valence Electron (hole, h^+) Can Still Increase Conductivity



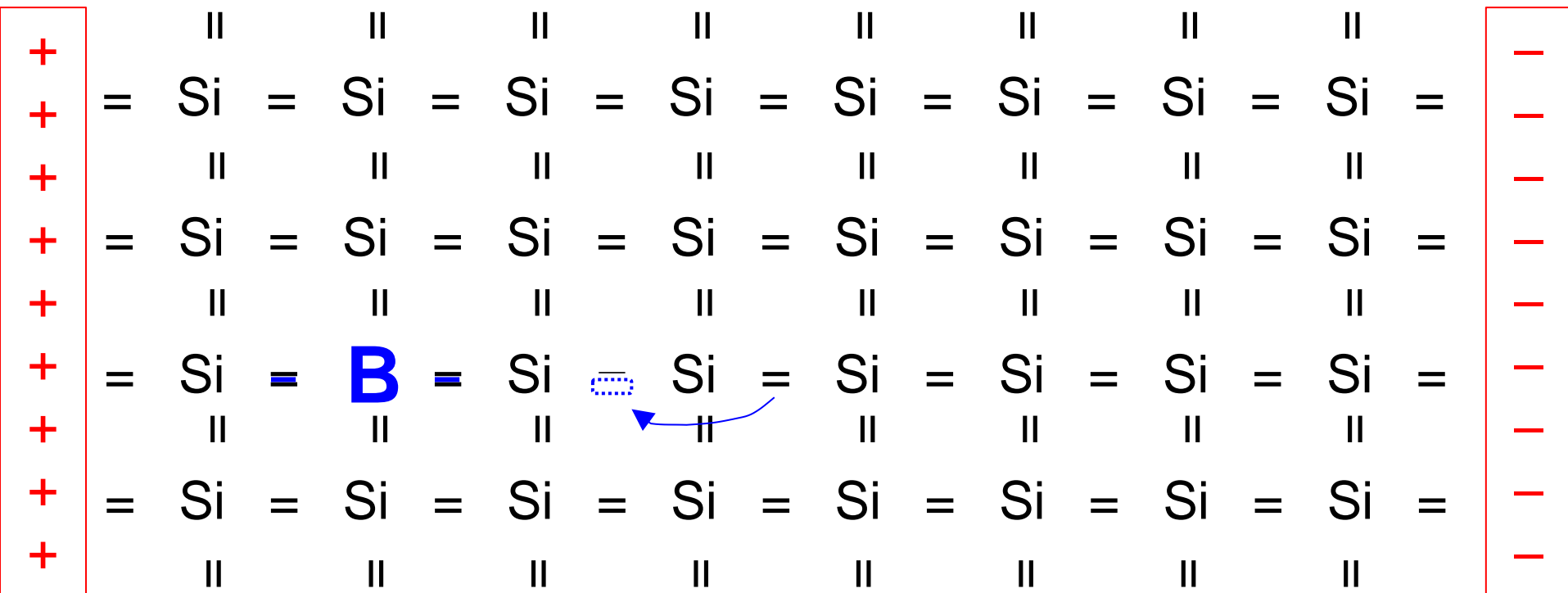
Boron Has One Fewer Valence Electron (hole, h^+) Can Still Increase Conductivity



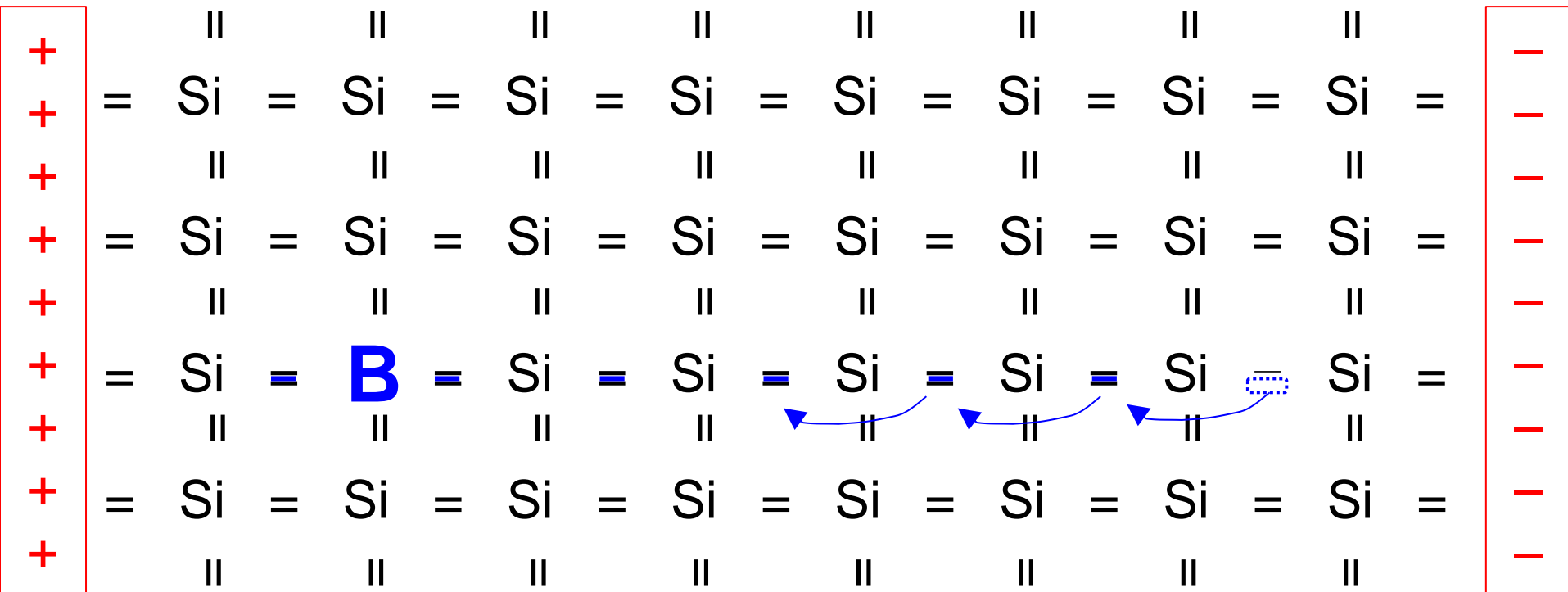
Boron Has One Fewer Valence Electron (hole, h^+) Can Still Increase Conductivity



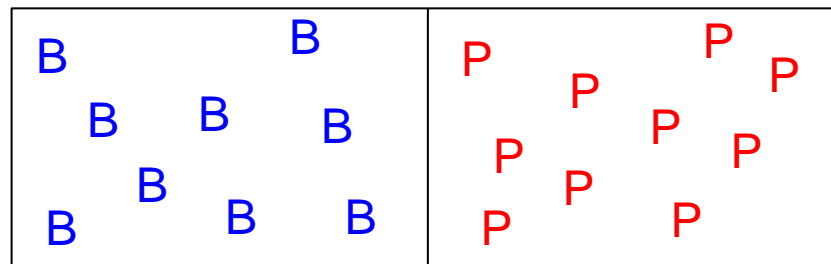
Boron Has One Fewer Valence Electron (hole, h^+) Can Still Increase Conductivity



Boron Has One Fewer Valence Electron (hole, h^+) Can Still Increase Conductivity



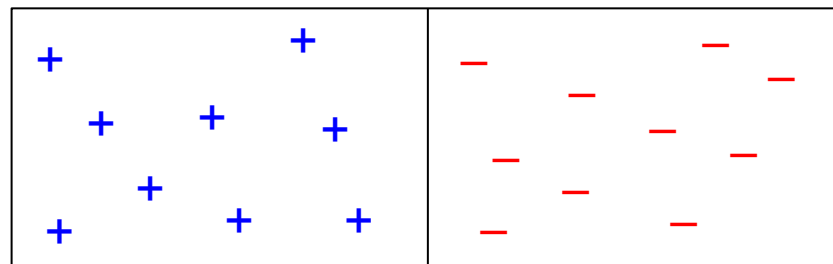
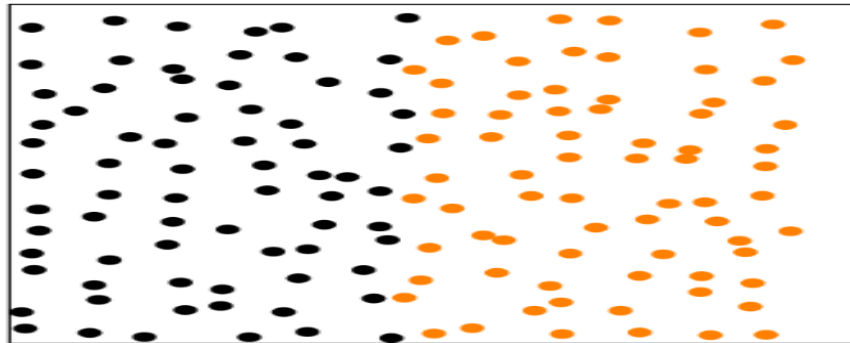
Add a Small Amount of **Boron** (extra h^+)
and **Phosphorus** (extra e^-) to Separate Areas



Extra Holes (h^+)
Fewer Electrons
P-Type Silicon

Extra Electrons (e^-)
N-Type Silicon

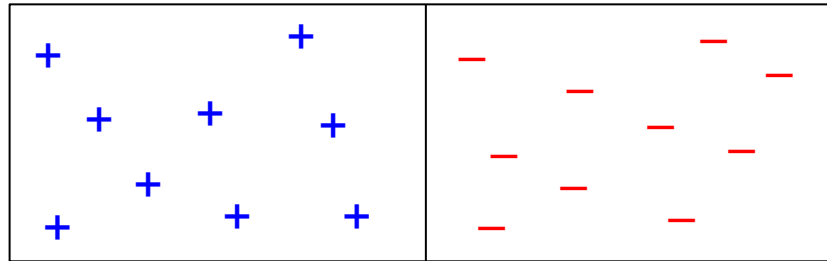
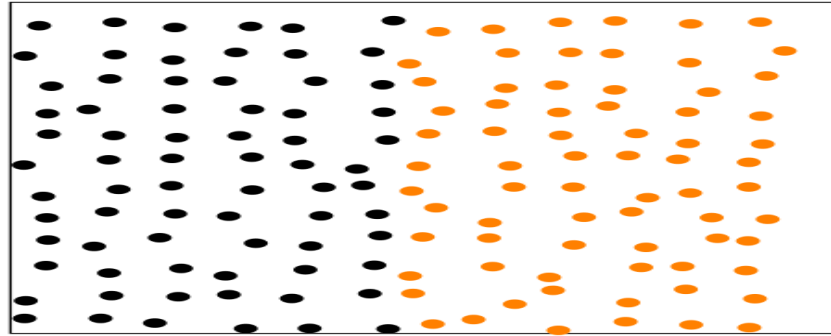
Extra (e^-) and Missing (h^+) Electrons Are Free to Diffuse (Randomly Drift Around)



Extra Holes (h^+)
Fewer Electrons
P-Type Silicon

Extra Electrons (e^-)
N-Type Silicon

Extra (e^-) and Missing (h^+) Electrons Are Free to Diffuse (Randomly Drift Around)



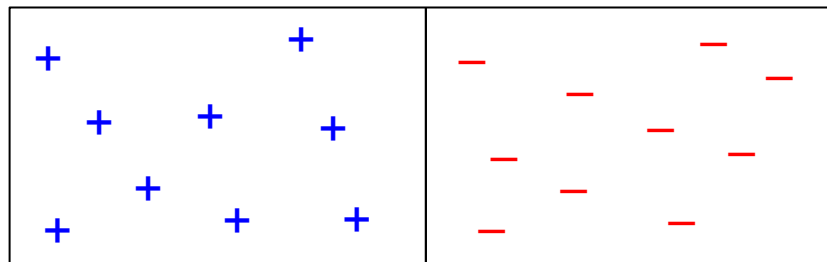
Extra Holes (h^+)
Fewer Electrons
P-Type Silicon

Extra Electrons (e^-)
N-Type Silicon

Extra (e^-) and Missing (h^+) Electrons Are Free to Diffuse (Randomly Drift Around)



Electrons diffuse
to areas of lower
concentration



Extra Holes (h^+)
Fewer Electrons
P-Type Silicon

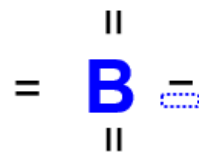
Extra Electrons (e^-)

N-Type Silicon

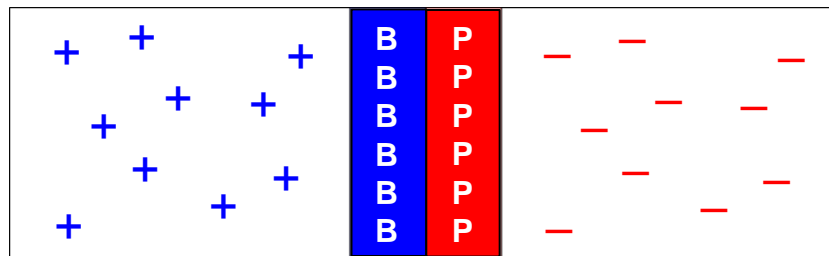
Missing electrons
(or holes) diffuse
to areas of lower
concentration



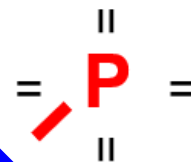
P Nucleus Has One Additional Positive Charge **B Nucleus** Has One Less Positive Charge



Electrons diffuse
to areas of lower
concentration



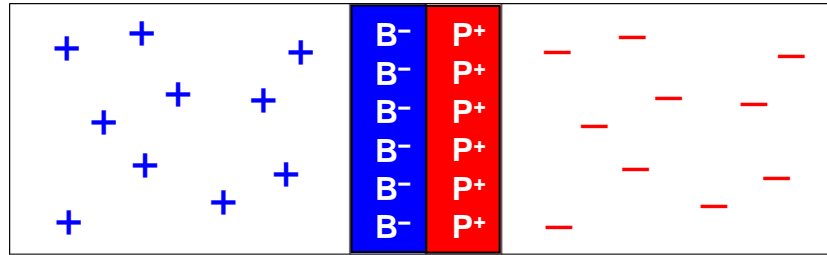
Missing electrons
(or holes) diffuse
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concentration



P Nucleus Has One Additional Positive Charge

B Nucleus Has One Less Positive Charge

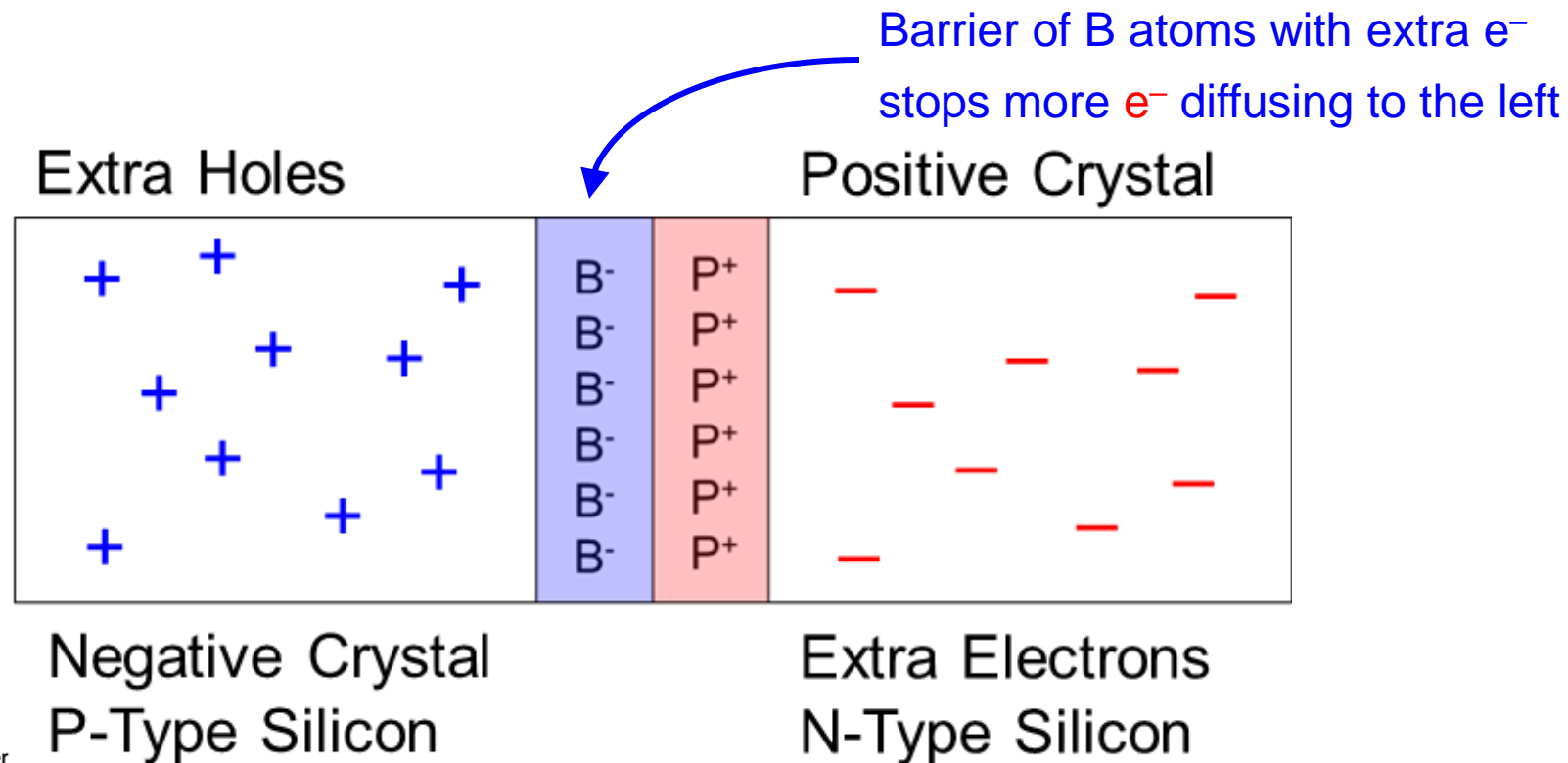
B^- is negatively charged = $\overset{||}{B}_{||}$ ← **Electrons diffuse to areas of lower concentration**



Missing electrons (or holes) diffuse to areas of lower concentration

= $\overset{||}{P}_{||}$ = **P^+ is positively charged**

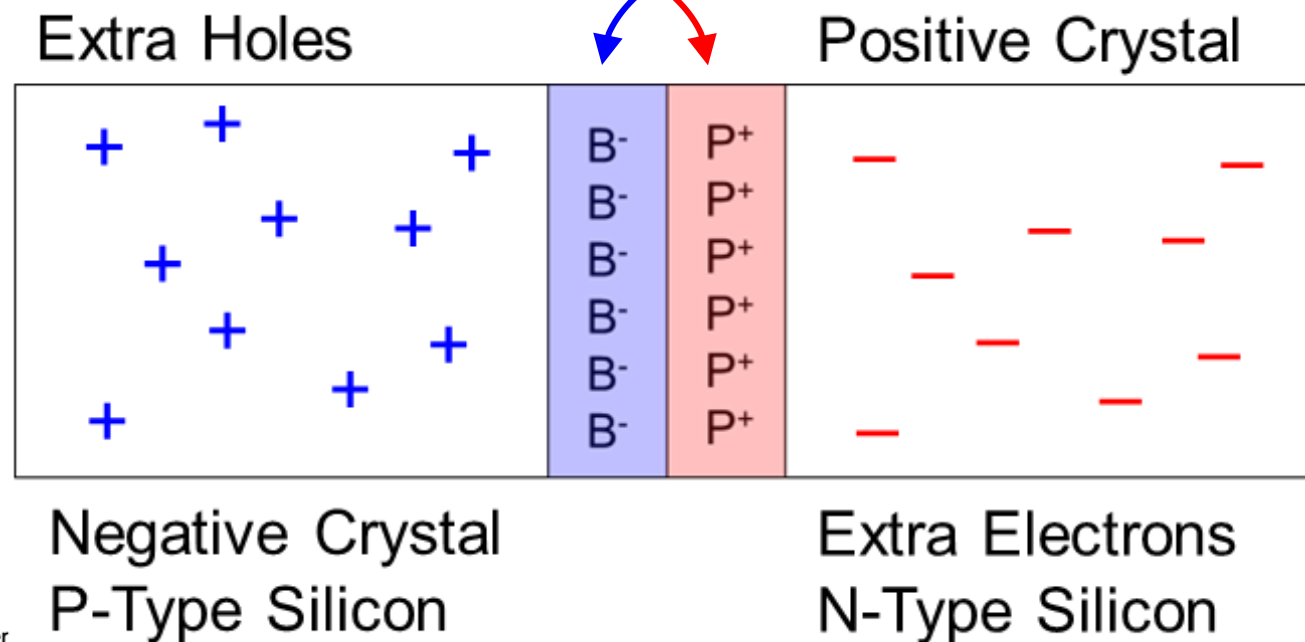
Charged Barrier ($\sim 0.7V$) Prevents More Diffusion



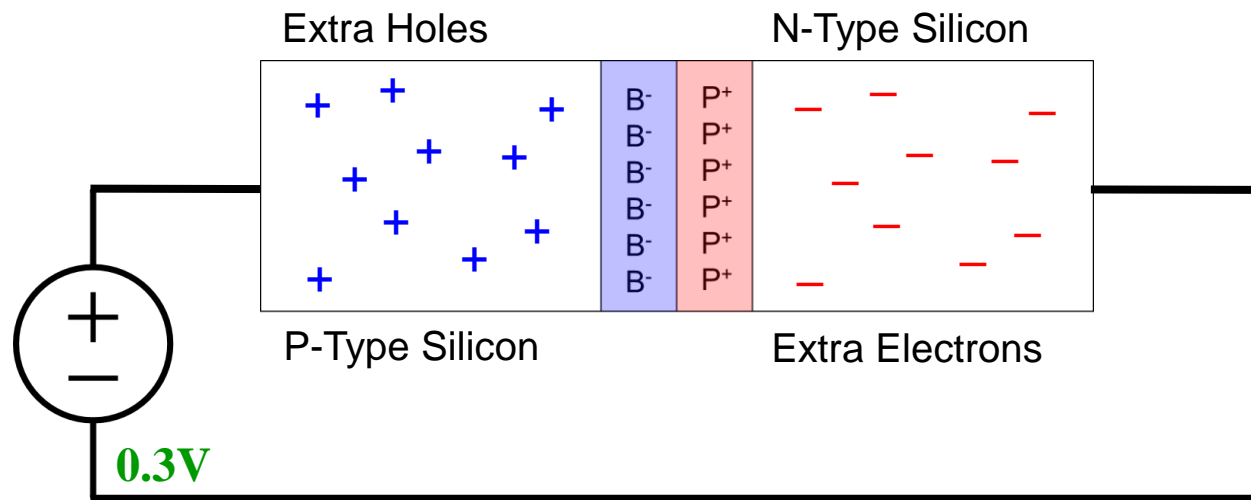
Charged Barrier ($\sim 0.7V$) Prevents More Diffusion

Barrier of P atoms with less e^-
stops more h^+ diffusing to the right

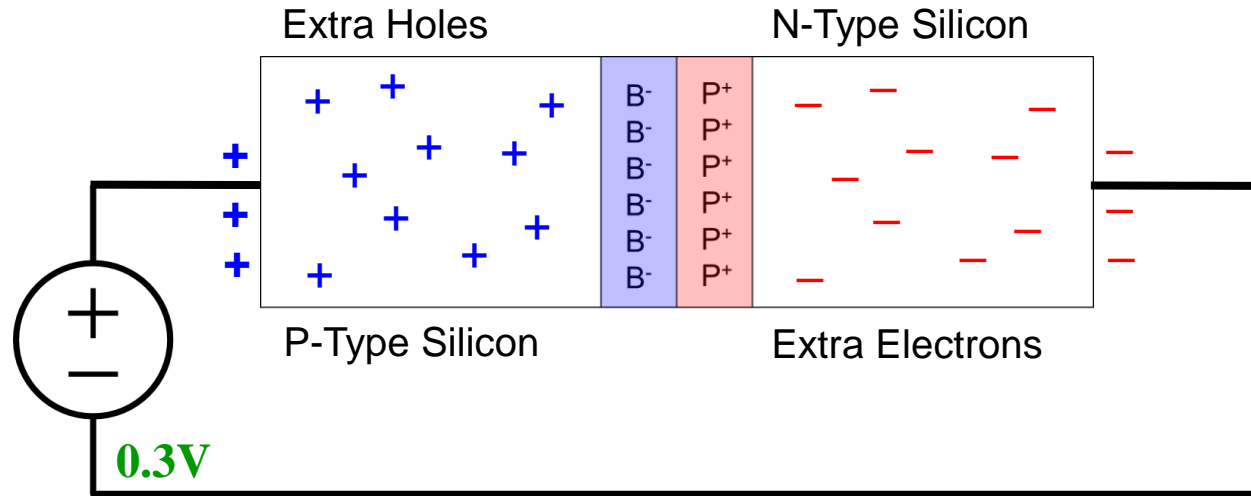
Barrier of B atoms with extra e^-
stops more e^- diffusing to the left



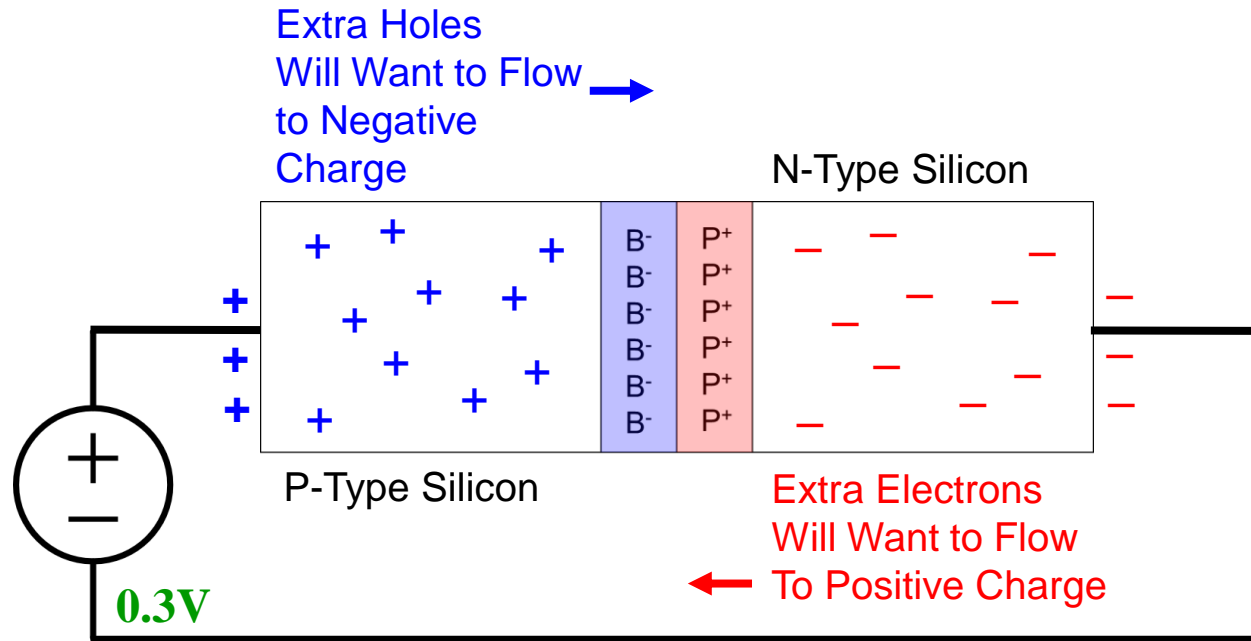
Let's Apply a Small Positive Voltage ($\sim 0.3V$)



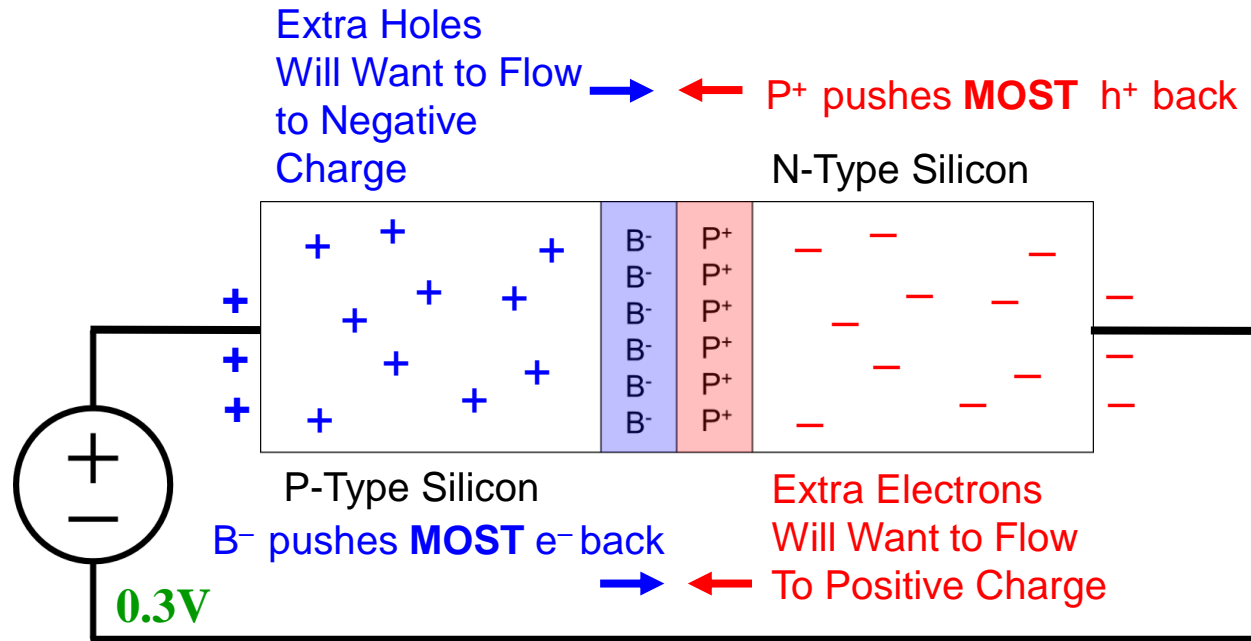
Let's Apply a Small Positive Voltage ($\sim 0.3V$)



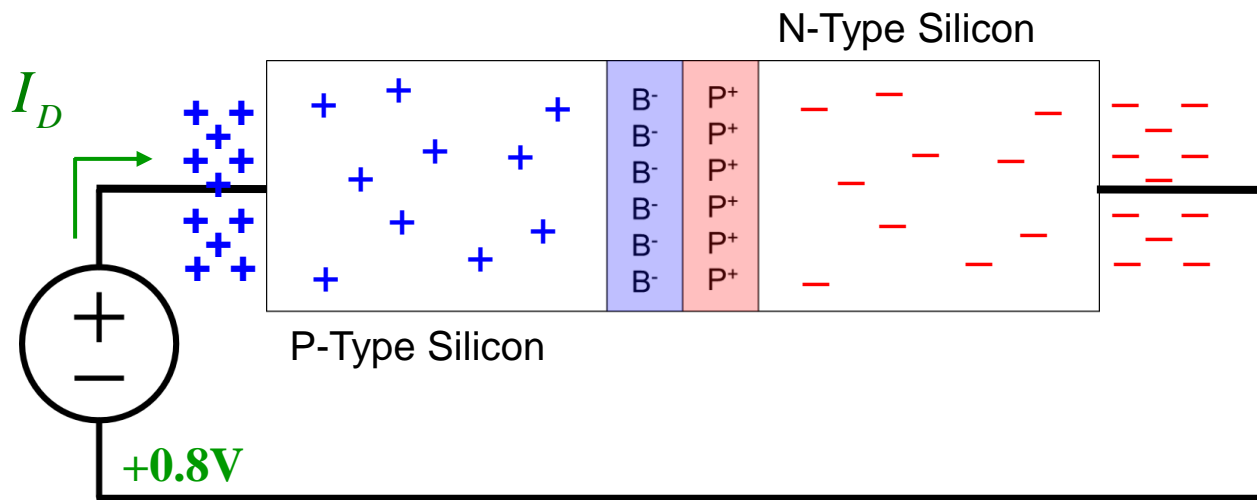
Let's Apply a Small Positive Voltage ($\sim 0.3V$)



Let's Apply a Small Positive Voltage ($\sim 0.3V$)



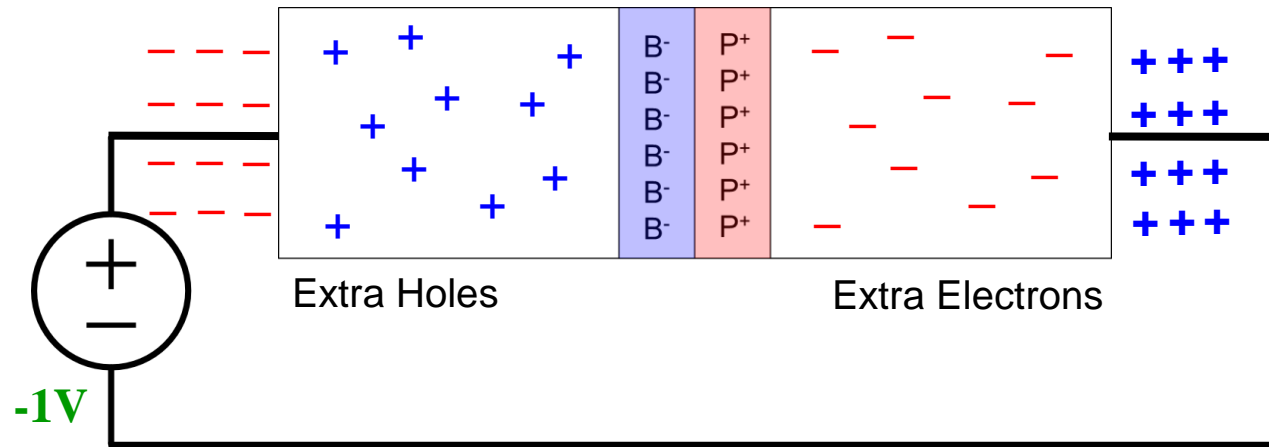
Larger Positive Voltage (+0.7V) Overcomes B^- / P^+ Barrier



Lots of current can flow

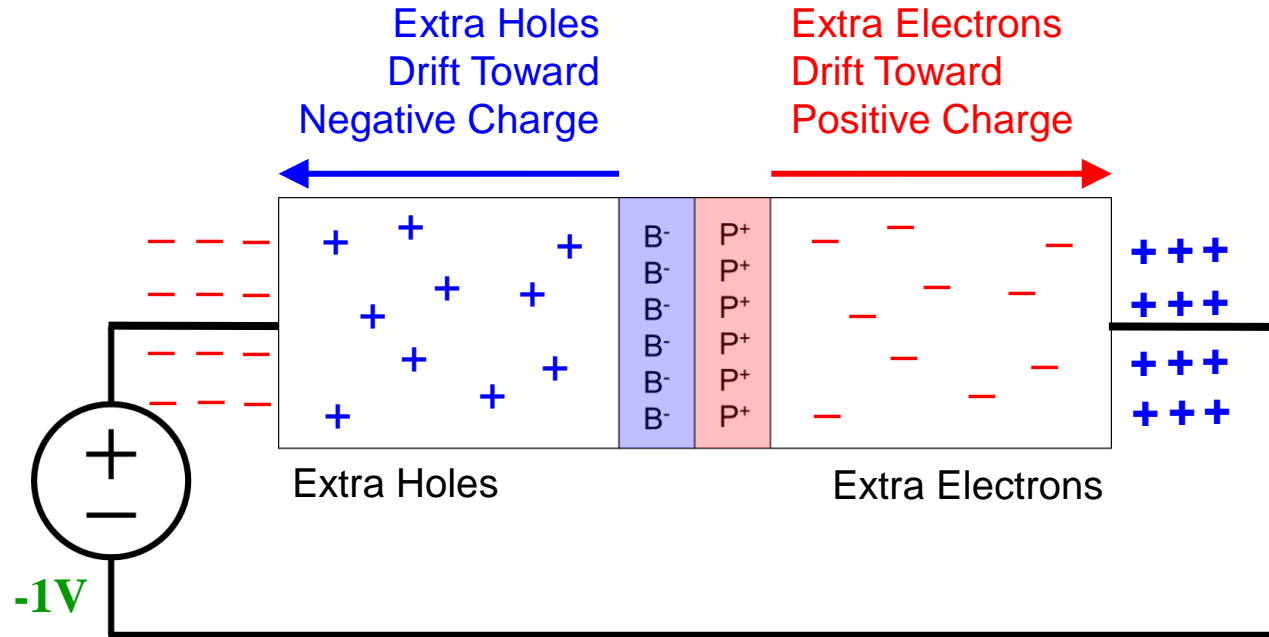
Apply a Negative Diode Voltage ($-1V$)

Almost No Diode Current Flows



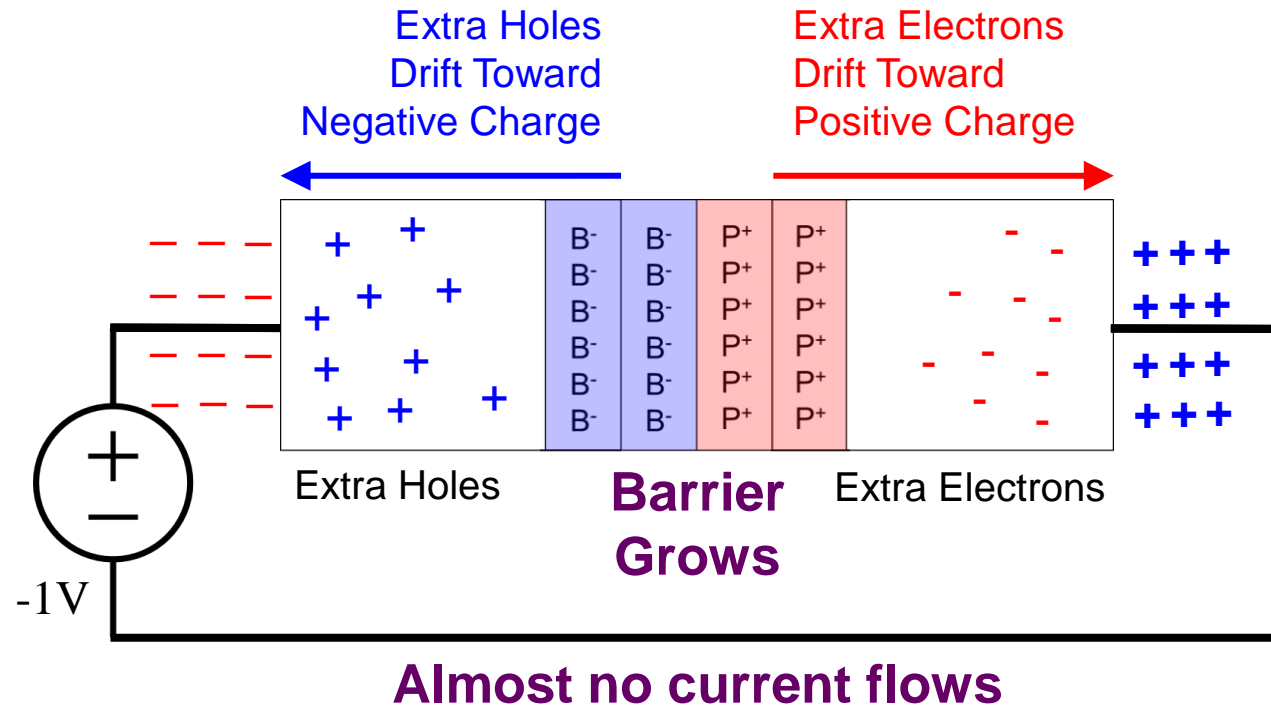
Apply a Negative Diode Voltage ($-1V$)

Almost No Diode Current Flows



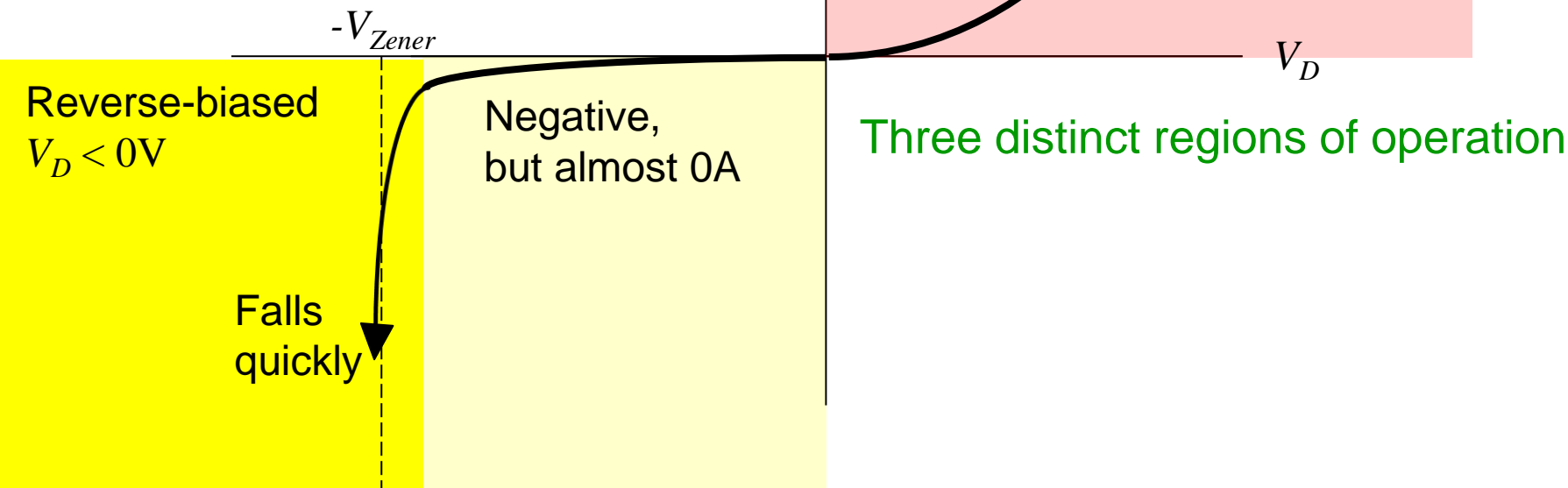
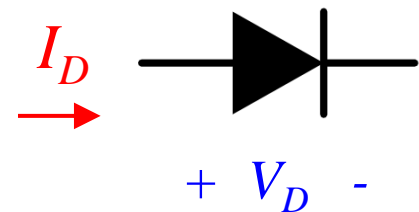
Apply a Negative Diode Voltage ($-1V$)

Almost No Diode Current Flows



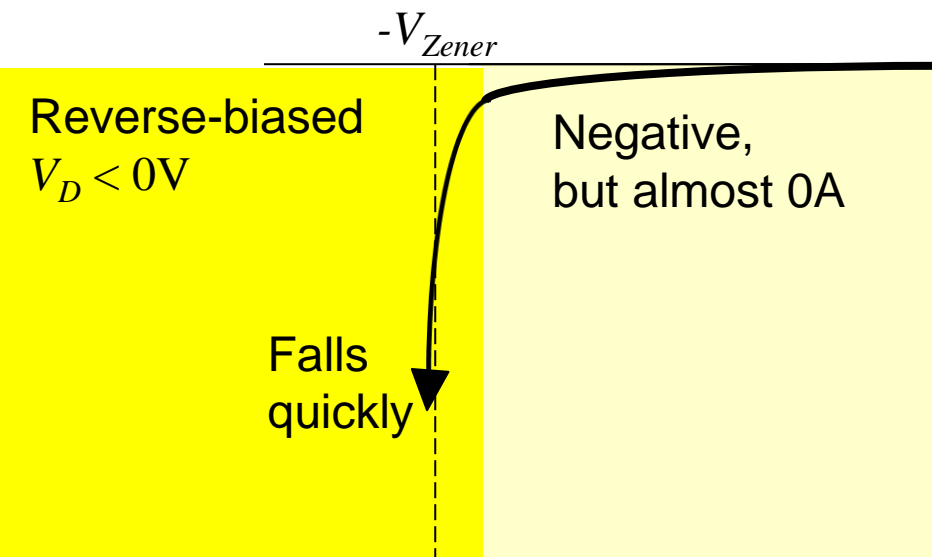
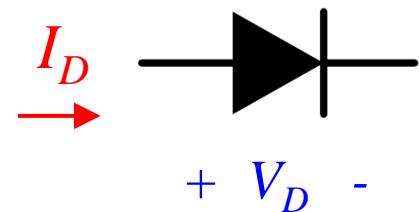
I-V Characteristics

Diodes (Non-linear)



I-V Characteristics

Diodes (Non-linear)



Forward-biased
 $V_D > 0V$

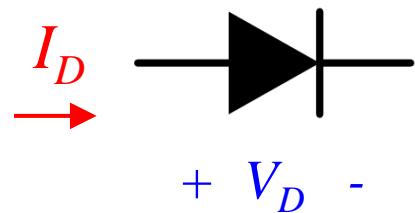
Exponential

Three distinct regions of operation

Diodes are relatively complicated,
so we use **models (approximations)**
to make our work easier

Knee Model 18-100

$$I_D = 0\text{A for } V_D \leq V_{KNEE}$$



“Reverse Bias”
($V_D < 0\text{V}$)

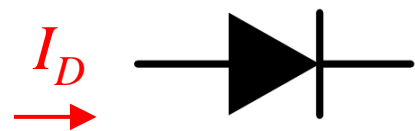
“Forward Bias”
Region ($V_D > 0\text{V}$)



Three Rules:

Knee Model 18-100

$$I_D = 0A \text{ for } V_D \leq V_{KNEE}$$



+ V_D -

“Reverse Bias”
($V_D < 0V$)

I_D

“Forward Bias”
Region ($V_D > 0V$)

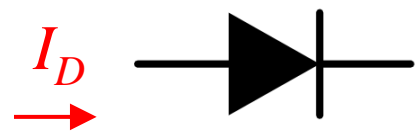
V_{KNEE} V_D

Three Rules:

- If $V_D < V_{KNEE}$, $I_D = 0A$

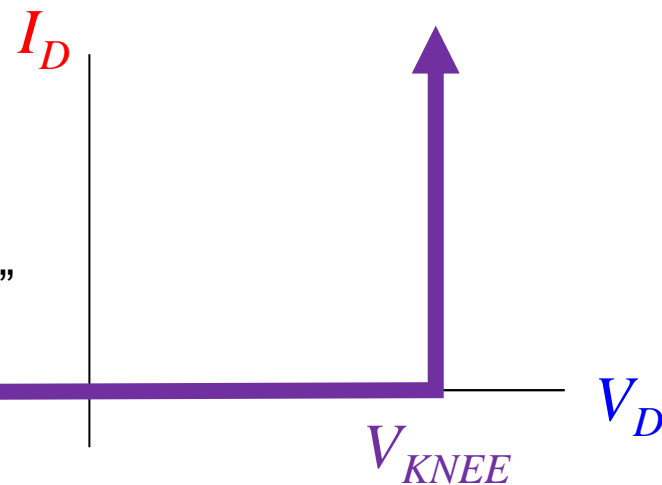
Knee Model 18-100

$$I_D = 0A \text{ for } V_D \leq V_{KNEE}$$



+ V_D -

“Reverse Bias”
($V_D < 0V$)

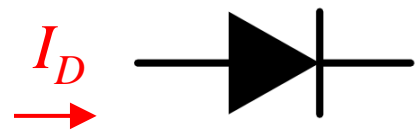


Three Rules:

- If $V_D < V_{KNEE}$, $I_D = 0A$
- If $V_D = V_{KNEE}$, $I_D \geq 0A$

Knee Model 18-100

$$I_D = 0A \text{ for } V_D \leq V_{KNEE}$$



+ V_D -

“Reverse Bias”
($V_D < 0V$)

I_D

“Forward Bias”
Region ($V_D > 0V$)

$$V_D \leq V_{KNEE}$$

V_{KNEE}

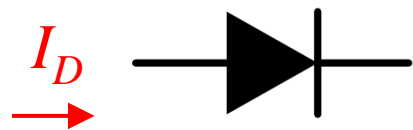
V_D

Three Rules:

- If $V_D < V_{KNEE}$, $I_D = 0A$
- If $V_D = V_{KNEE}$, $I_D \geq 0A$
- $V_D \leq V_{KNEE}$

Knee Model 18-100

$$I_D = 0A \text{ for } V_D \leq V_{KNEE}$$



+ V_D -

“Reverse Bias”
($V_D < 0V$)

I_D

“Forward Bias”
Region ($V_D > 0V$)

$$V_D \leq V_{KNEE}$$

V_{KNEE}

V_D

Three Rules:

- If $V_D < V_{KNEE}$, $I_D = 0A$
- If $V_D = V_{KNEE}$, $I_D \geq 0A$
- $V_D \leq V_{KNEE}$

~0.7V for silicon diodes

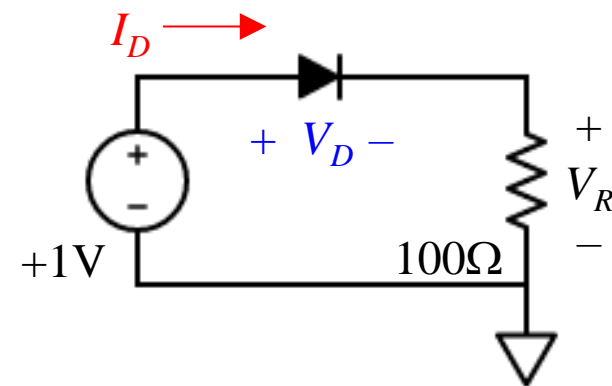
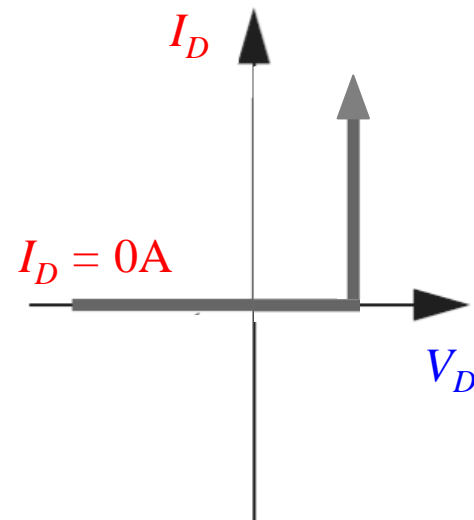
~2V for red LEDs

~2.5V for green LEDs

~3V for blue LEDs

Using the Diode Knee Model

($V_{KNEE} = 0.7V$)

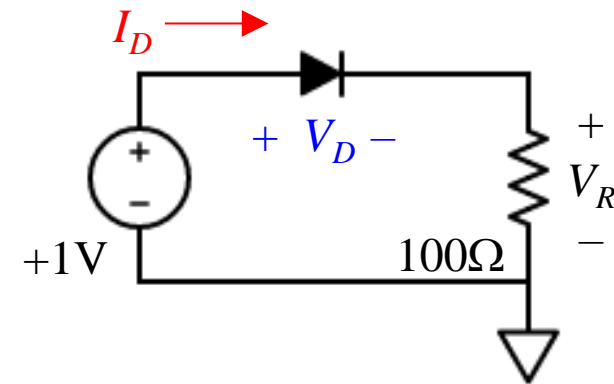
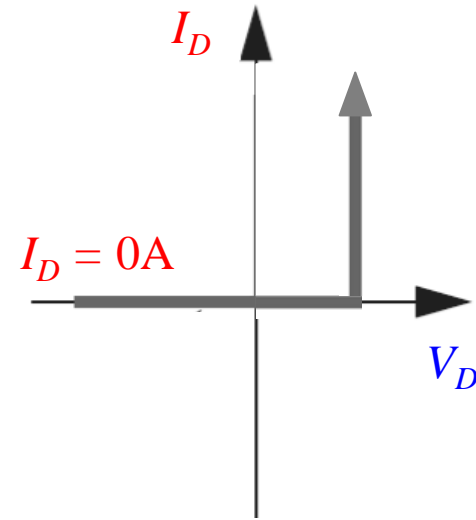


Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$



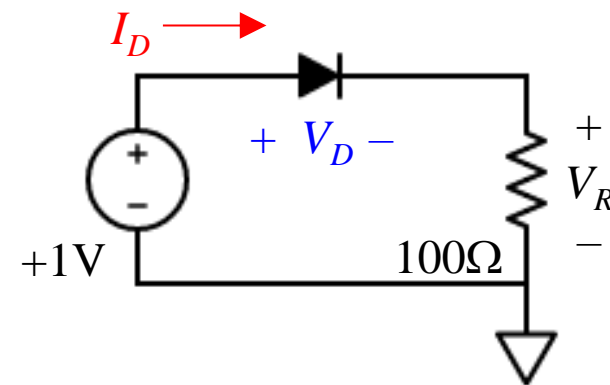
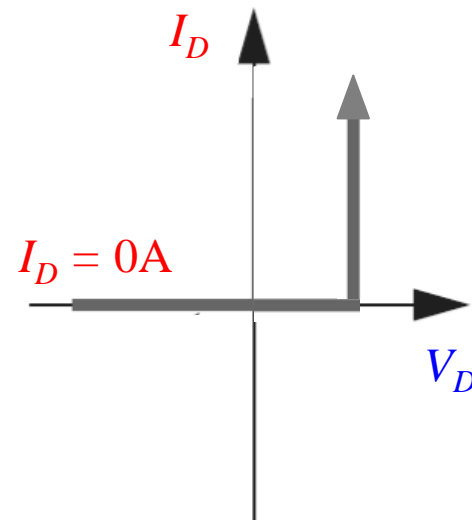
Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$

$$+1V = V_D + (I_D)(100\Omega)$$



Using the Diode Knee Model

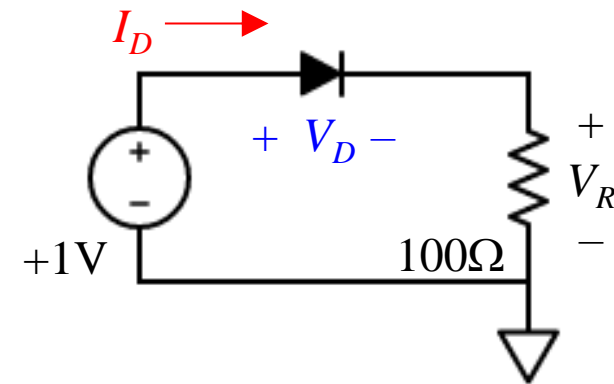
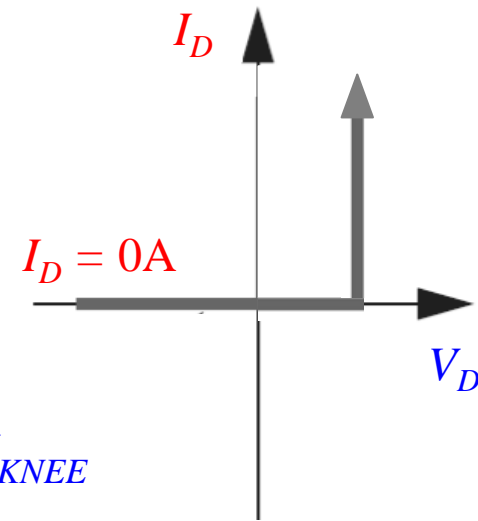
$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$

Assume diode is on: $V_D = V_{KNEE}$

$$+1V = V_D + (I_D)(100\Omega)$$



Using the Diode Knee Model

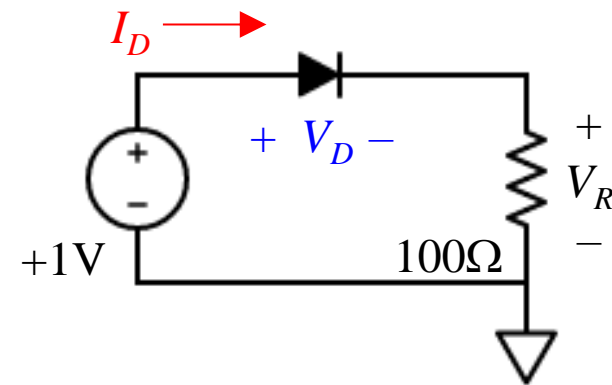
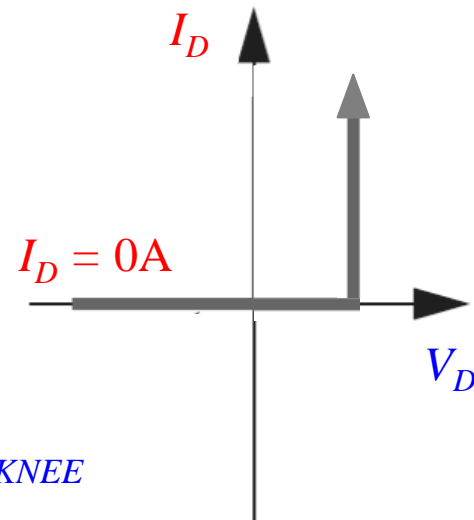
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Assume diode is on: $V_D = V_{KNEE}$

$$+1V = V_D + (I_D)(100\Omega) = 0.7V + (I_D)(100\Omega)$$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

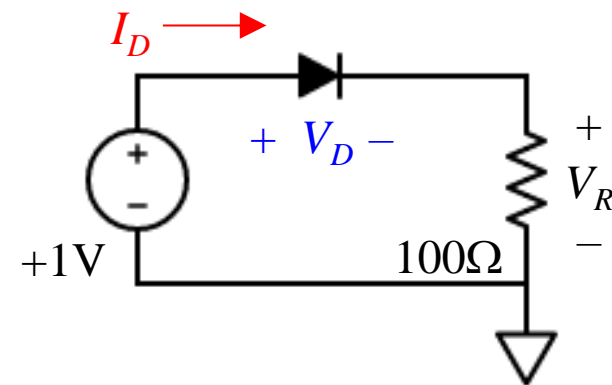
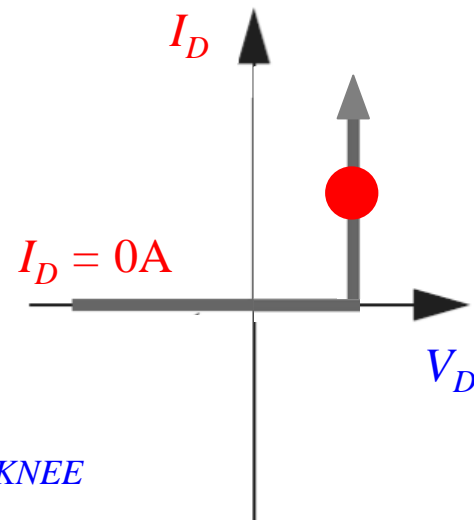
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$$+1V = V_D + V_R$$

Assume diode is on: $V_D = V_{KNEE}$

$$+1V = 0.7V + (I_D)(100\Omega)$$

$$I_D =$$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

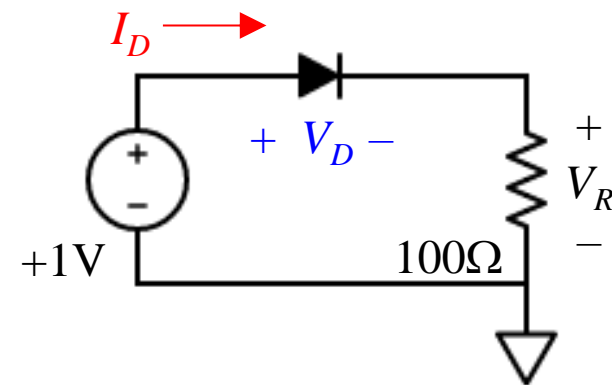
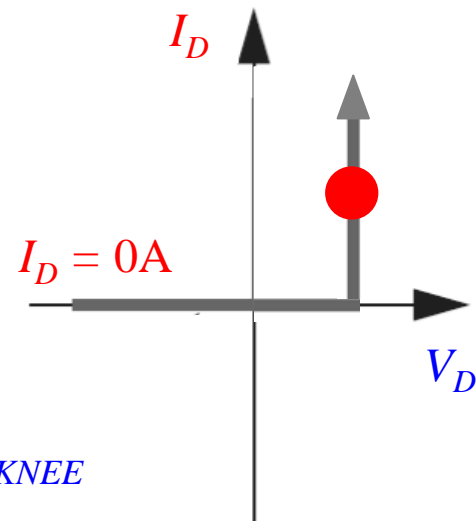
KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$

Assume diode is on: $V_D = V_{KNEE}$

$$+1V = 0.7V + (I_D)(100\Omega)$$

$$I_D = (1V - 0.7V) / 100\Omega = 3mA$$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

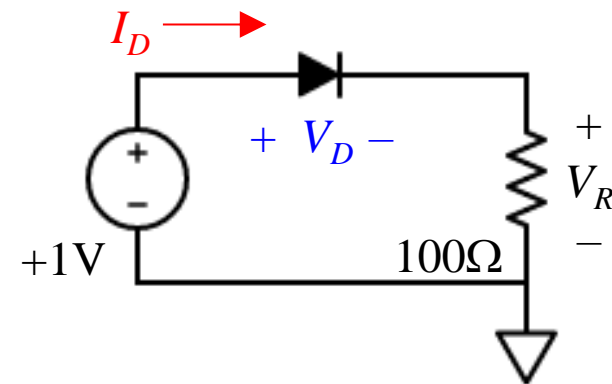
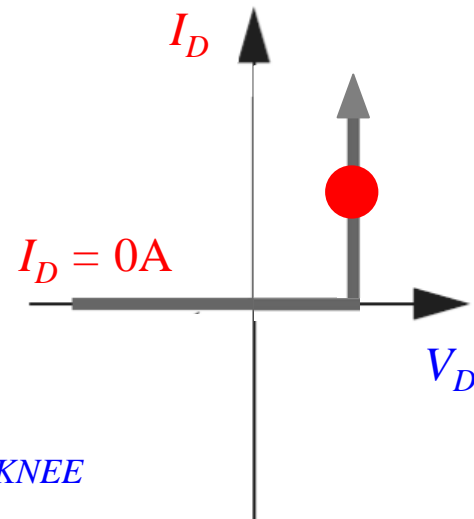
$$+1V = V_D + V_R$$

Assume diode is on: $V_D = V_{KNEE}$

$$+1V = V_D + (I_D)(100\Omega) = 0.7V + (I_D)(100\Omega)$$

$$I_D = (1V - 0.7V) / 100\Omega = 3mA$$

Check assumption:



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

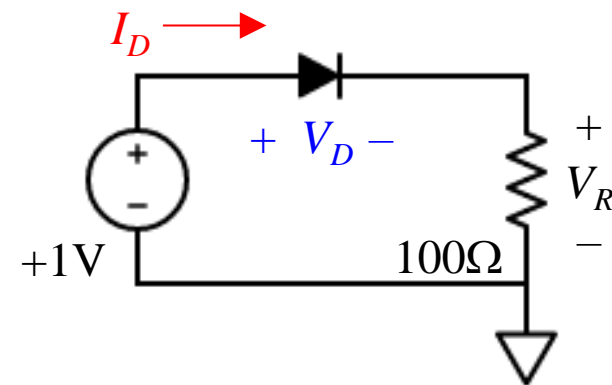
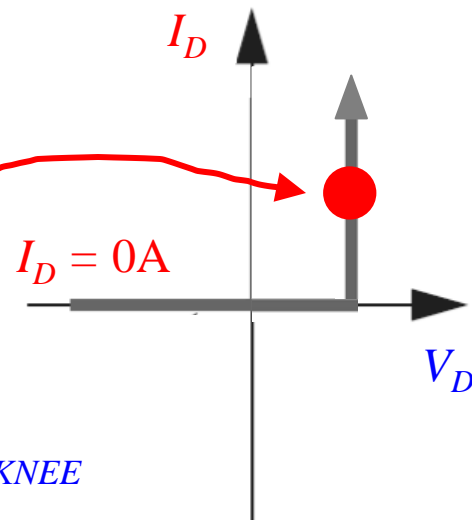
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$$I_D = (1V - 0.7V) / 100\Omega = 3mA$$

Check assumption: If diode is on, $I_D \geq 0A$

Assume diode is on: $V_D = V_{KNEE}$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$

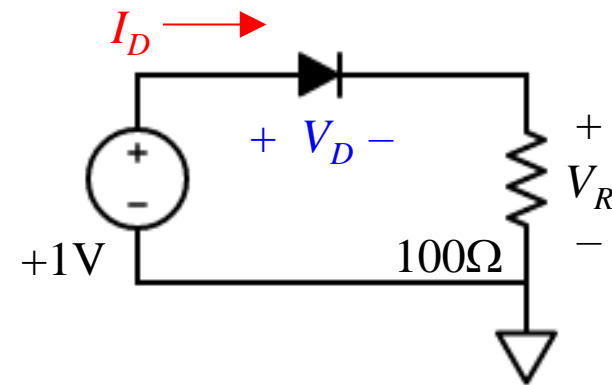
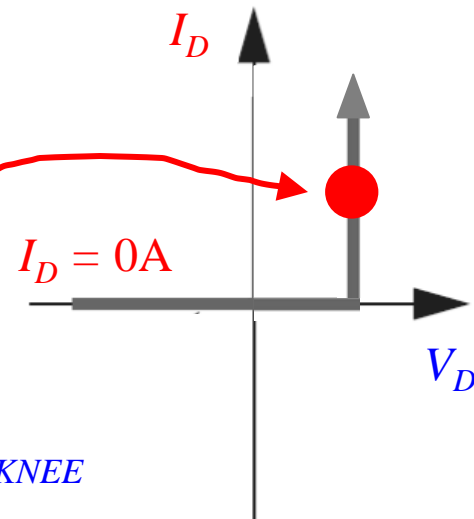
$$+1V = V_D + (I_D)(100\Omega) = 0.7V + (I_D)(100\Omega)$$

$$I_D = (1V - 0.7V) / 100\Omega = 3mA$$

Assume diode is on: $V_D = V_{KNEE}$

Check assumption: If diode is on, $I_D \geq 0A$

$3mA \geq 0A$, **assumption confirmed!**



Using the Diode Knee Model (approximation)

($V_{KNEE} = 0.7V$)

KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$

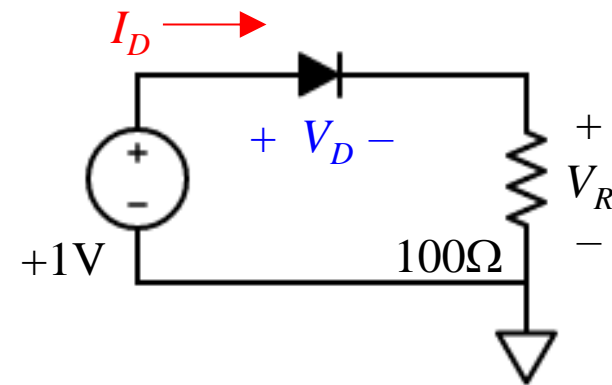
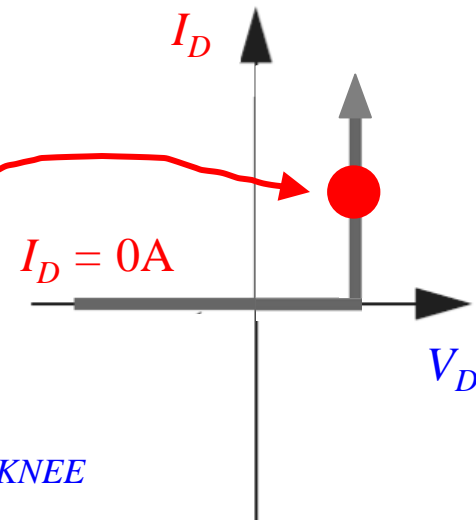
$$+1V = V_D + (I_D)(100\Omega) = 0.7V + (I_D)(100\Omega)$$

$$I_D = (1V - 0.7V) / 100\Omega = 3mA$$

Check assumption: If diode is on, $I_D \geq 0A$

$3mA \geq 0A$, **assumption confirmed!**

Assume diode is on: $V_D = V_{KNEE}$



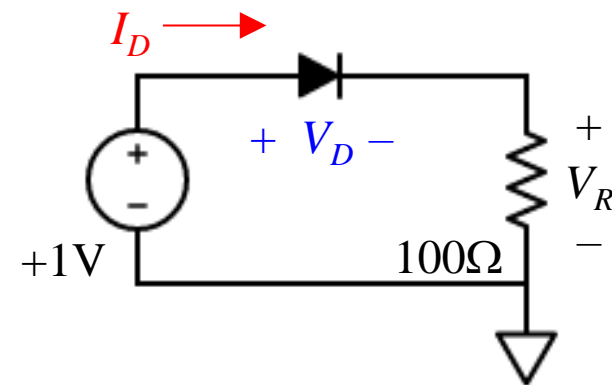
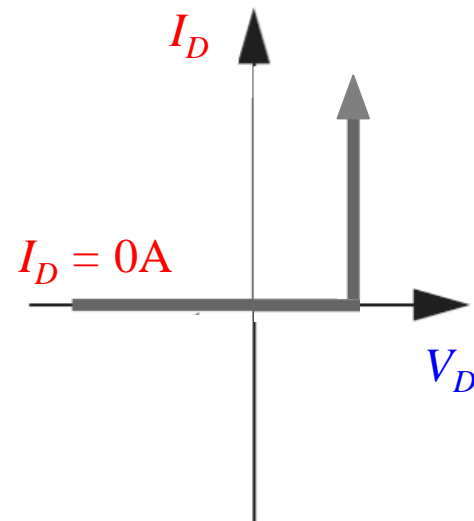
Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

KVL is always true. It does not depend upon the diode being on.

$$+1V = V_D + V_R$$

Let's try a different input voltage



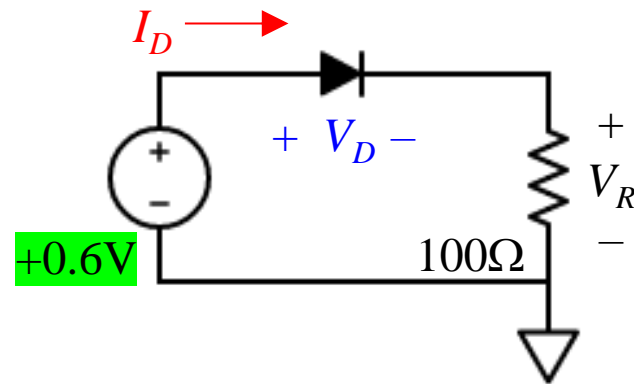
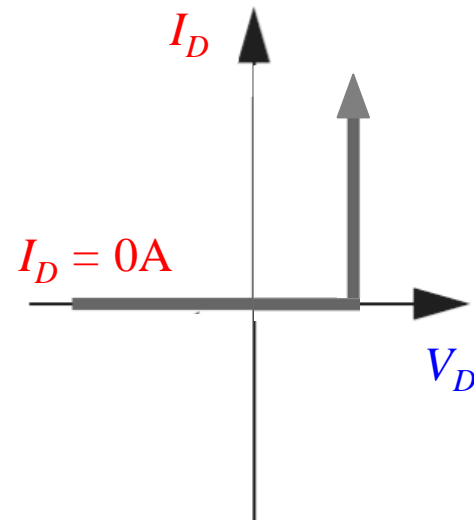
Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

KVL is always true. It does not depend upon the diode being on.

$$+0.6V = V_D + (I_D)(100\Omega)$$

Let's try a different input voltage



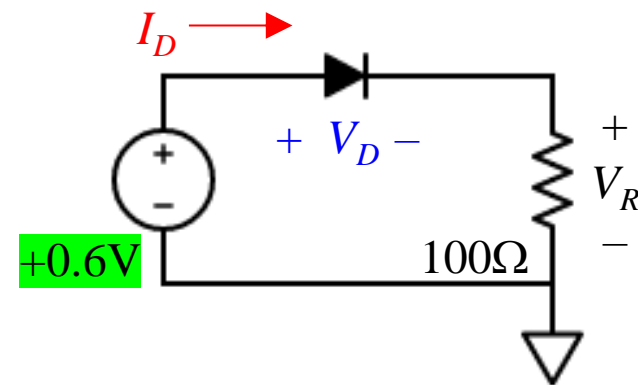
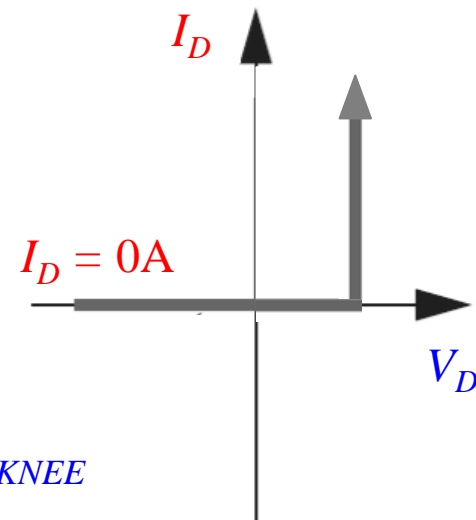
Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

KVL is always true. It does not depend upon the diode being on.

$$+0.6V = V_D + (I_D)(100\Omega)$$

Assume diode is on: $V_D = V_{KNEE}$



Using the Diode Knee Model

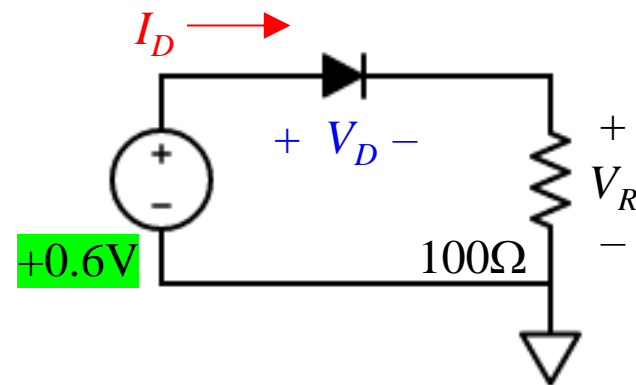
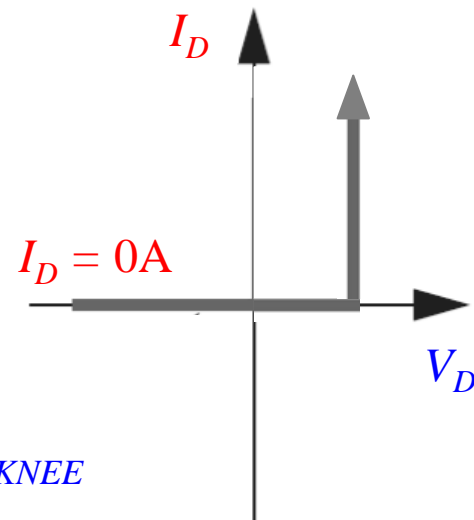
($V_{KNEE} = 0.7V$) (approximation)

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Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

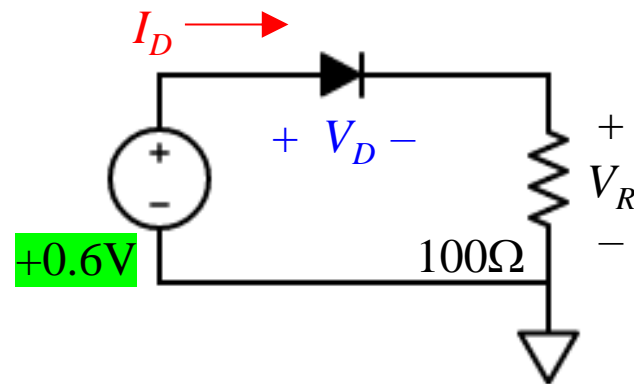
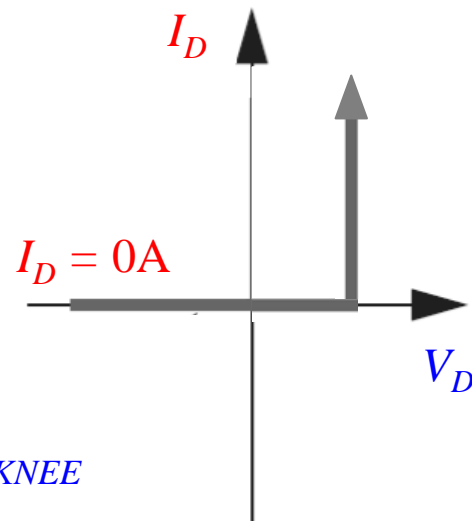
KVL is always true. It does not depend upon the diode being on.

$$+0.6V = V_D + (I_D)(100\Omega)$$

Assume diode is on: $V_D = V_{KNEE}$

$$+0.6V = 0.7V + (I_D)(100\Omega)$$

$$I_D =$$



Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

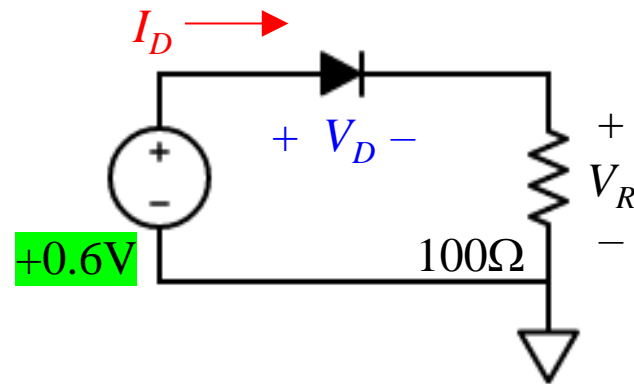
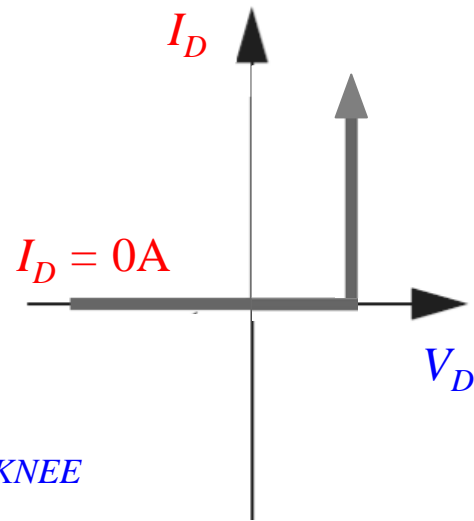
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$$+0.6V = V_D + (I_D)(100\Omega)$$

Assume diode is on: $V_D = V_{KNEE}$

$$+0.6V = 0.7V + (I_D)(100\Omega)$$

$$I_D = (0.6V - 0.7V) / 100\Omega = -1mA$$



Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

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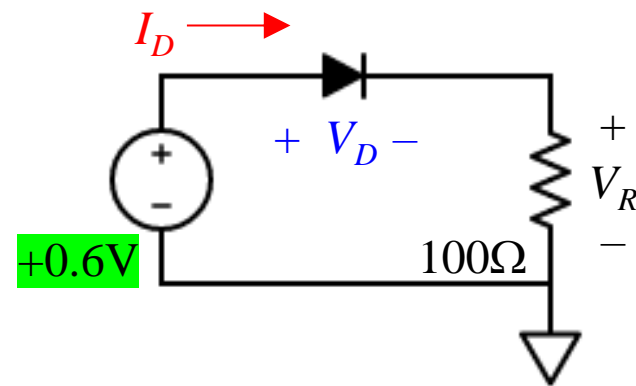
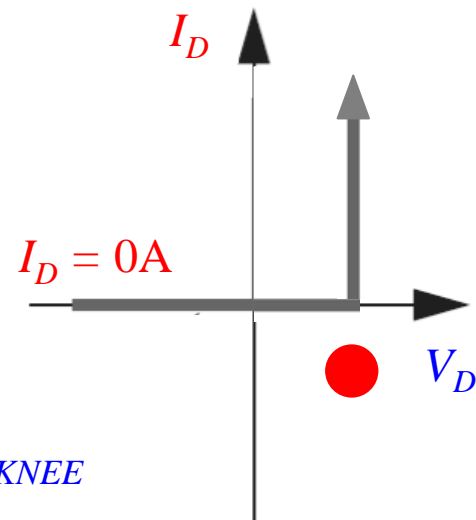
$$+0.6V = V_D + (I_D)(100\Omega)$$

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Check assumption: If diode is on, $I_D \geq 0A$



Using the Diode Knee Model

($V_{KNEE} = 0.7V$) (approximation)

KVL is always true. It does not depend upon the diode being on.

$$+0.6V = V_D + (I_D)(100\Omega)$$

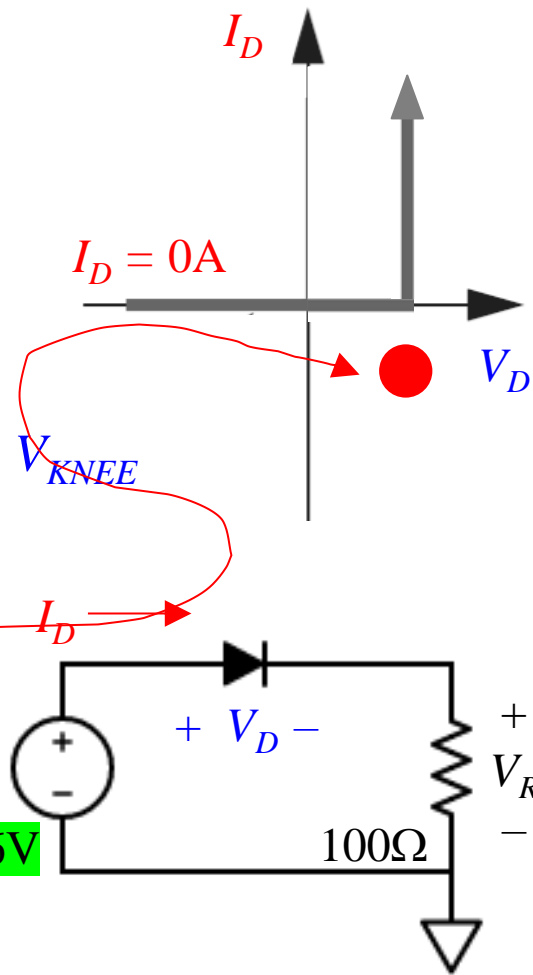
Assume diode is on: $V_D = V_{KNEE}$

$$+0.6V = 0.7V + (I_D)(100\Omega)$$

$$I_D = (0.6V - 0.7V) / 100\Omega = -1mA$$

Check assumption: If diode is on, $I_D \geq 0A$

$-1mA \not\geq 0A$, assumption was wrong!

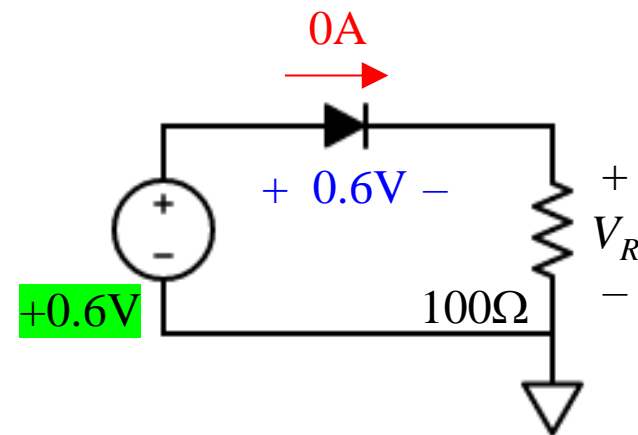
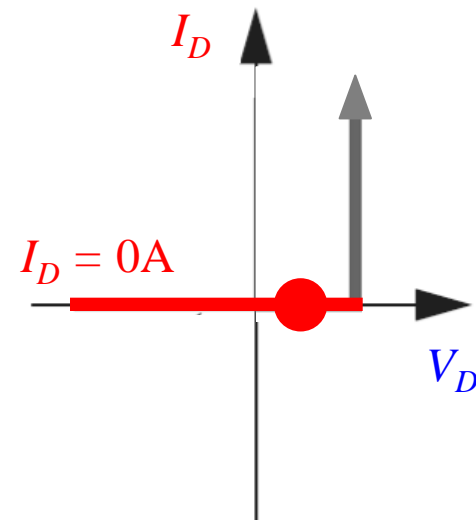


Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

Diode is off: $I_D = 0A$



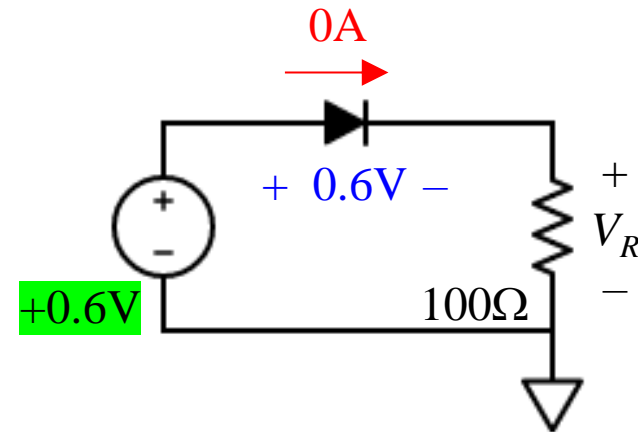
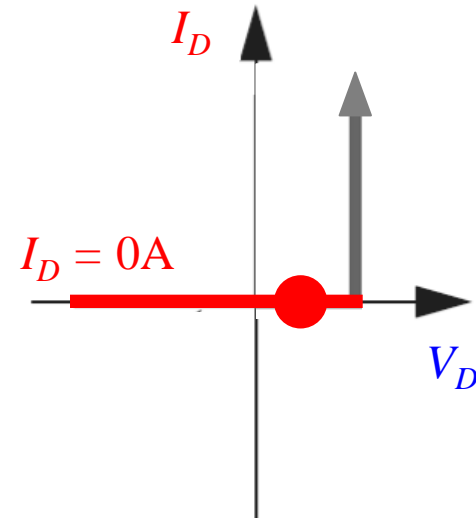
Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

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Diode is off: $I_D = 0A$



Using the Diode Knee Model

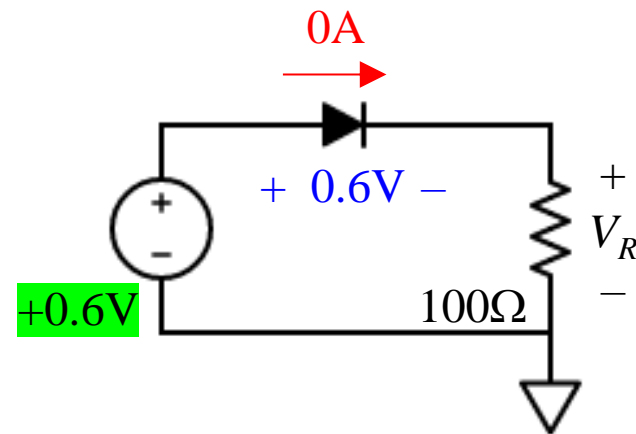
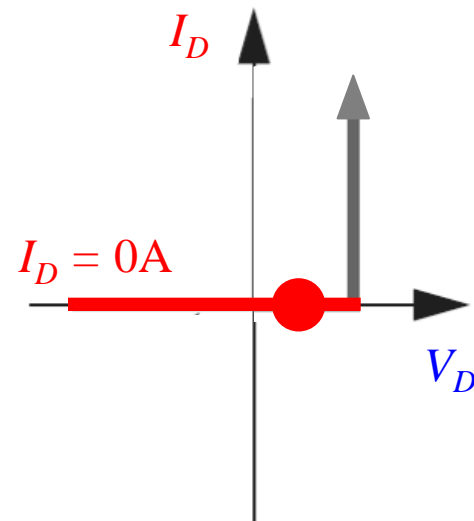
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Diode is off: $I_D = 0A$

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Using the Diode Knee Model

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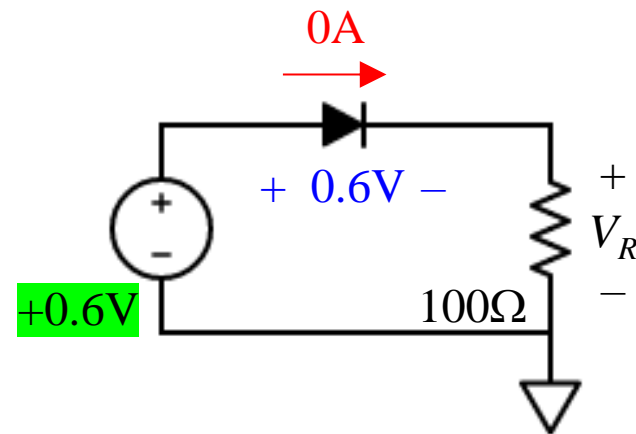
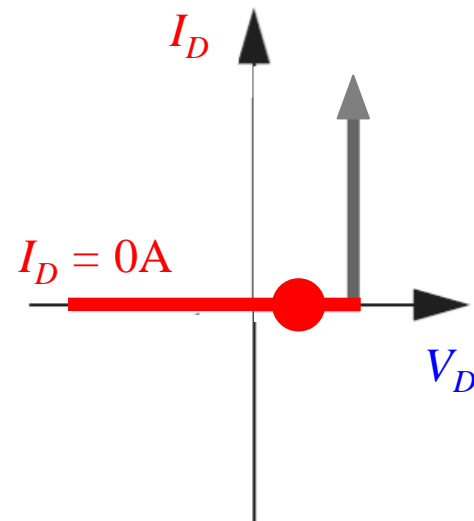
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$$+0.6V = V_D + (I_D)(100\Omega)$$

Diode is off: $I_D = 0A$

$$+0.6V = V_D + (0A)(100\Omega)$$

$$V_D =$$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

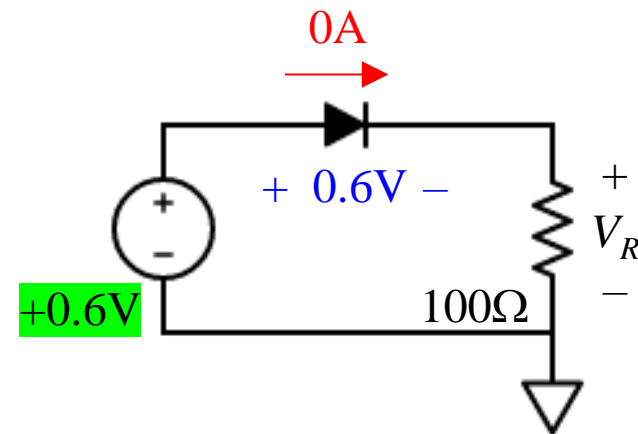
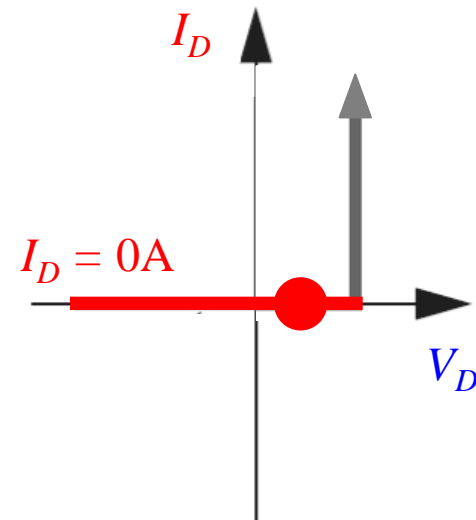
KVL is always true. It does not depend upon the diode being on.

$$+0.6V = V_D + (I_D)(100\Omega)$$

Diode is off: $I_D = 0A$

$$+0.6V = V_D + (0A)(100\Omega)$$

$$V_D = +0.6V - (0A)(100\Omega) = +0.6V$$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

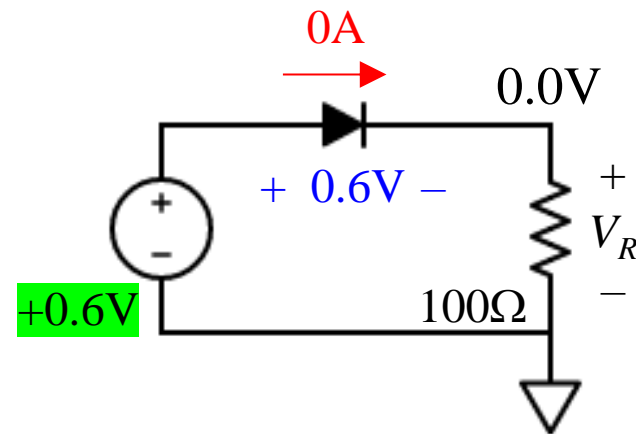
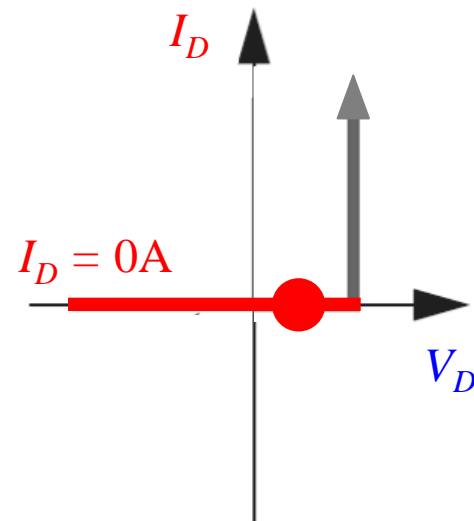
$$+0.6V = V_D + (I_D)(100\Omega)$$

Diode is off: $I_D = 0A$

$$+0.6V = V_D + (0A)(100\Omega)$$

$$V_D = +0.6V - (0A)(100\Omega) = +0.6V$$

$$V_R = 0.6V - 0.6V = 0V = (0A)(100\Omega)$$



Using the Diode Knee Model

$$(V_{KNEE} = 0.7V)$$

KVL is always true. It does not depend upon the diode being on.

$$+0.6V = V_D + (I_D)(100\Omega)$$

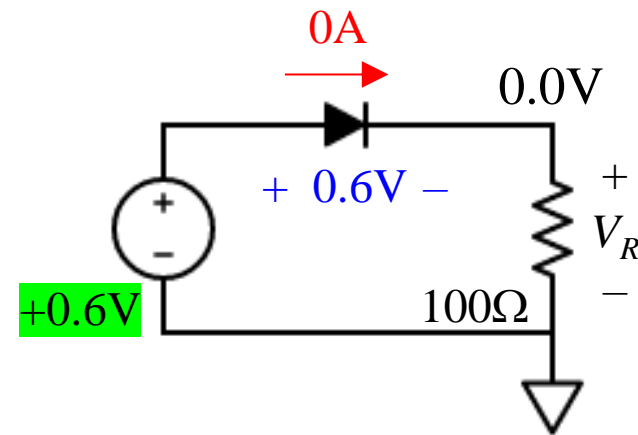
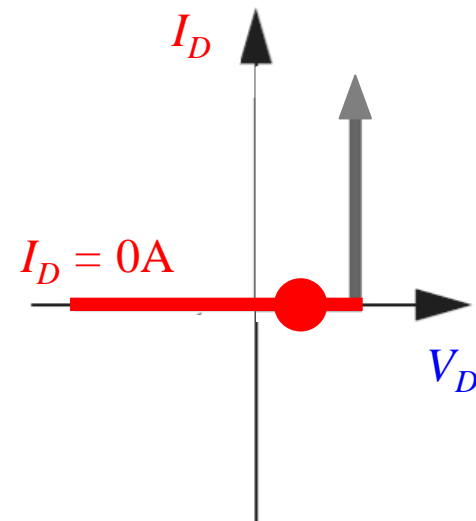
Diode is off: $I_D = 0A$

$$+0.6V = V_D + (0A)(100\Omega)$$

$$V_D = +0.6V - (0A)(100\Omega) = +0.6V$$

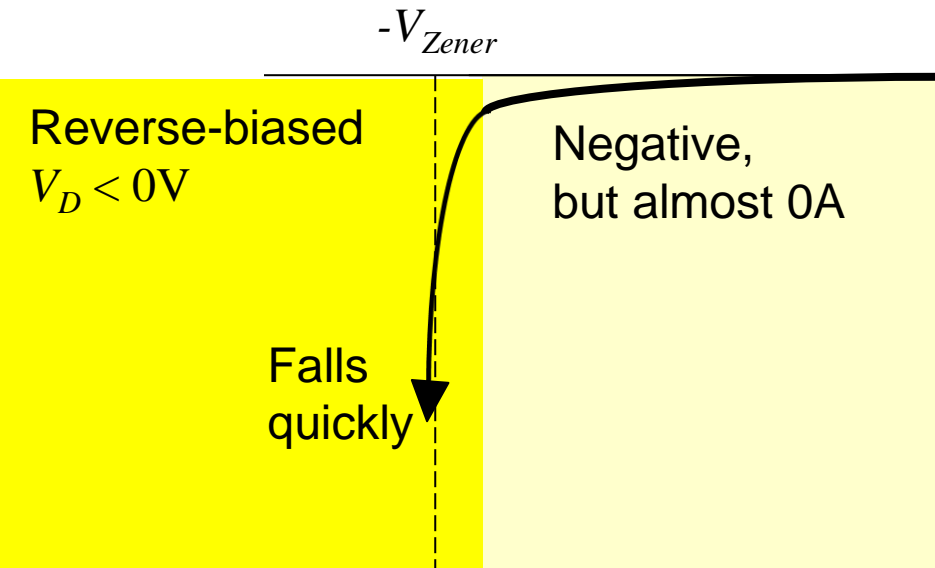
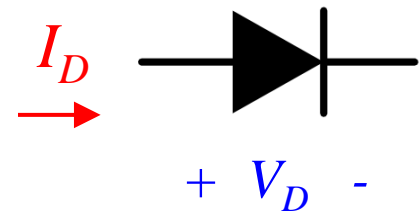
$$V_R = 0.6V - 0.6V = 0V = (0A)(100\Omega)$$

Diode is off: $I_D = 0A$, and $V_D = 0.6V < V_{KNEE}$



I-V Characteristics

Diodes (Non-linear)

 I_D

Forward-biased
 $V_D > 0V$

Exponential

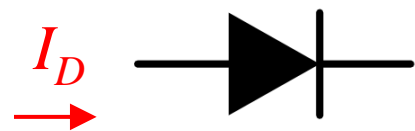
 V_D

Three distinct regions of operation

Diodes are relatively complicated,
so we use **models (approximations)**
to make our work easier

Knee Model 18-100

$$I_D = 0A \text{ for } V_D \leq V_{KNEE}$$



+ V_D -

“Reverse Bias”
($V_D < 0V$)

I_D

“Forward Bias”
Region ($V_D > 0V$)

$$V_D \leq V_{KNEE}$$

V_{KNEE}

V_D

Three Rules:

- If $V_D < V_{KNEE}$, $I_D = 0A$
- If $V_D = V_{KNEE}$, $I_D \geq 0A$
- $V_D \leq V_{KNEE}$

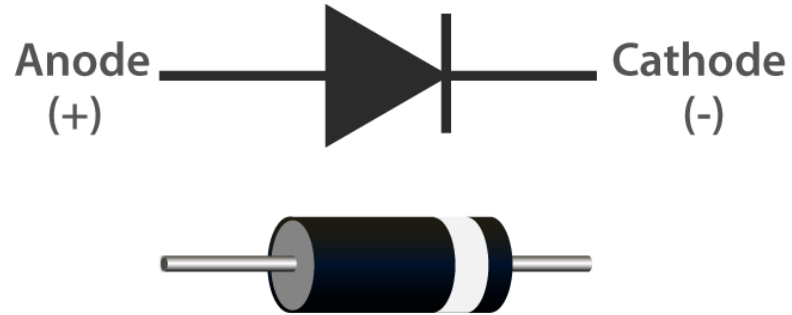
~0.7V for silicon diodes

~2V for red LEDs

~2.5V for green LEDs

~3V for blue LEDs

Diodes IRL (In Real Life)



Light Emitting Diodes (LEDs)



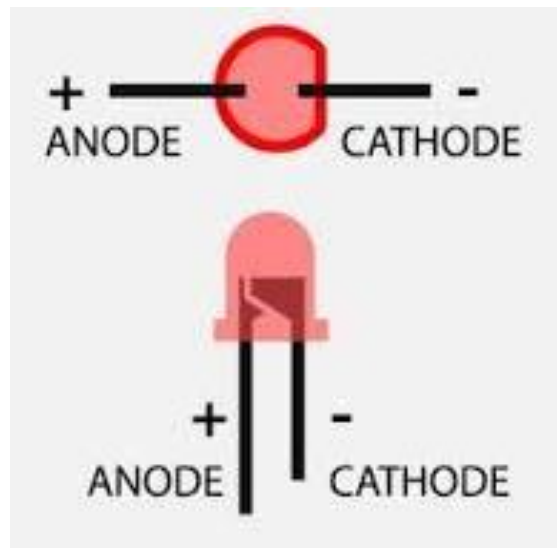
Lighting



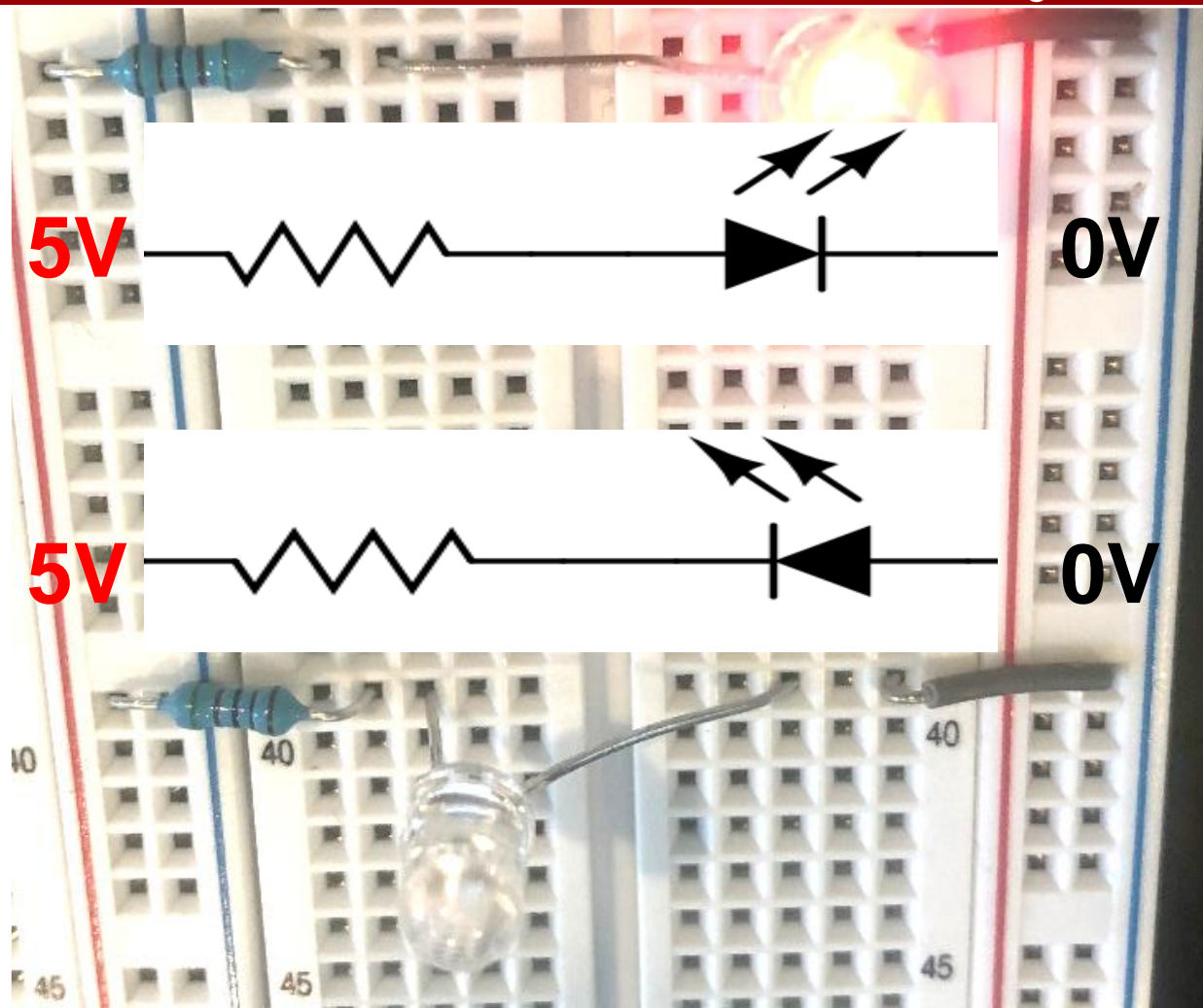
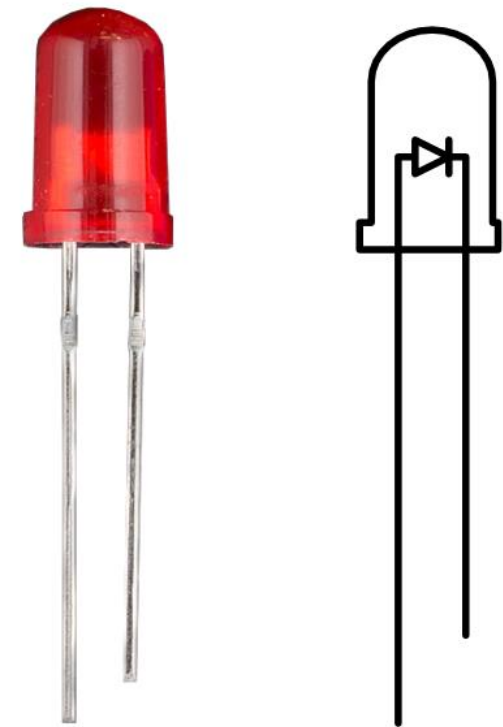
Display



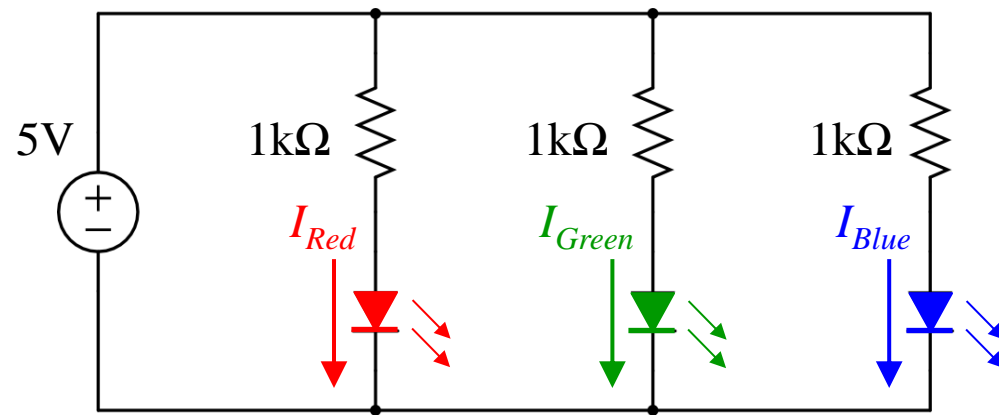
Micro-LED
Display



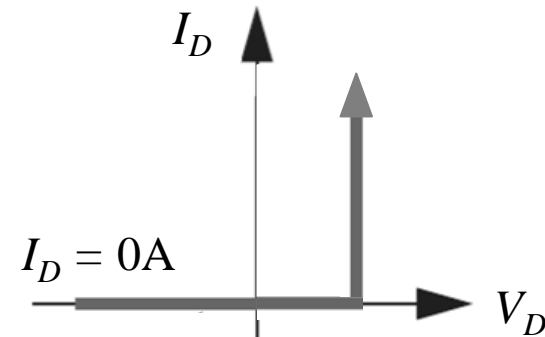
Wiring Diodes



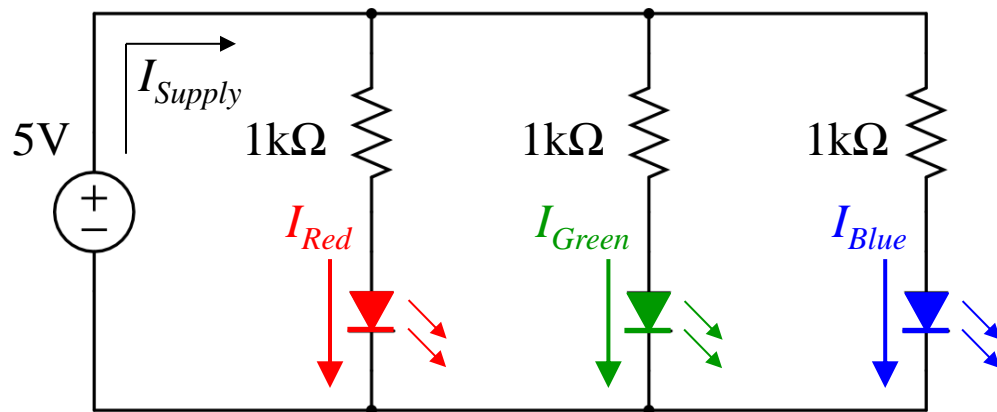
Red ($V_{KNEE} = 2V$)
Green ($V_{KNEE} = 2.5V$) &
Blue ($V_{KNEE} = 3V$)
LEDs



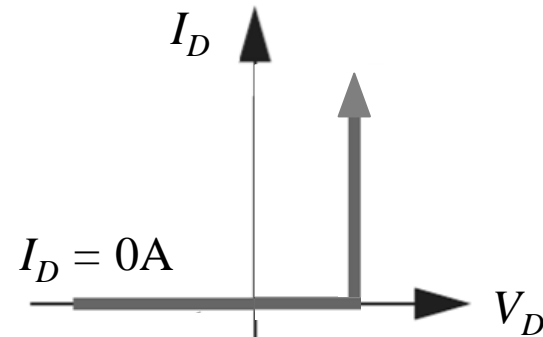
2025_01_24A



Red ($V_{KNEE} = 2V$)
Green ($V_{KNEE} = 2.5V$) &
Blue ($V_{KNEE} = 3V$)
LEDs: Find I_{Supply}

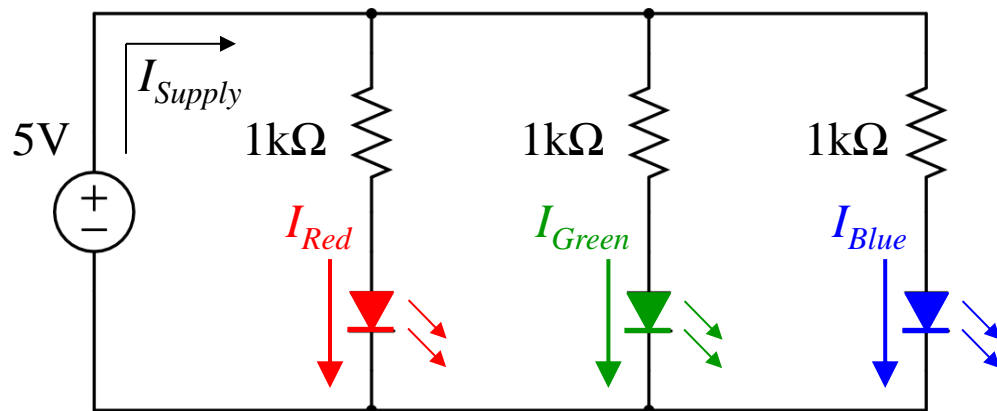


2025_01_24A

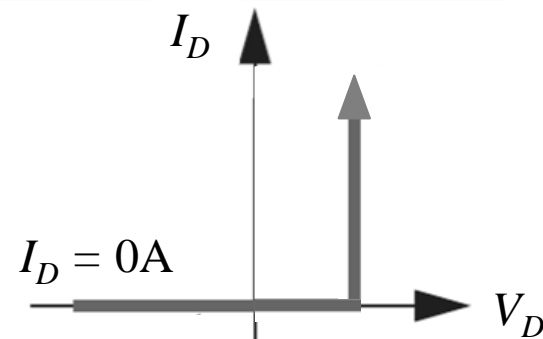


Red ($V_{KNEE} = 2V$)
 Green ($V_{KNEE} = 2.5V$) &
 Blue ($V_{KNEE} = 3V$)
 LEDs: Find I_{Supply}

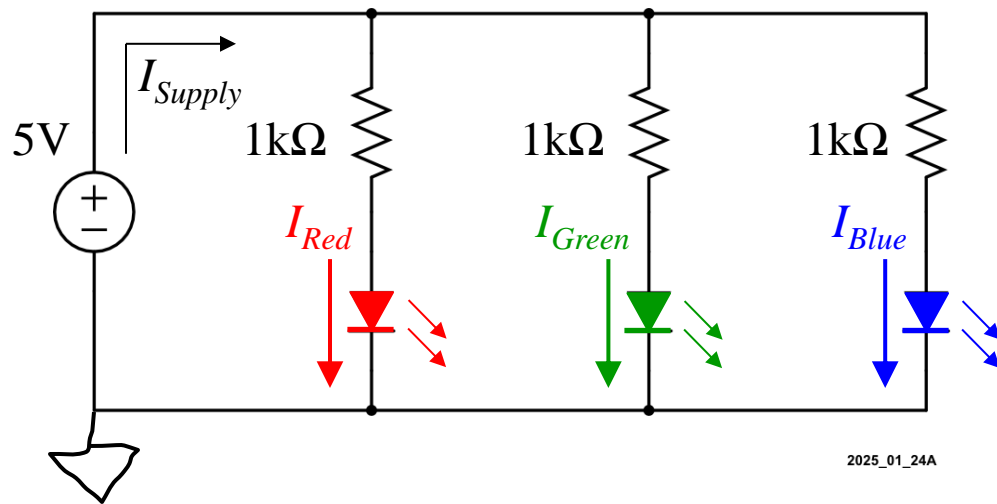
Assume On ($V_D = V_{KNEE}$)



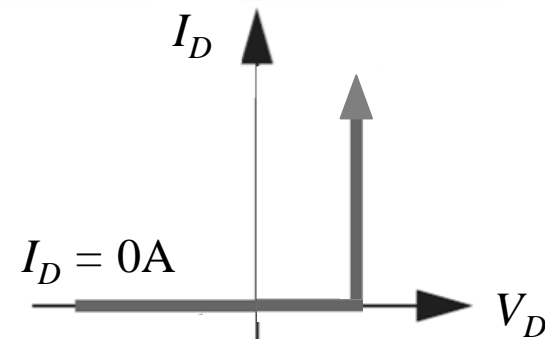
2025_01_24A



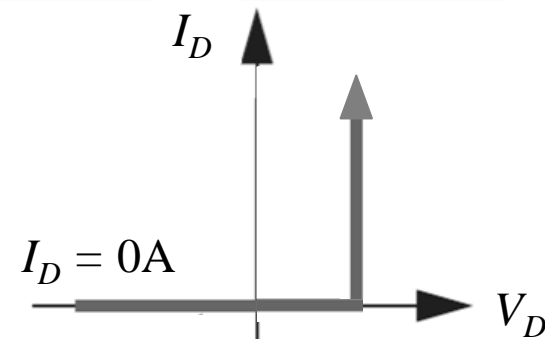
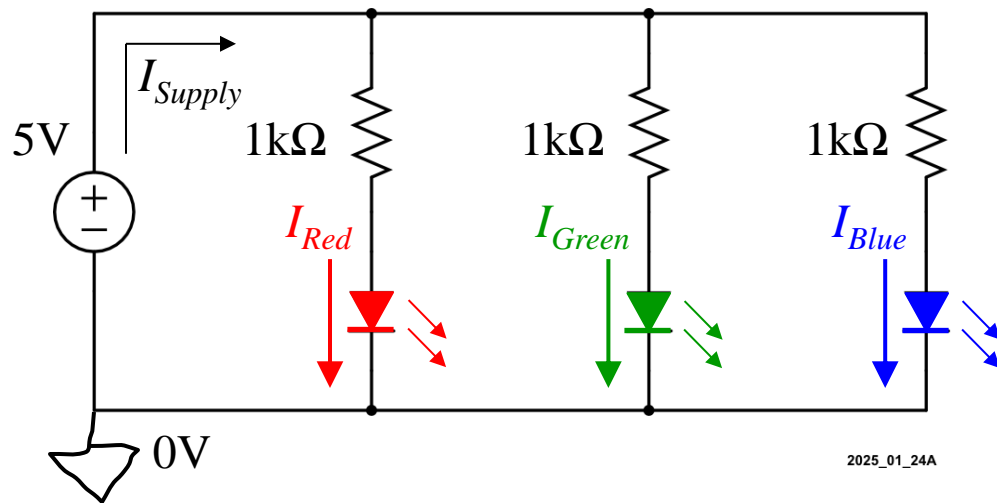
Red ($V_{KNEE} = 2V$)
 Green ($V_{KNEE} = 2.5V$) &
 Blue ($V_{KNEE} = 3V$)
 LEDs: Find I_{Supply}
 Assume On ($V_D = V_{KNEE}$)



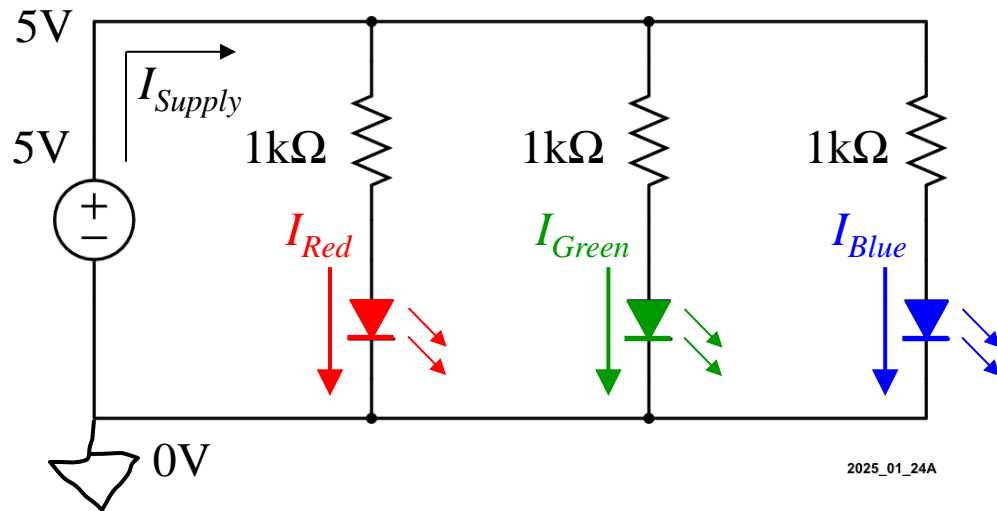
2025_01_24A



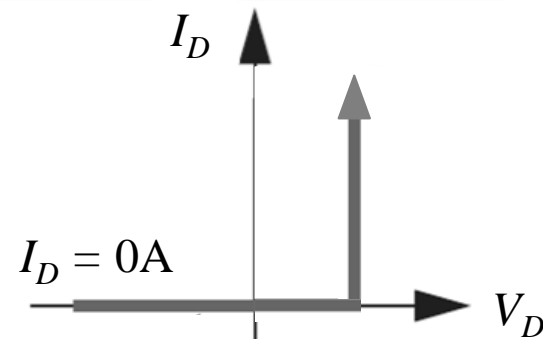
Red ($V_{KNEE} = 2V$)
 Green ($V_{KNEE} = 2.5V$) &
 Blue ($V_{KNEE} = 3V$)
 LEDs: Find I_{Supply}
 Assume On ($V_D = V_{KNEE}$)



Red ($V_{KNEE} = 2V$)
 Green ($V_{KNEE} = 2.5V$) &
 Blue ($V_{KNEE} = 3V$)
 LEDs: Find I_{Supply}
 Assume On ($V_D = V_{KNEE}$)



2025_01_24A



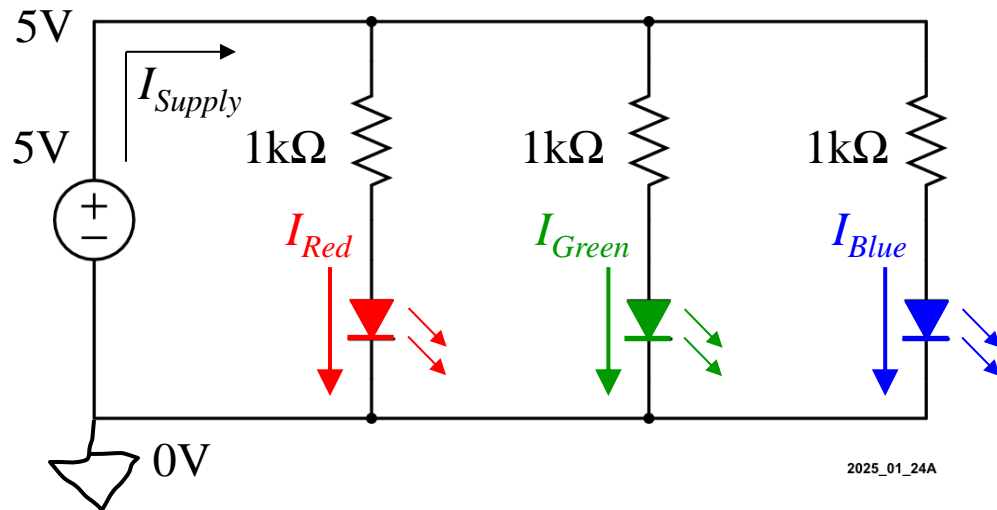
Red ($V_{KNEE} = 2V$)

Green ($V_{KNEE} = 2.5V$) &

Blue ($V_{KNEE} = 3V$)

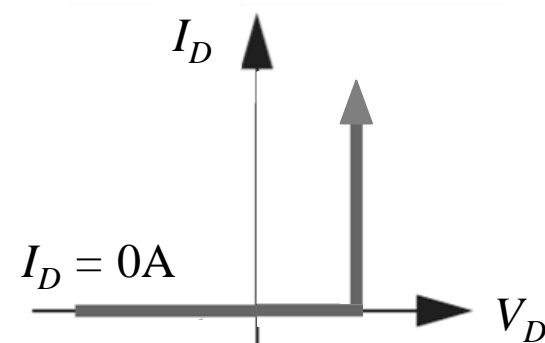
LEDs: Find I_{Supply}

Assume On ($V_D = V_{KNEE}$)



2025_01_24A

KVL is always true: $5V = I_{Red}(1k\Omega) + 2V$



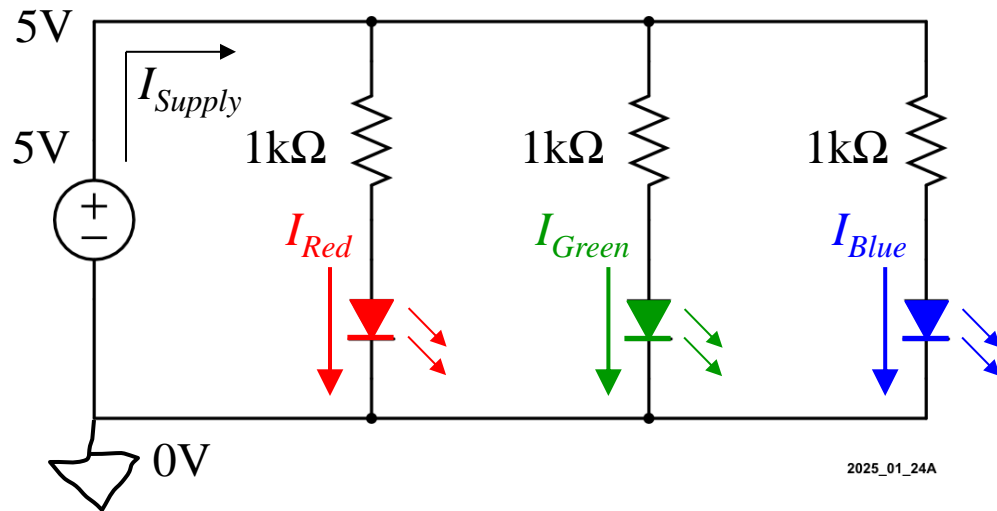
Red ($V_{KNEE} = 2V$)

Green ($V_{KNEE} = 2.5V$) &

Blue ($V_{KNEE} = 3V$)

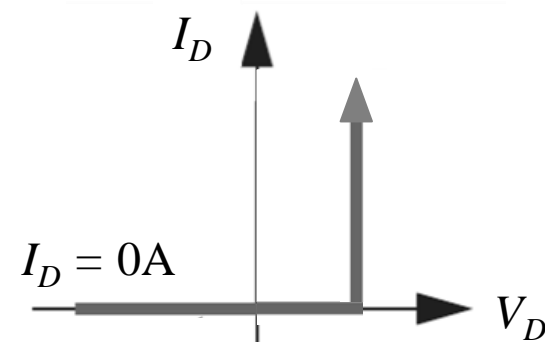
LEDs: Find I_{Supply}

Assume On ($V_D = V_{KNEE}$)



2025_01_24A

KVL is always true: $5V = I_{Red}(1k\Omega) + 2V$
 $5V = I_{Green}(1k\Omega) + 2.5V$



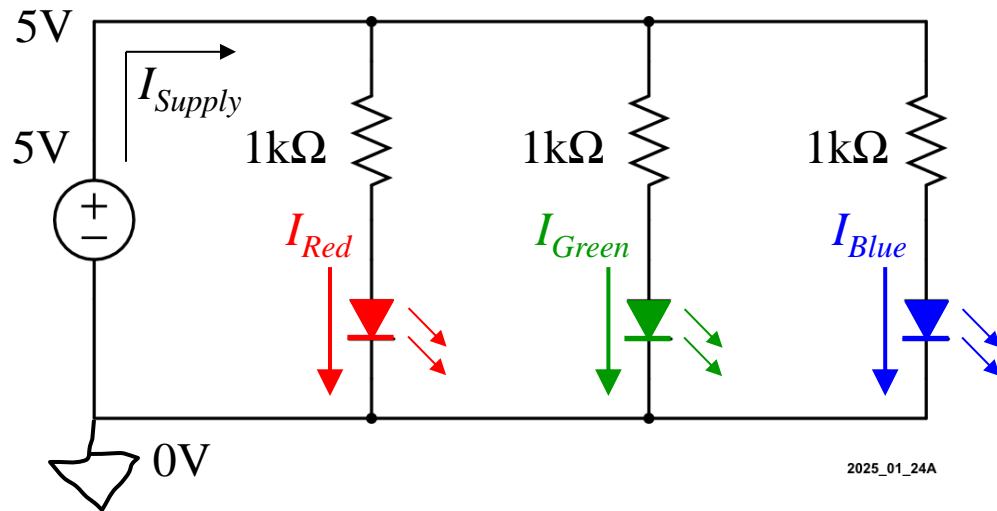
Red ($V_{KNEE} = 2V$)

Green ($V_{KNEE} = 2.5V$) &

Blue ($V_{KNEE} = 3V$)

LEDs: Find I_{Supply}

Assume On ($V_D = V_{KNEE}$)

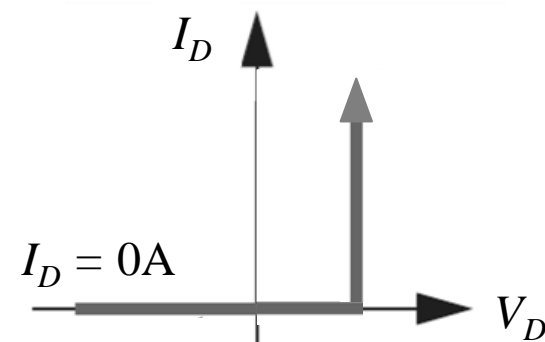


2025_01_24A

KVL is always true:

$$5V = I_{Red}(1k\Omega) + 2V$$

$$5V = I_{Green}(1k\Omega) + 2.5V$$

$$5V = I_{Blue}(1k\Omega) + 3V$$


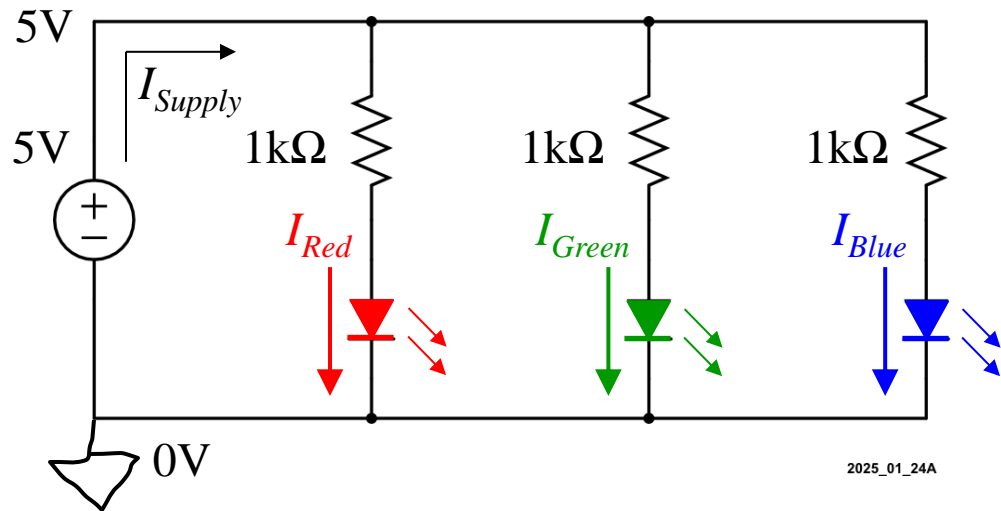
Red ($V_{KNEE} = 2V$)

Green ($V_{KNEE} = 2.5V$) &

Blue ($V_{KNEE} = 3V$)

LEDs: Find I_{Supply}

Assume On ($V_D = V_{KNEE}$)



KVL is always true:

$$5V = I_{Red}(1k\Omega) + 2V$$

$$I_{Red} = 3.0mA$$

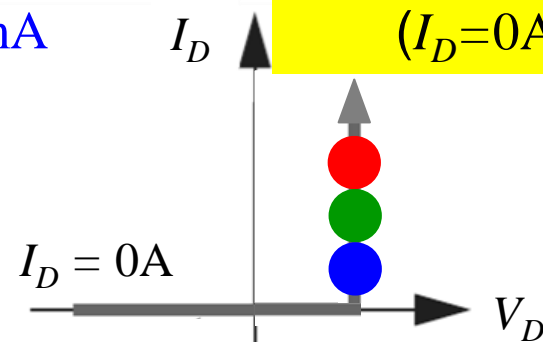
$$5V = I_{Green}(1k\Omega) + 2.5V$$

$$I_{Green} = 2.5mA$$

$$5V = I_{Blue}(1k\Omega) + 3V$$

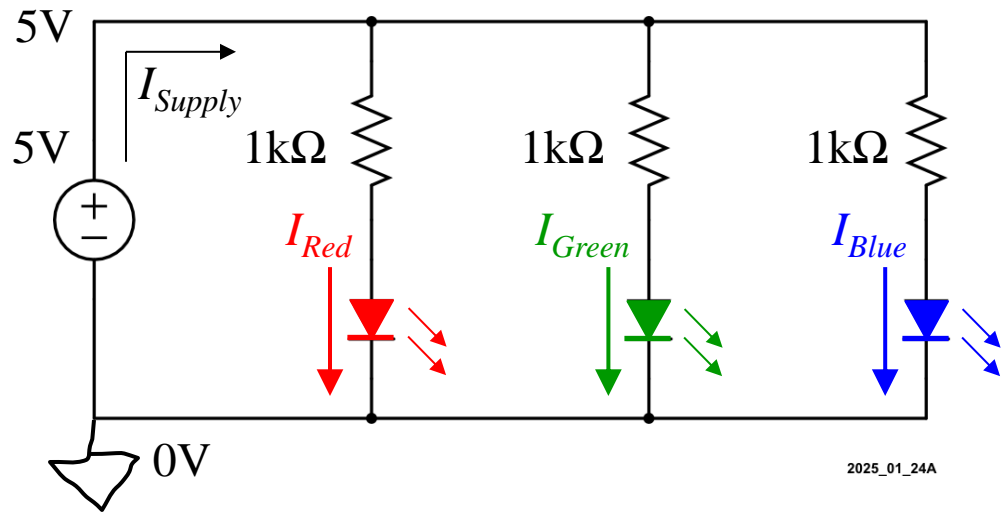
$$I_{Blue} = 2.0mA$$

Assumption
Confirmed
($I_D = 0A$)



Red ($V_{KNEE} = 2V$)
 Green ($V_{KNEE} = 2.5V$) &
 Blue ($V_{KNEE} = 3V$)
 LEDs: Find I_{Supply}

Assume On ($V_D = V_{KNEE}$)



KVL is always true:

$$5V = I_{Red}(1k\Omega) + 2V \quad I_{Red} = 3.0mA$$

$$5V = I_{Green}(1k\Omega) + 2.5V \quad I_{Green} = 2.5mA$$

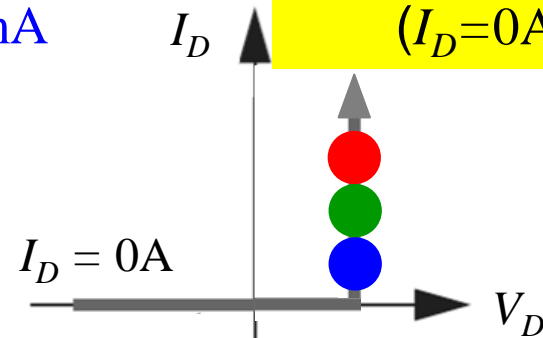
$$5V = I_{Blue}(1k\Omega) + 3V \quad I_{Blue} = 2.0mA$$

KCL is always true:

$$I_{Supply} = 3.0mA + 2.5mA + 2.0mA$$

$$= 7.5mA$$

Assumption
Confirmed
($I_D = 0A$)



Light Emitting Diode (LED)

- Converts electrical energy to photon energy

$$E_{\text{Photon}} \approx (e^-)(V_{\text{KNEE}})$$

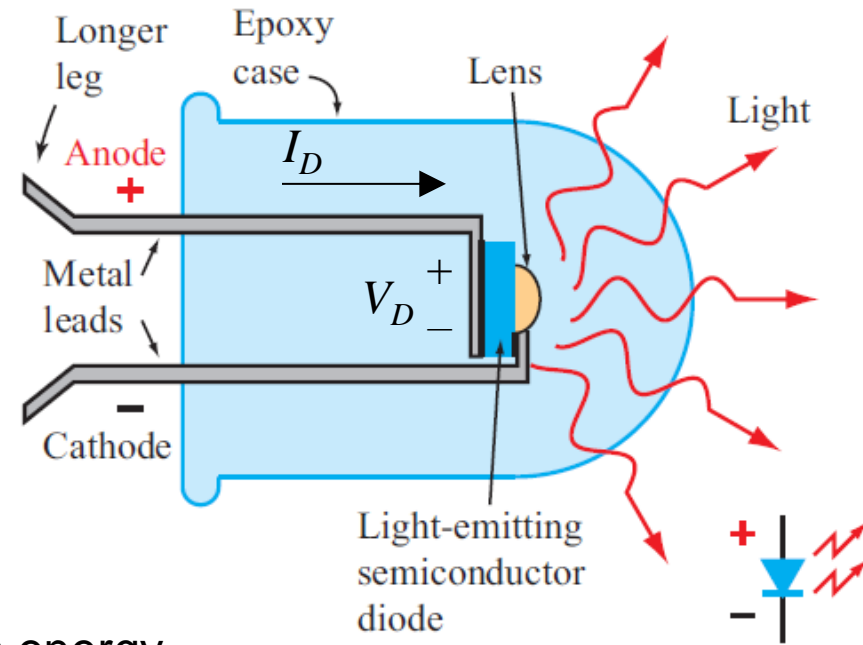
$$V_{\text{KNEE, RED LED}} \approx 2V$$

$$E_{\text{Photon}} \approx (1.60 \times 10^{-19} \text{ C})(2V) = 3.20 \times 10^{-19} \text{ J}$$

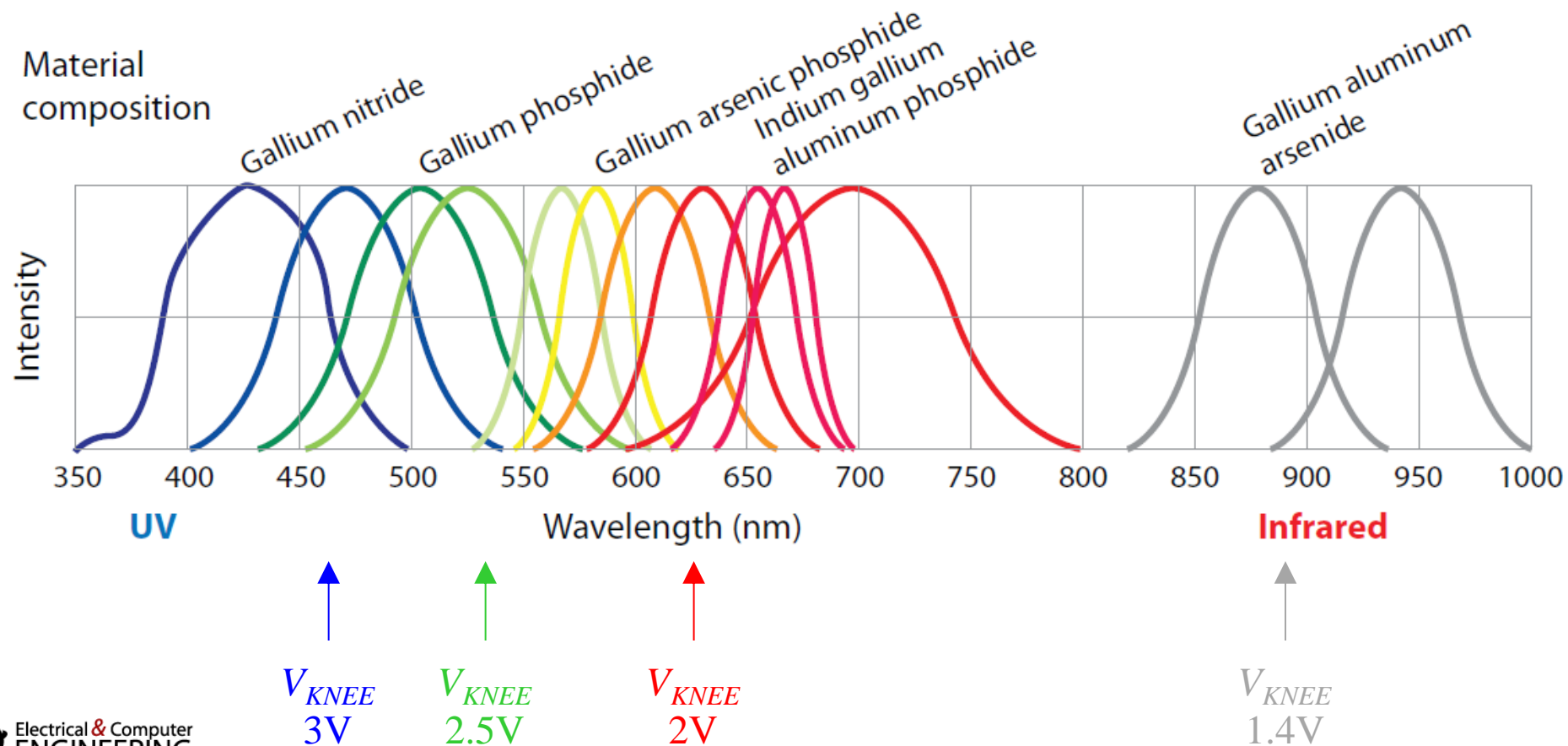
- Can calculate the photon wavelength from its energy

$$E_{\text{Photon}} = hf \quad f = \frac{c}{\lambda} \quad \lambda f = c$$

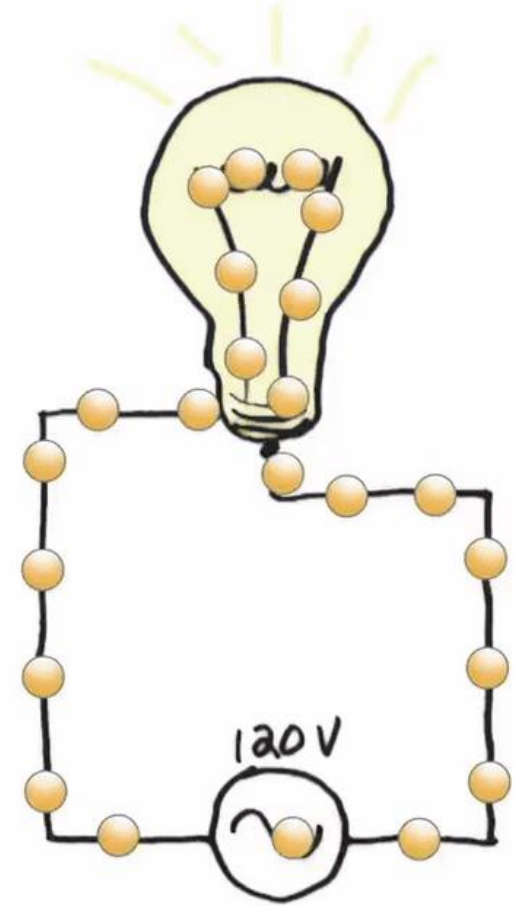
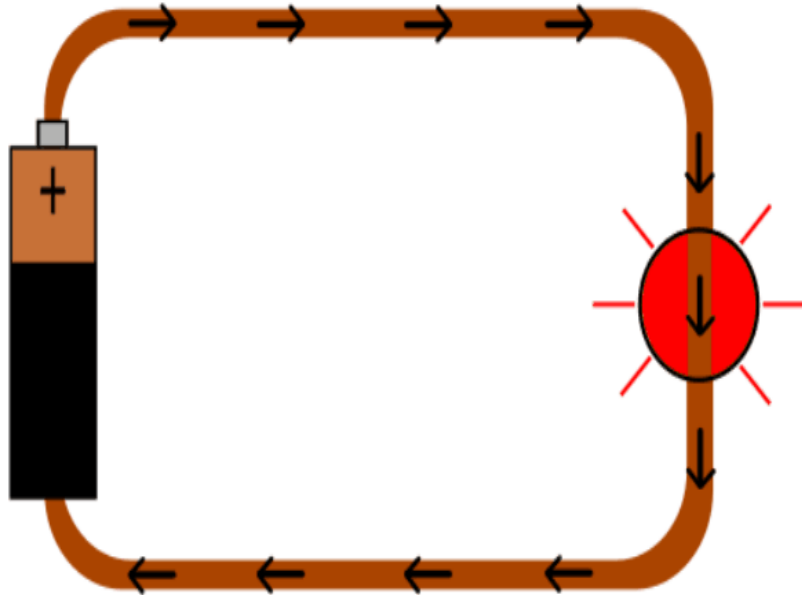
$$E_{\text{Photon}} = \frac{hc}{\lambda} \quad 3.20 \times 10^{-19} \text{ J} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{\lambda} \quad \lambda = 622 \text{ nm}$$



Light Emitting Diode (LED)



DC vs. AC Power Systems



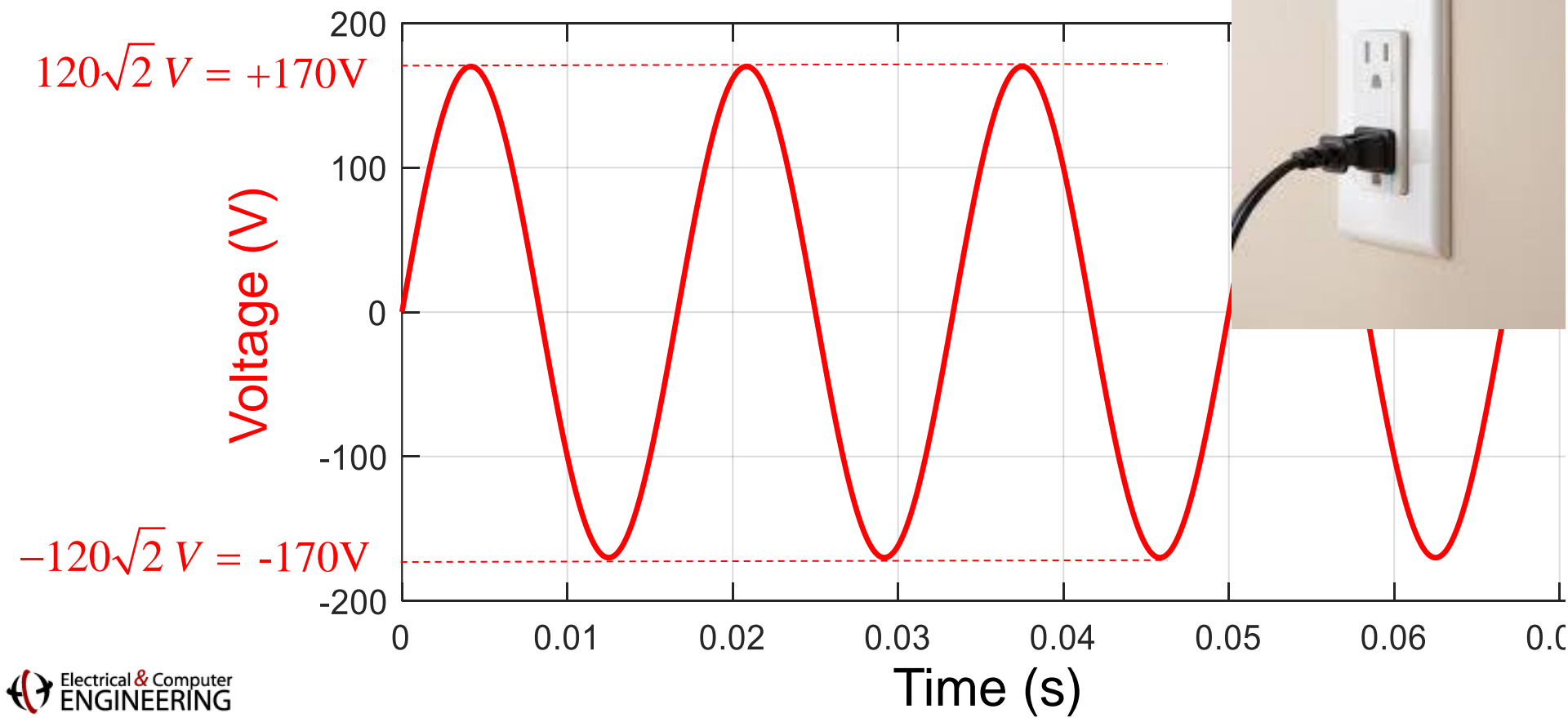
AC Voltages:

120V, 60Hz



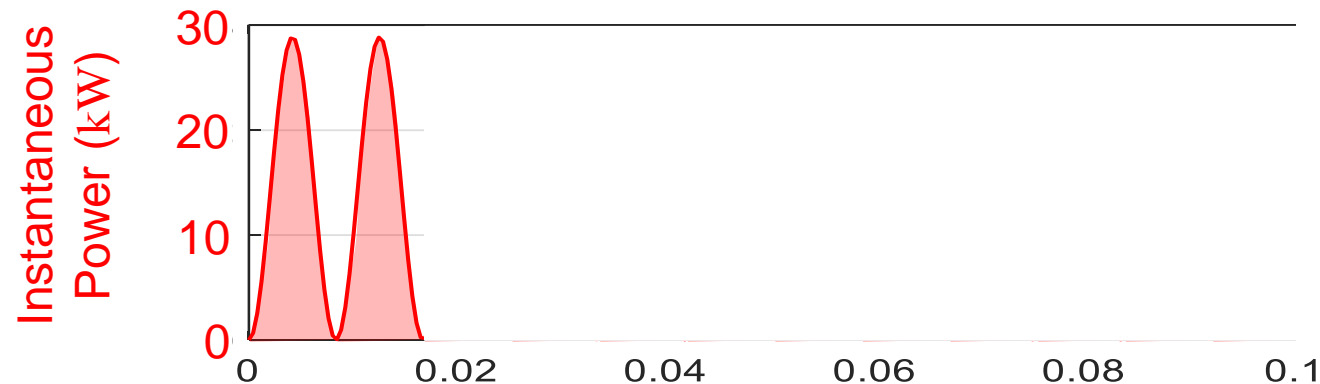
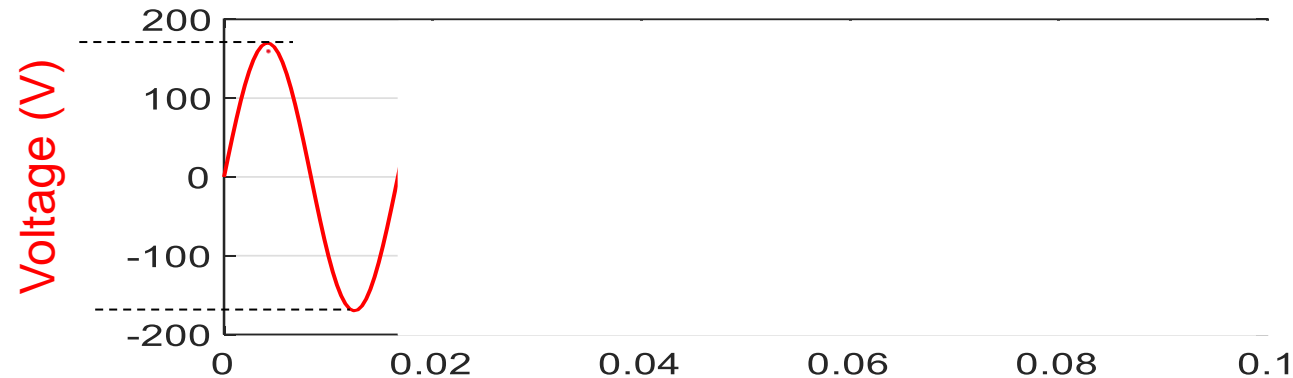
AC Voltages: $170\sin(2\pi*60\text{Hz}*t)$ V

120V, 60Hz



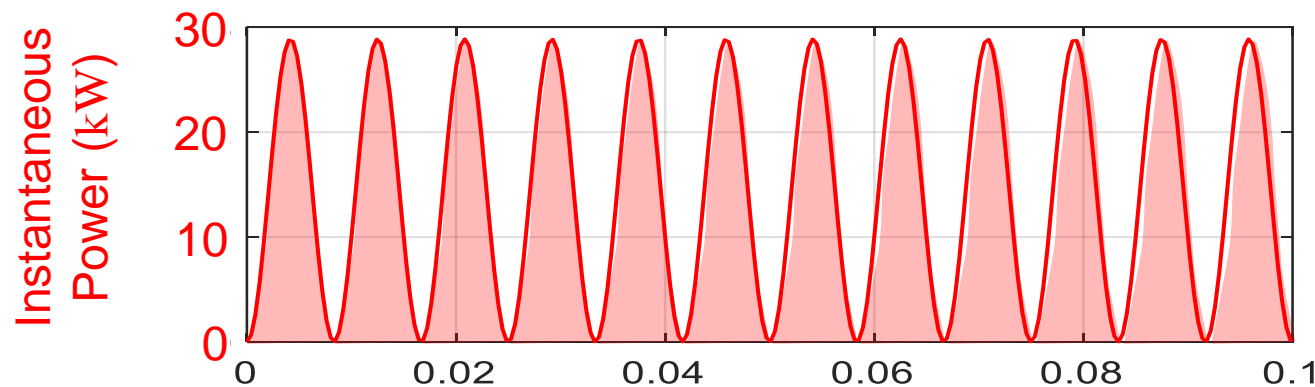
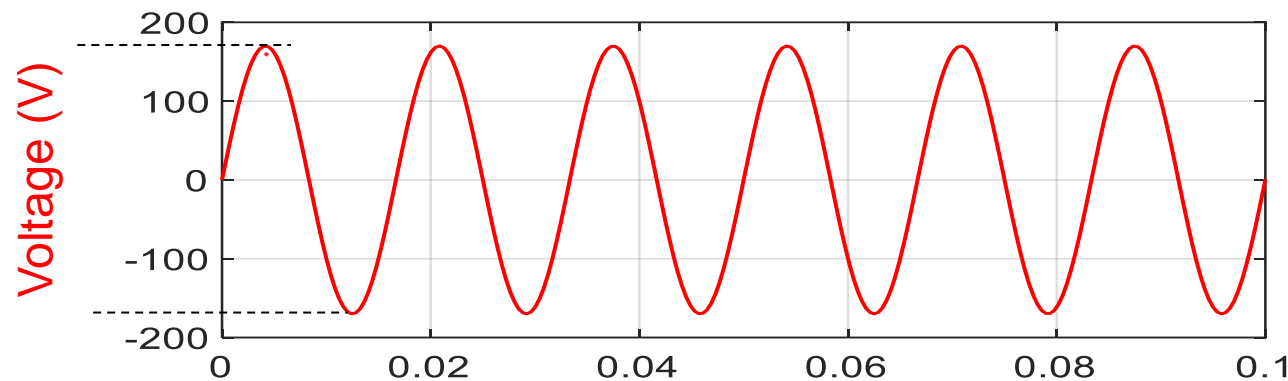
Instantaneous AC Power into a 1Ω Resistance ($P = I^2 R$)

$$P(t) = \frac{V^2(t)}{R}$$



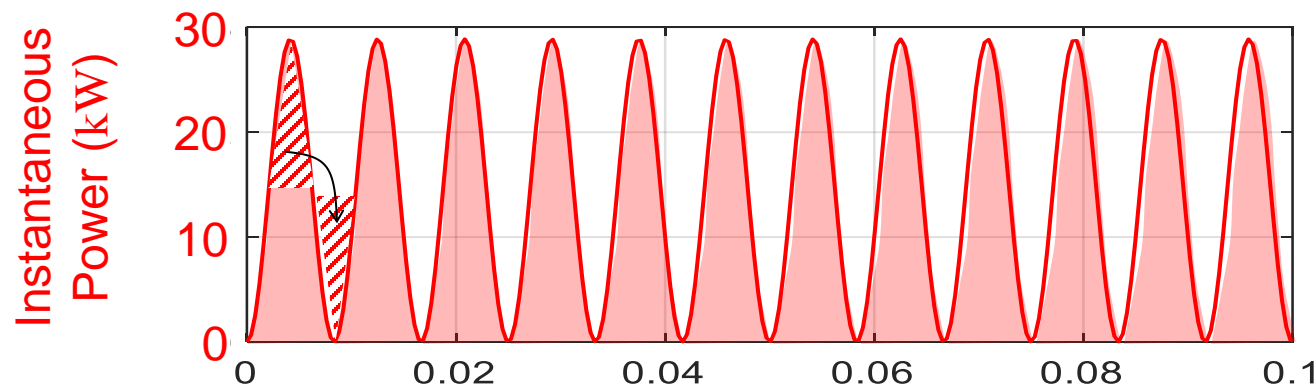
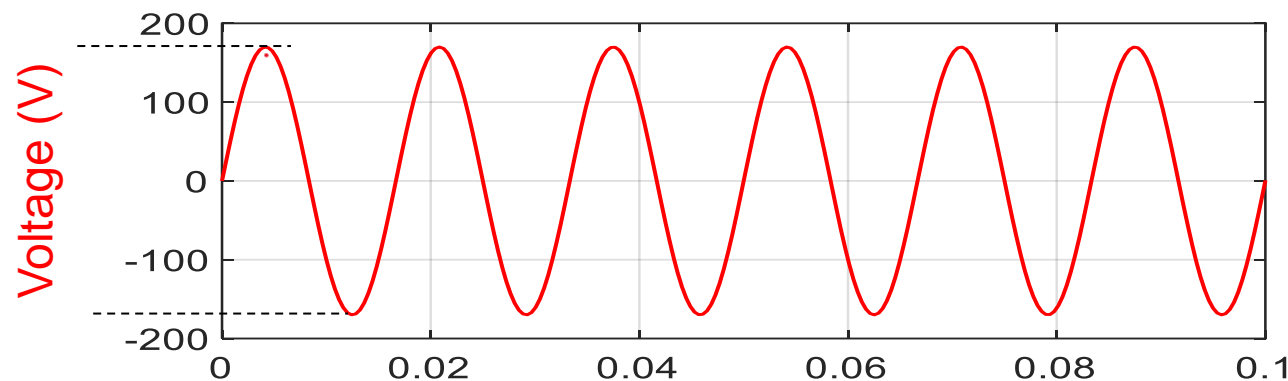
Instantaneous AC Power into a 1Ω Resistance ($P = I^2 R$)

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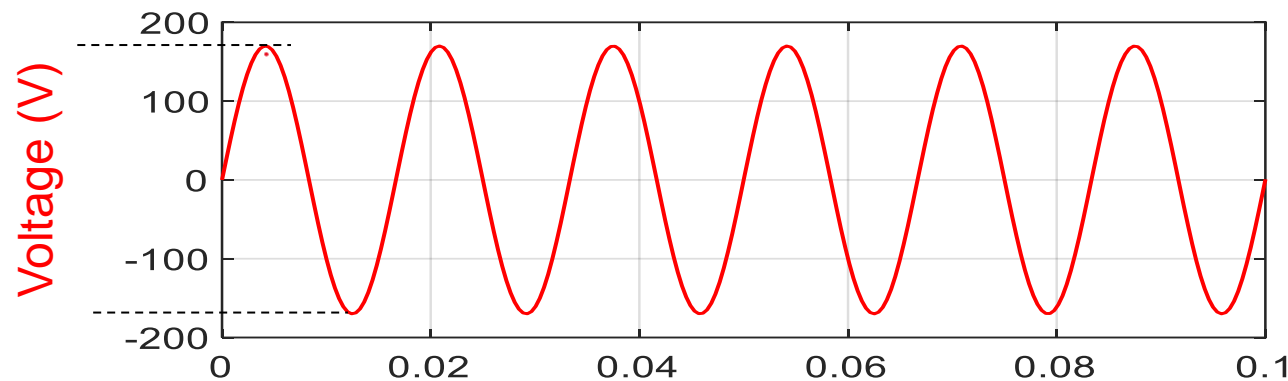
Instantaneous AC Power into a 1Ω Resistance ($P = I^2 R$)

$$P(t) = \frac{V^2(t)}{R}$$

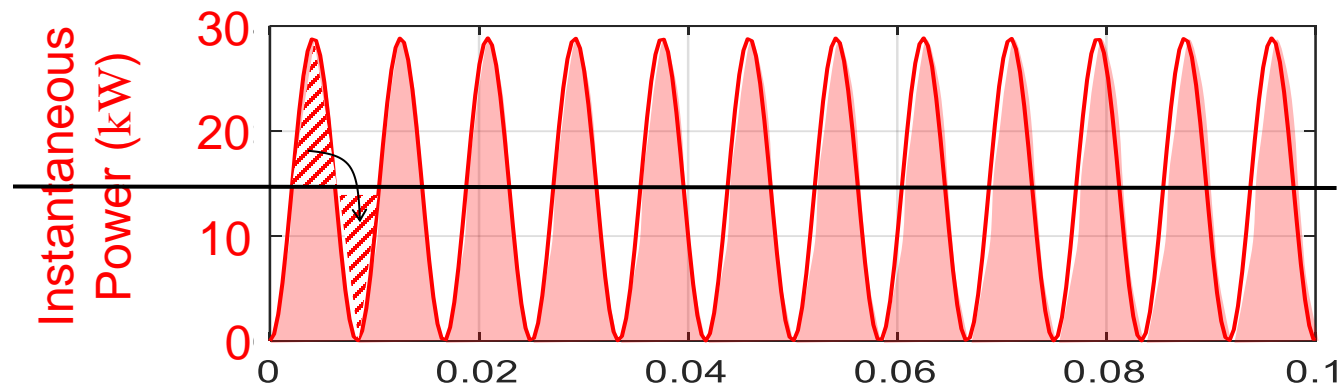


Instantaneous AC Power into a 1Ω Resistance ($P = I^2 R$)

$$P(t) = \frac{V^2(t)}{R}$$



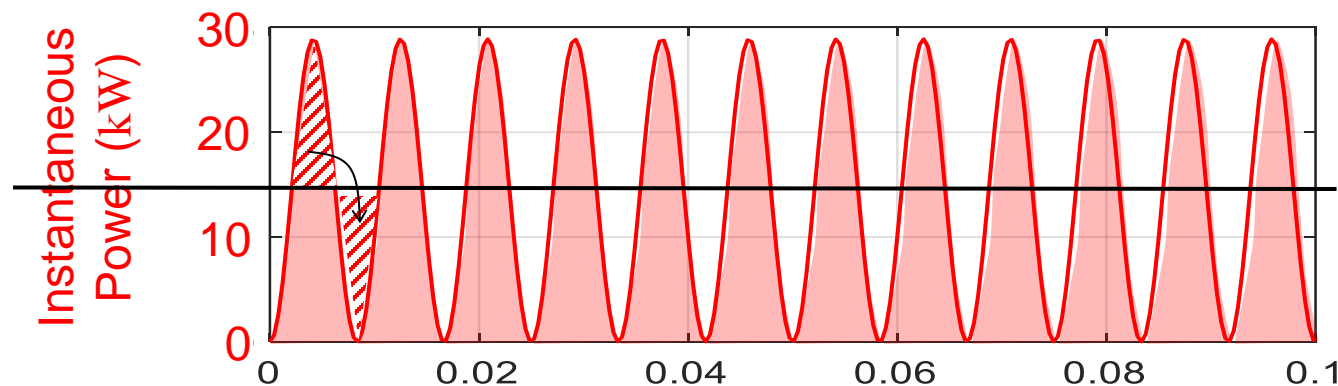
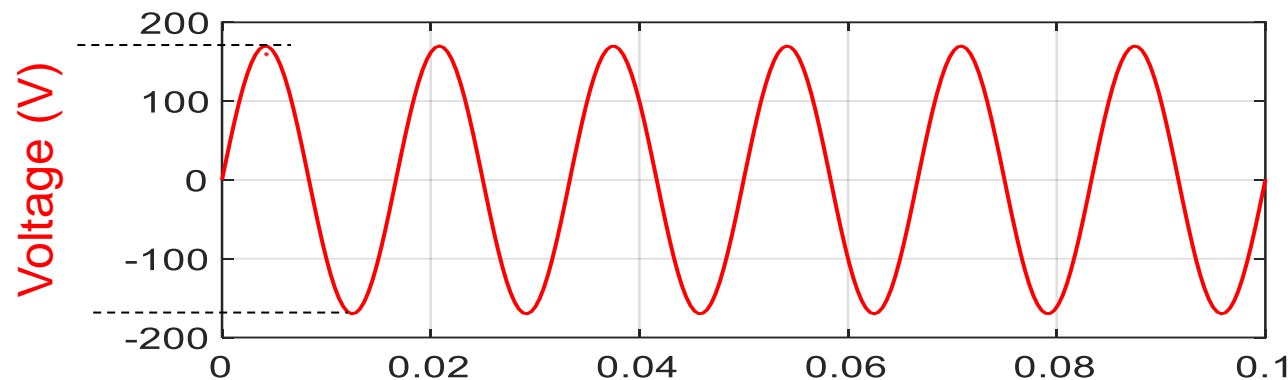
$$\frac{V_{Peak}^2(t)}{2R} = P_{AC,Avg}$$



Instantaneous AC Power into a 1Ω Resistance ($P = I^2 R$)

$$P(t) = \frac{V^2(t)}{R}$$

$$\frac{\left(\frac{V_{Peak}(t)}{\sqrt{2}}\right)^2}{R} = \frac{V_{Peak}^2(t)}{2R} = P_{AC,Avg}$$



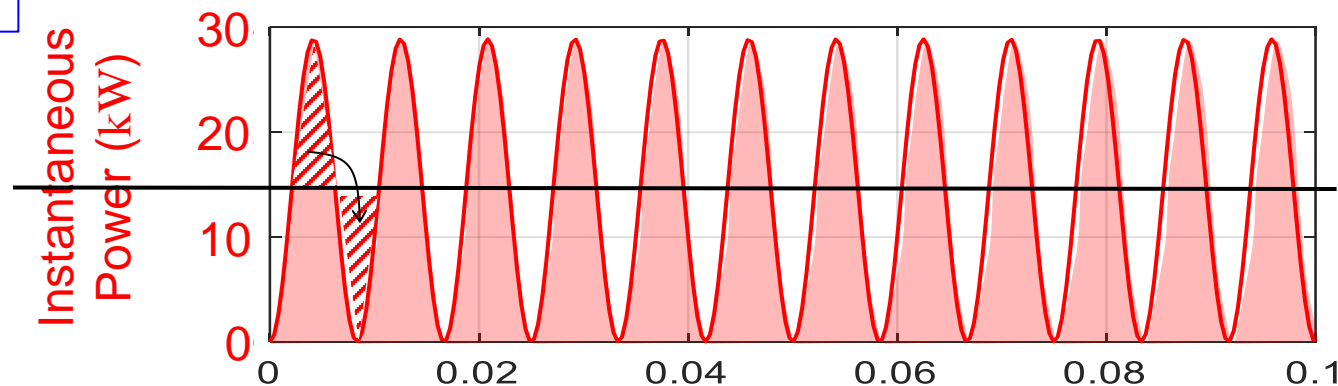
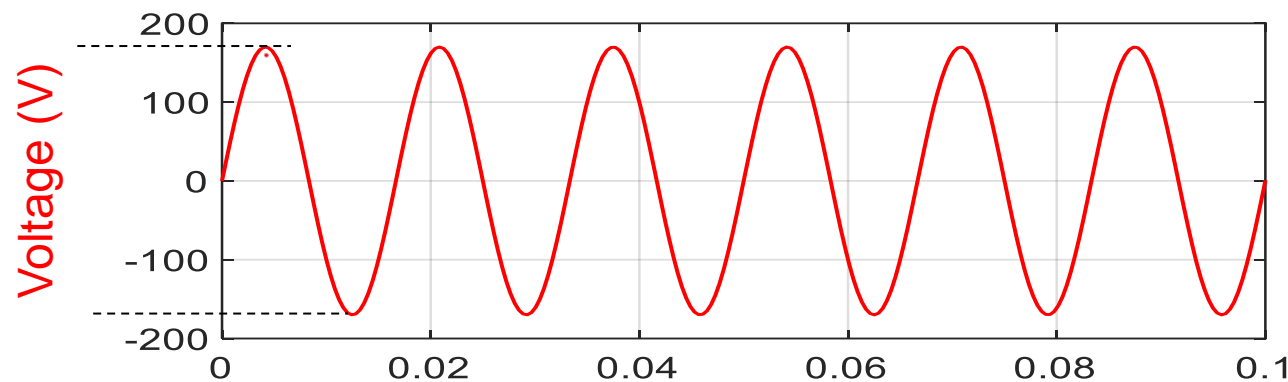
Instantaneous AC Power into a 1Ω Resistance ($P = I^2 R$)

$$P(t) = \frac{V^2(t)}{R}$$

$$P_{DC,Avg} = \frac{(120V_{DC})^2}{1\Omega} = 14.4kW$$

$$P_{AC,Avg} = \frac{(170V/\sqrt{2})^2}{1\Omega} = 14.4kW$$

$$\frac{\left(\frac{V_{Peak}(t)}{\sqrt{2}}\right)^2}{R} = \frac{V_{Peak}^2(t)}{2R} = P_{AC,Avg}$$



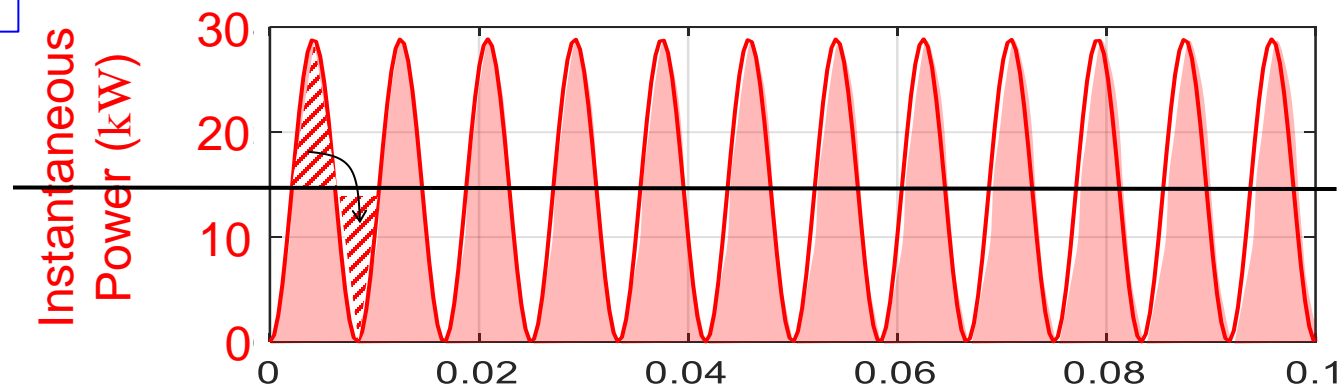
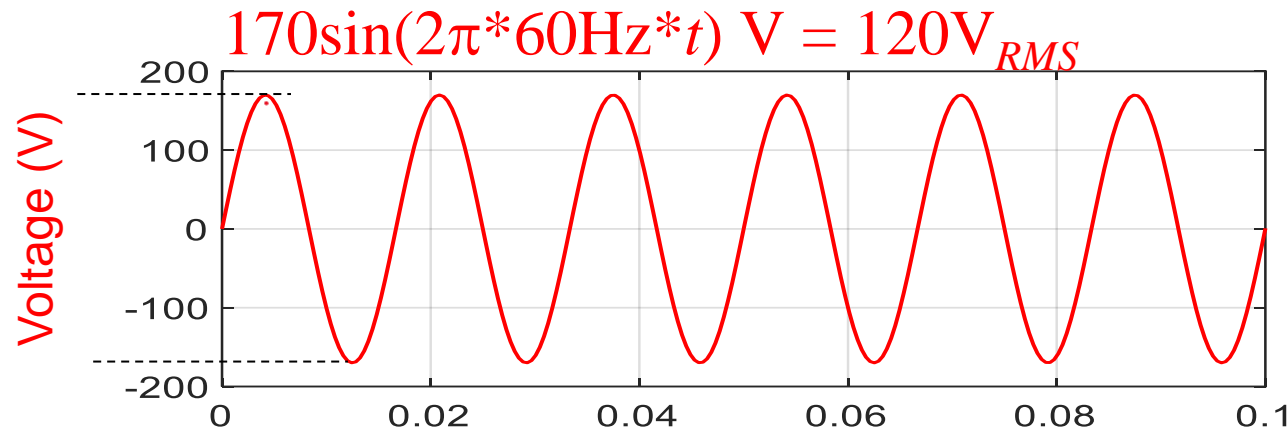
Instantaneous AC Power into a 1Ω Resistance ($P = I^2R$)

$$P(t) = \frac{V^2(t)}{R}$$

$$P_{DC,Avg} = \frac{(120V_{DC})^2}{1\Omega} = 14.4kW$$

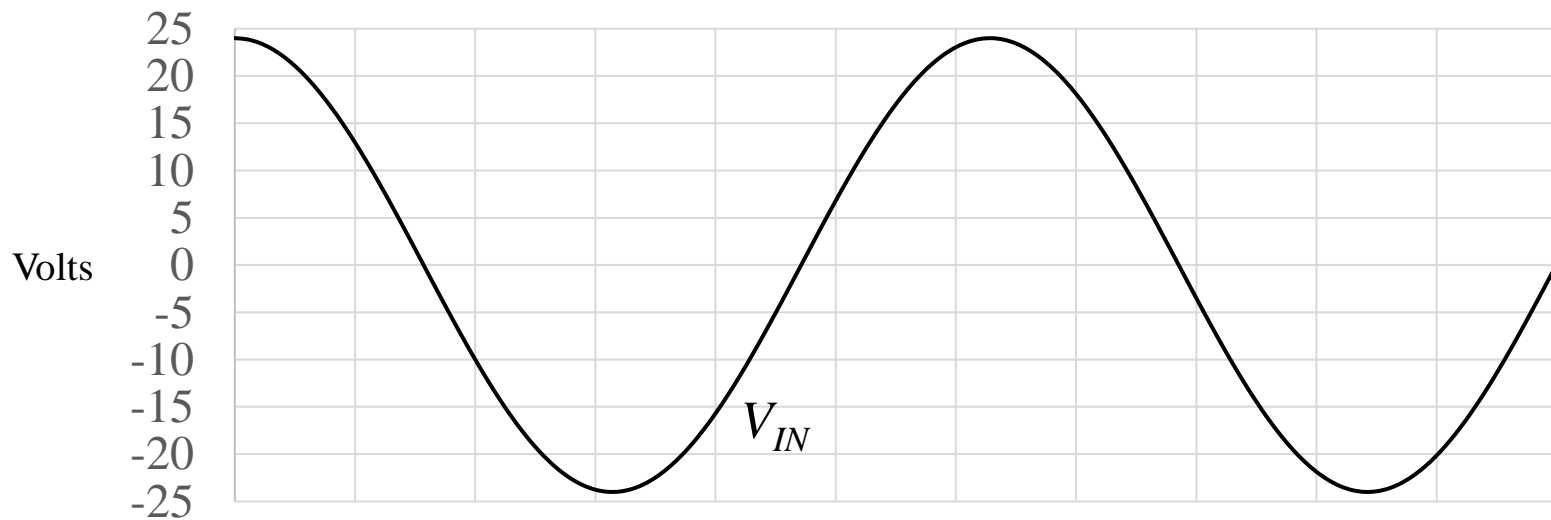
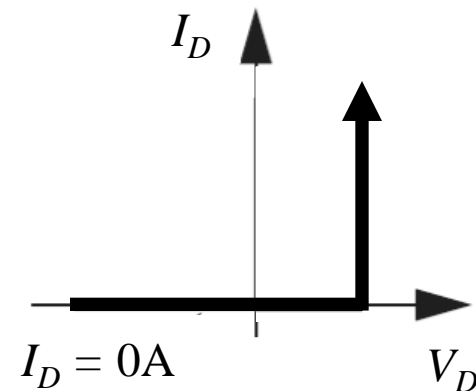
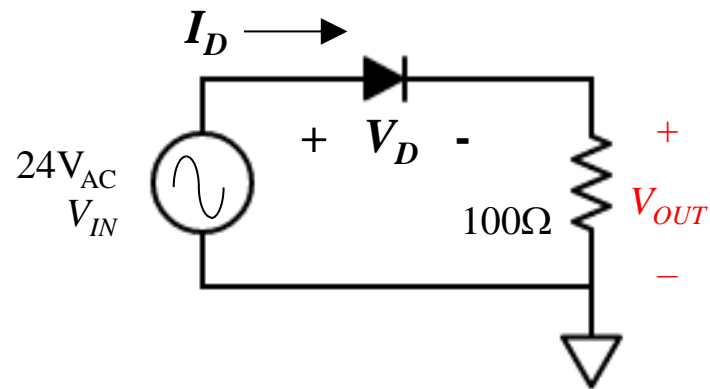
$$P_{AC,Avg} = \frac{(170V/\sqrt{2})^2}{1\Omega} = 14.4kW$$

$$\frac{\left(\frac{V_{Peak}(t)}{\sqrt{2}}\right)^2}{R} = \frac{V_{Peak}^2(t)}{2R} = P_{AC,Avg}$$

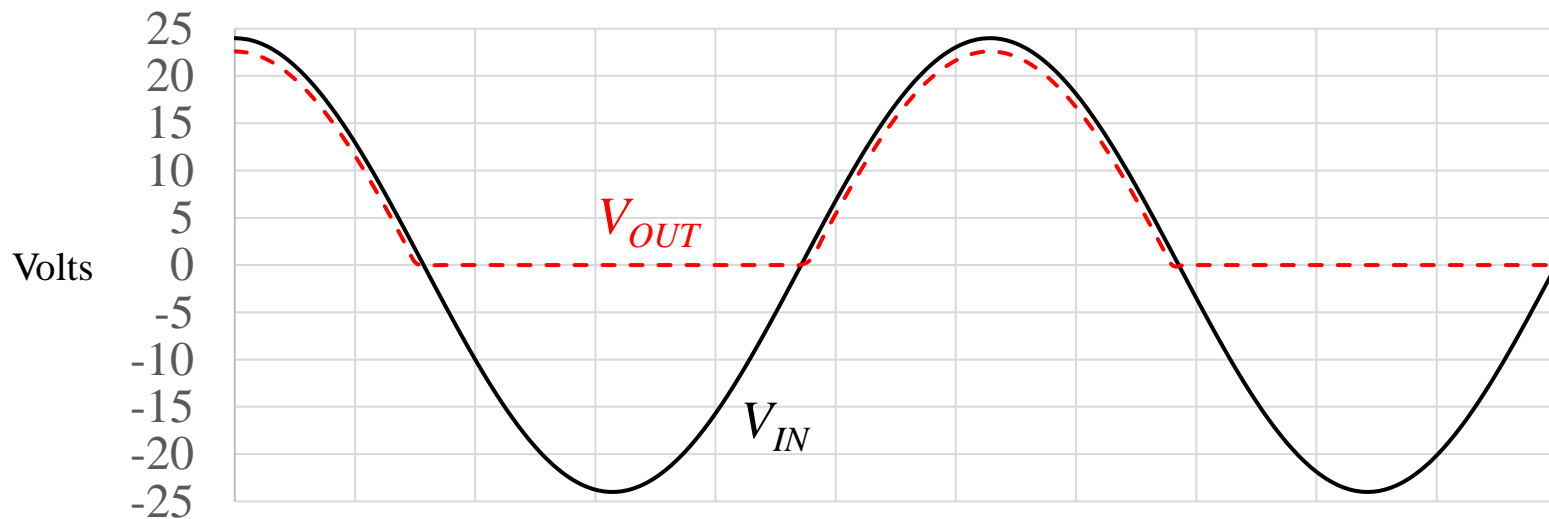
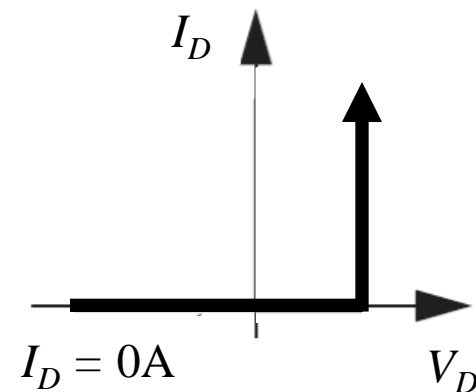
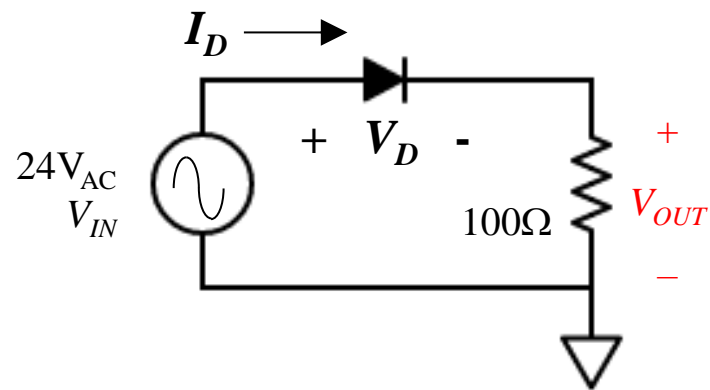


How Do We Convert AC Power to DC?

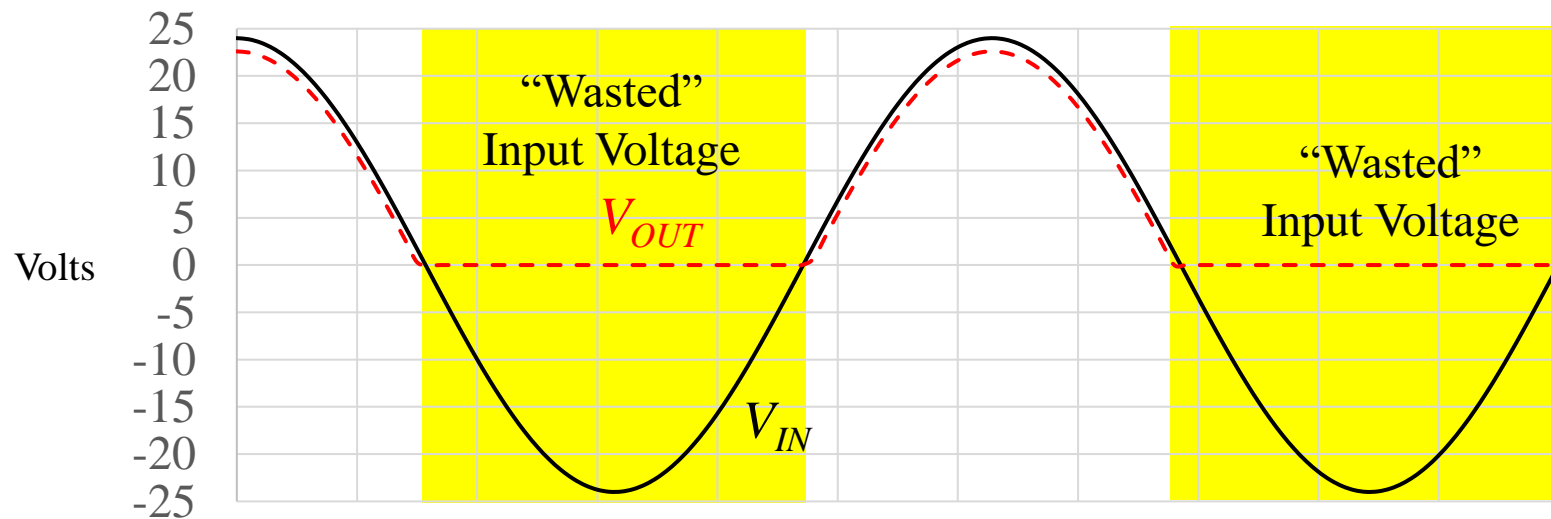
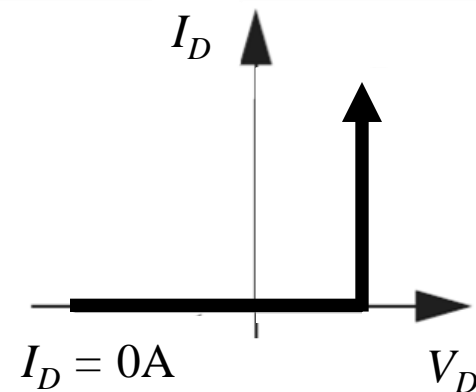
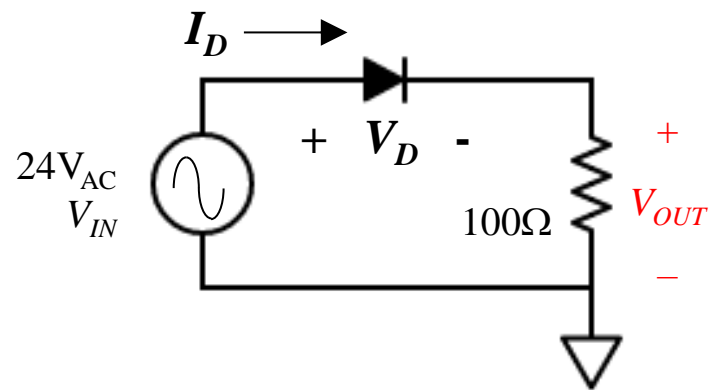
Diode Half-Wave Rectifier (Knee Model)



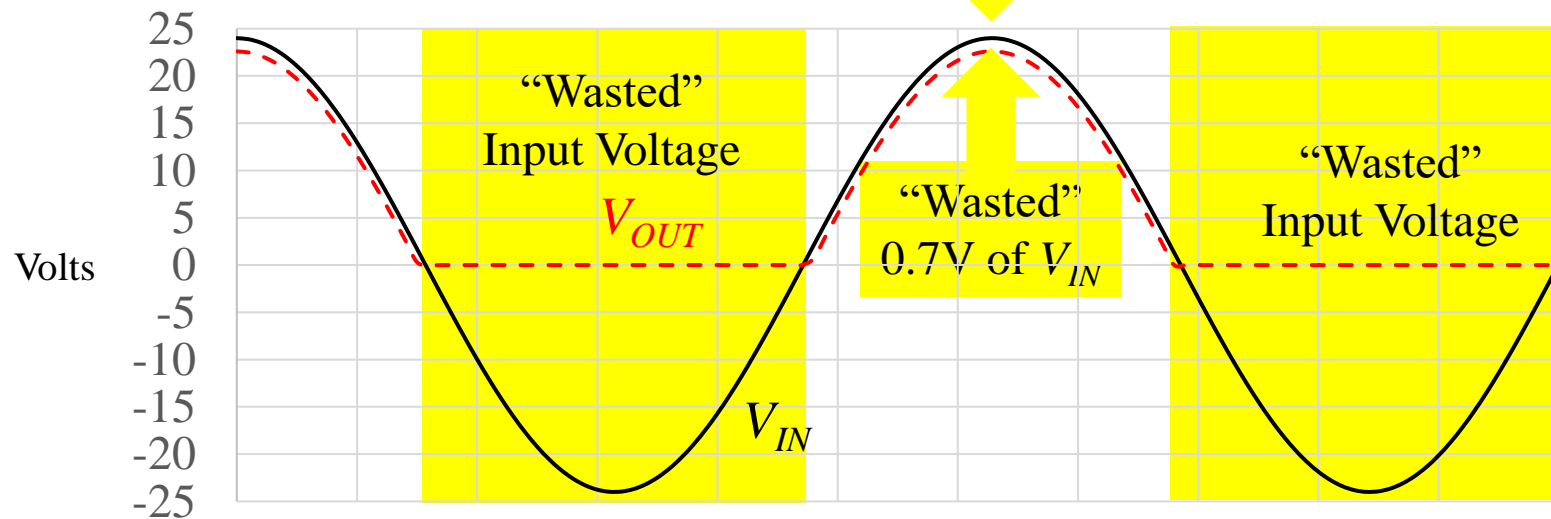
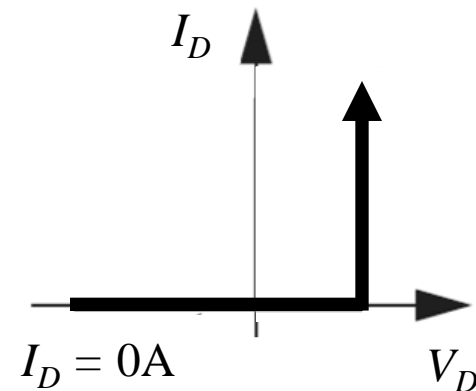
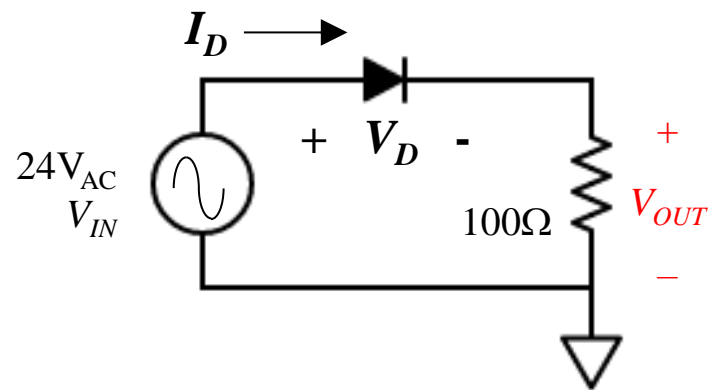
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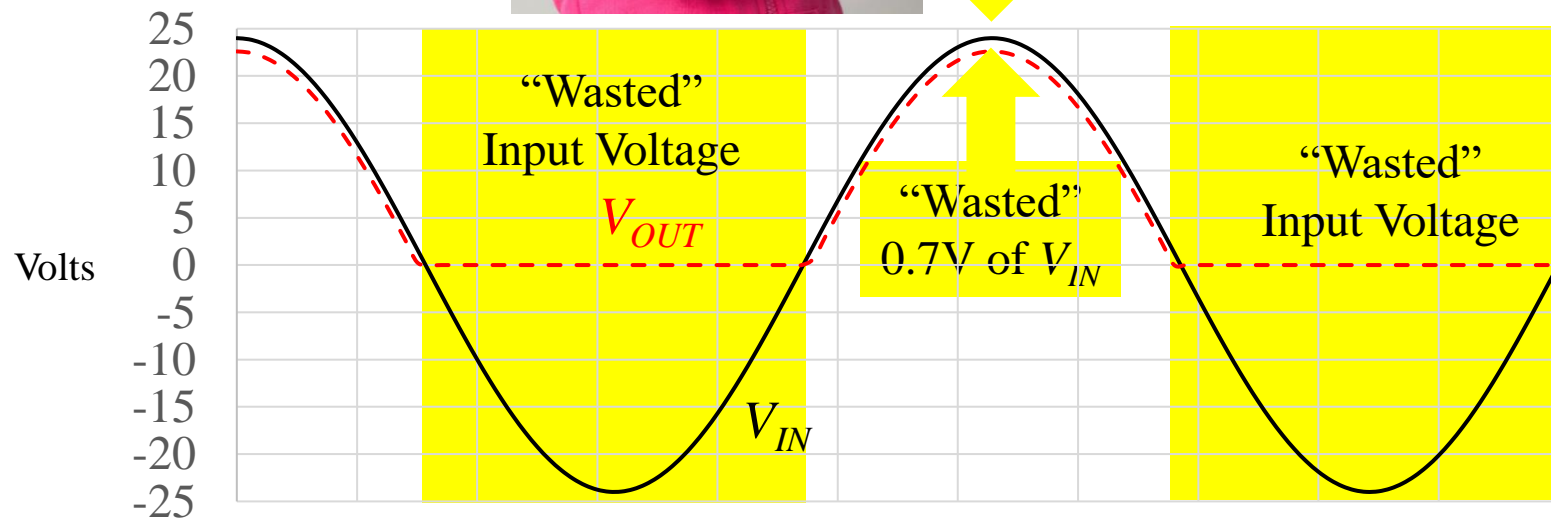
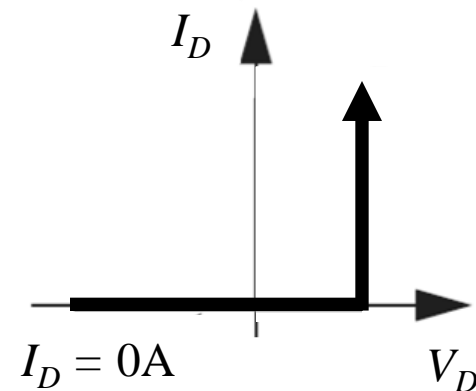
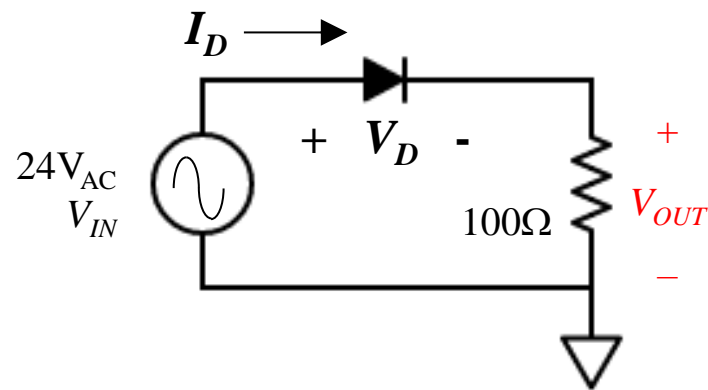
Diode Half-Wave Rectifier (Knee Model)



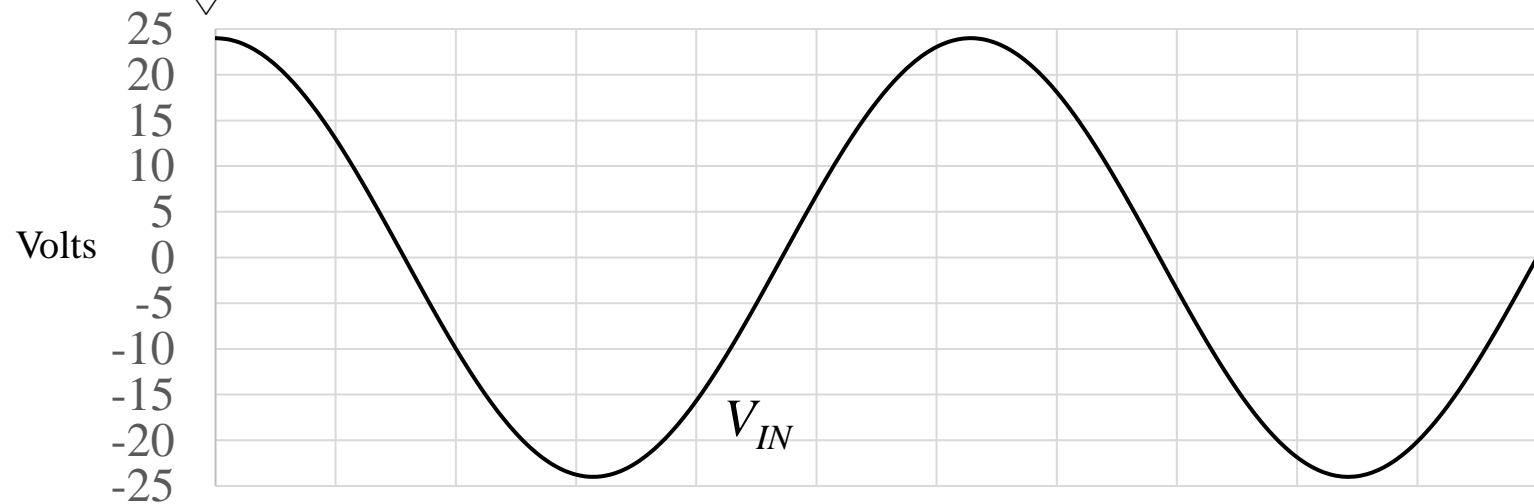
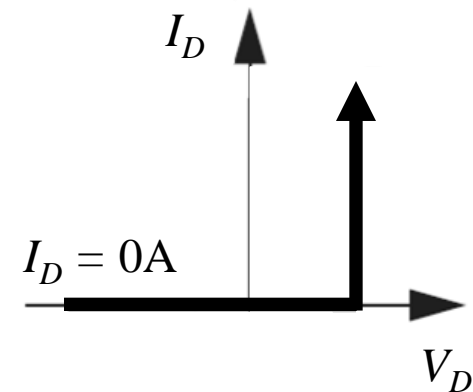
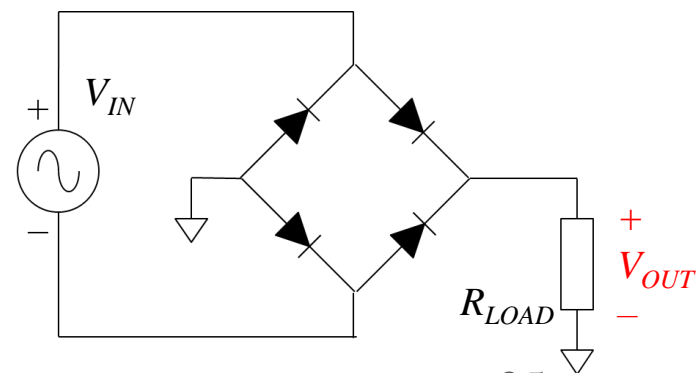
Diode Half-Wave Rectifier (Knee Model)



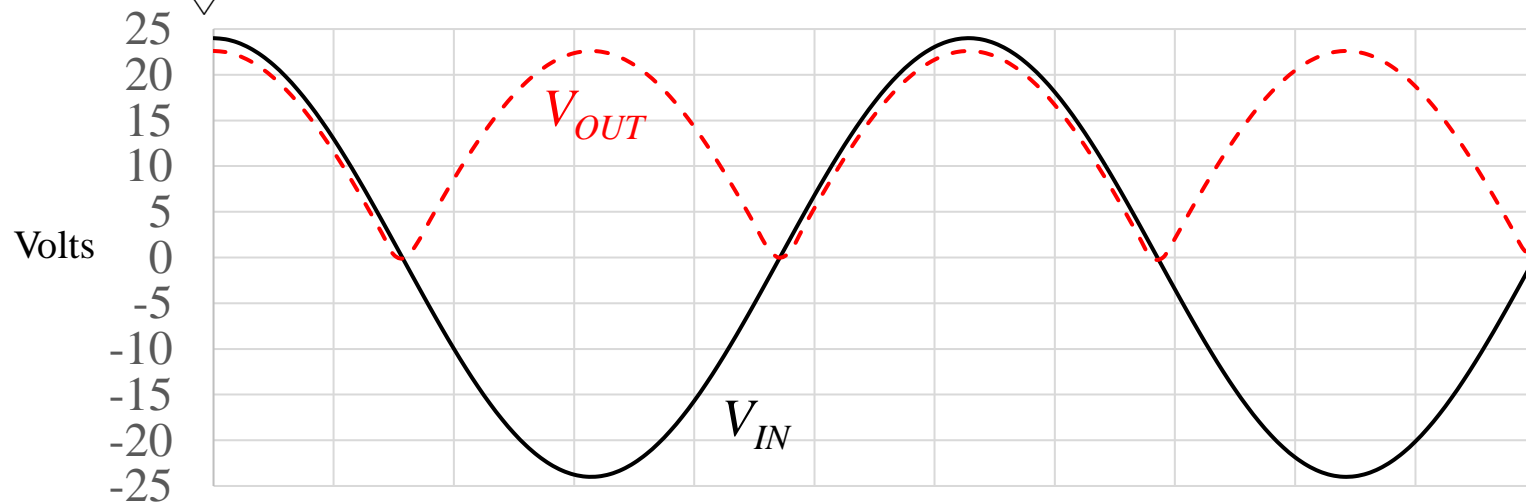
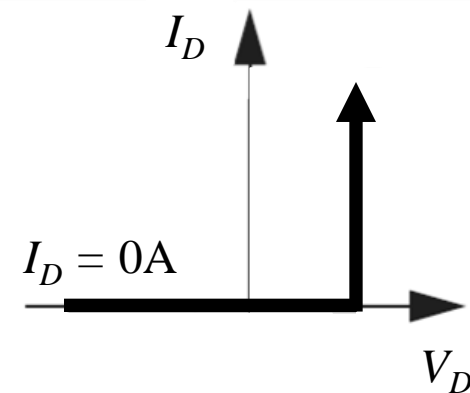
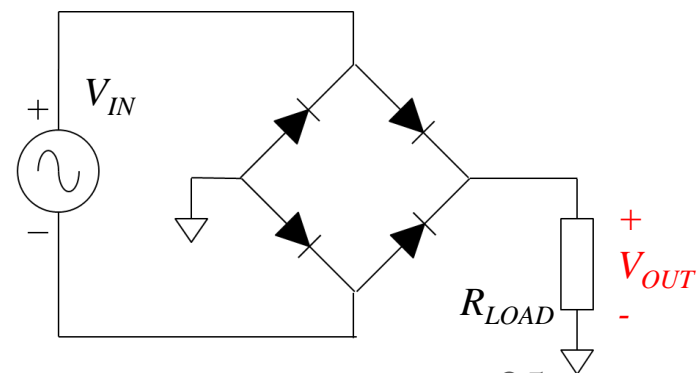
Diode Half-Wave Rectifier (Knee Model)



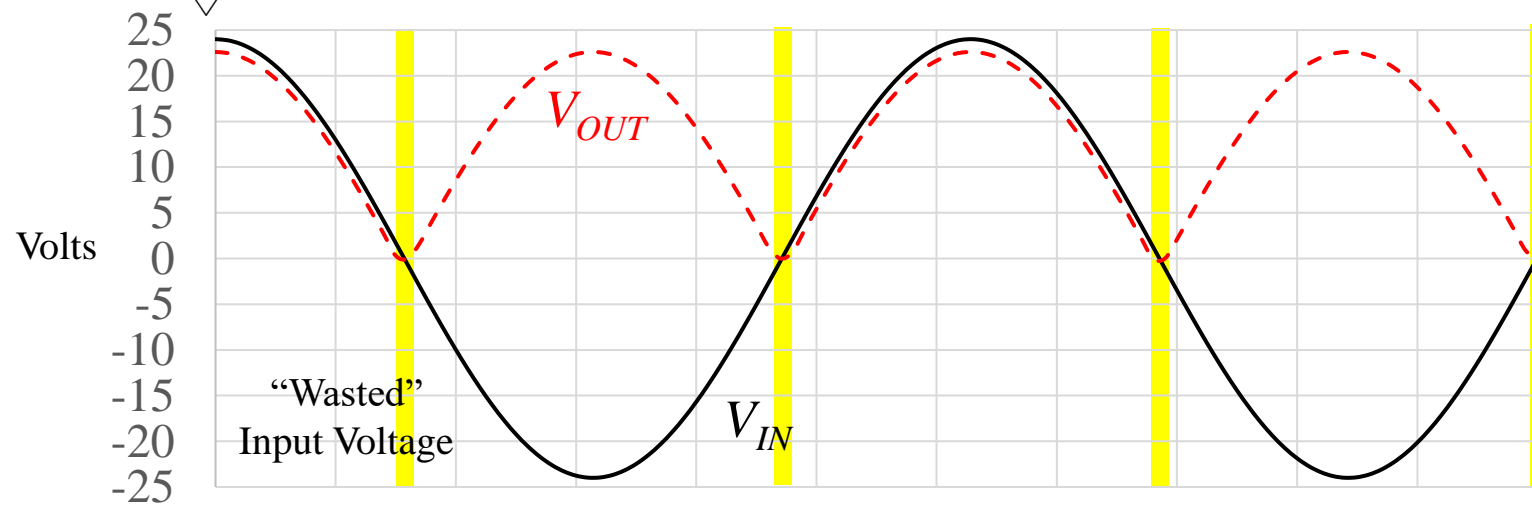
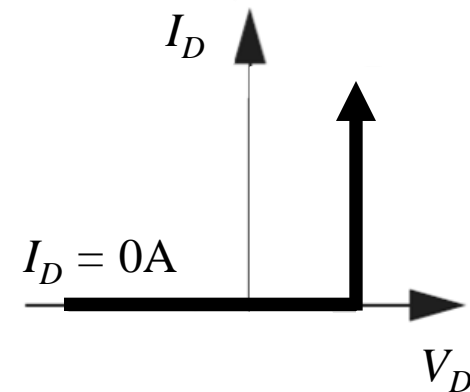
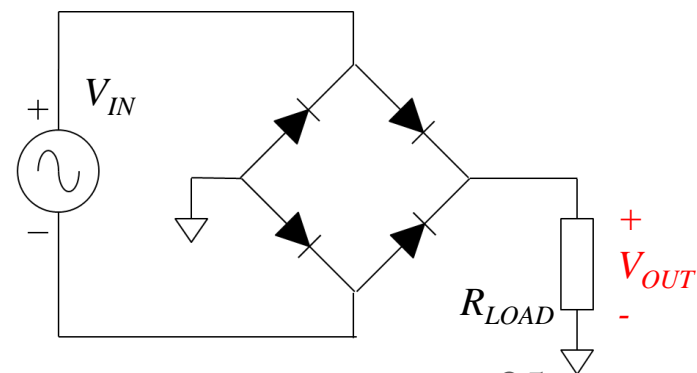
Diode Full-Wave Rectifier



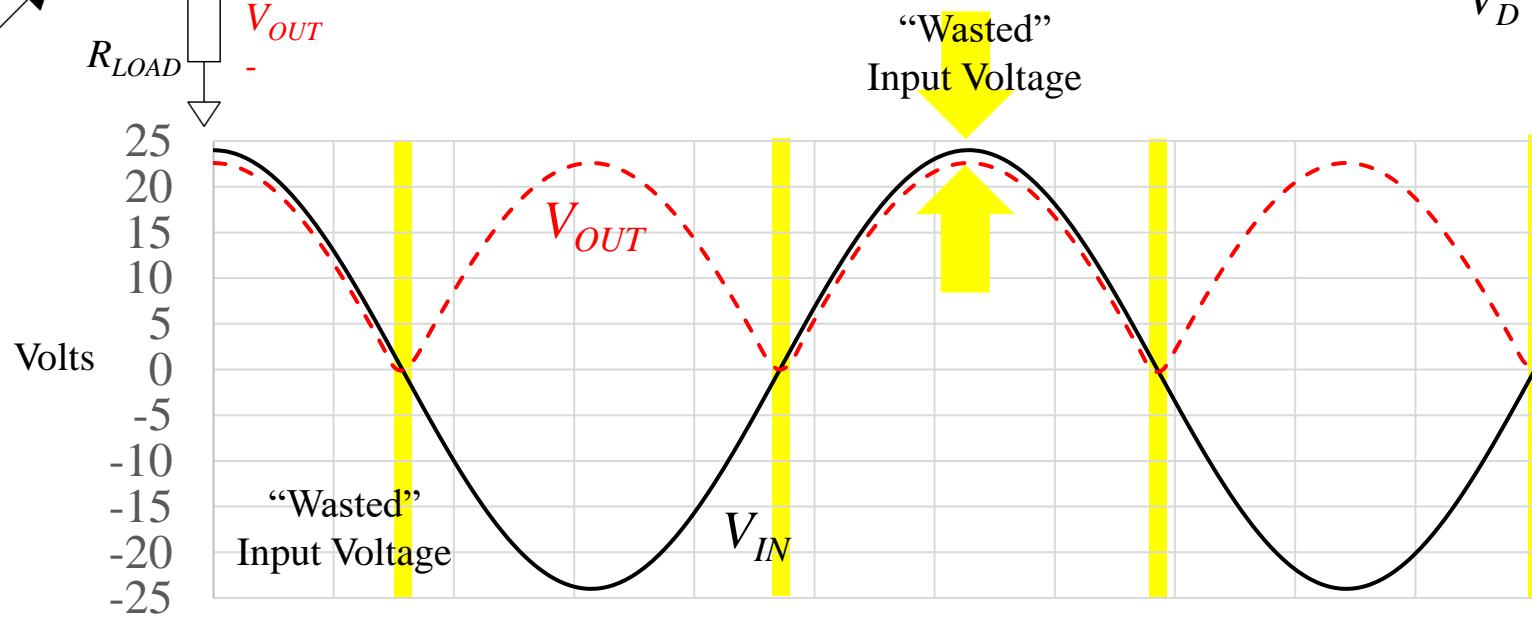
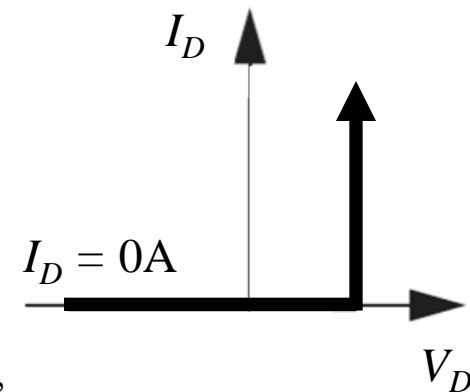
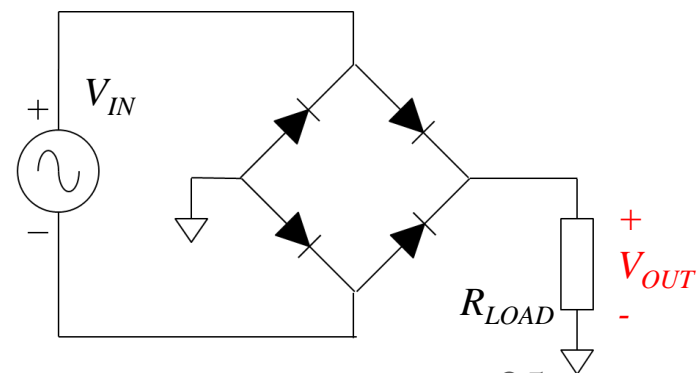
Diode Full-Wave Rectifier



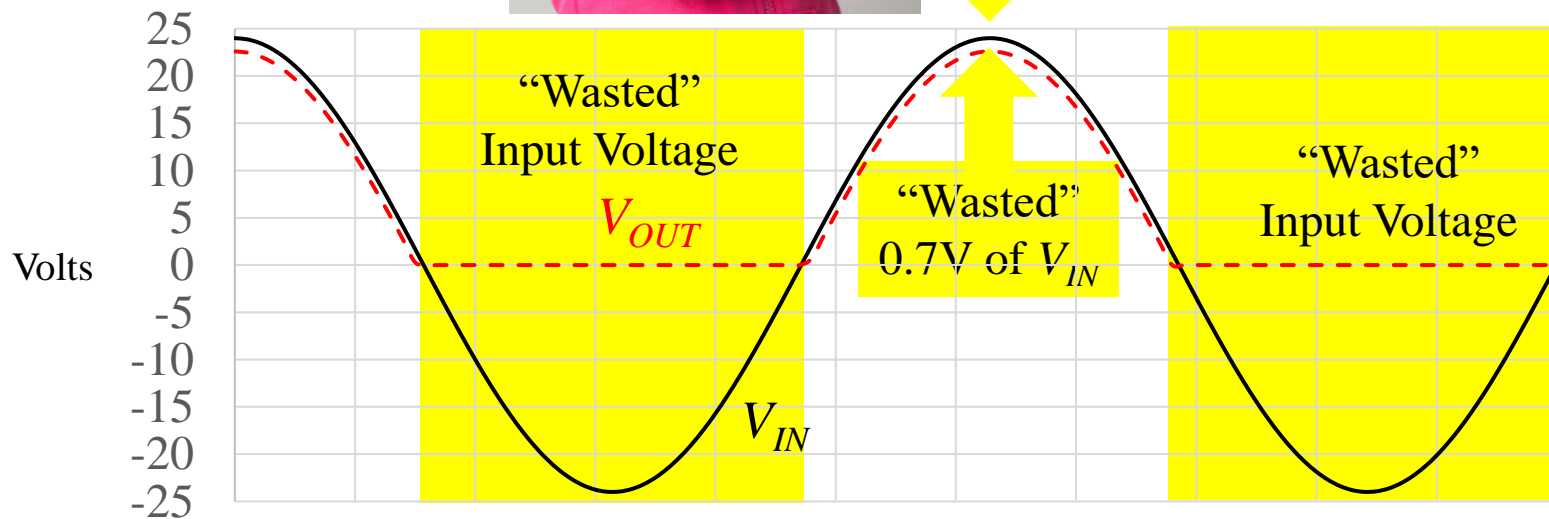
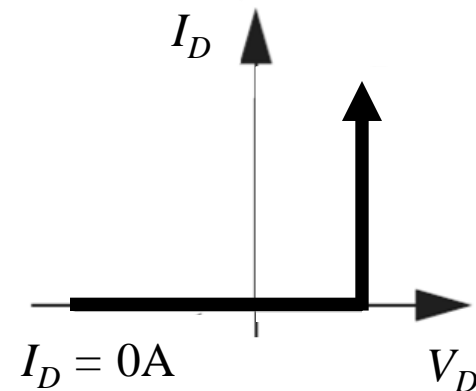
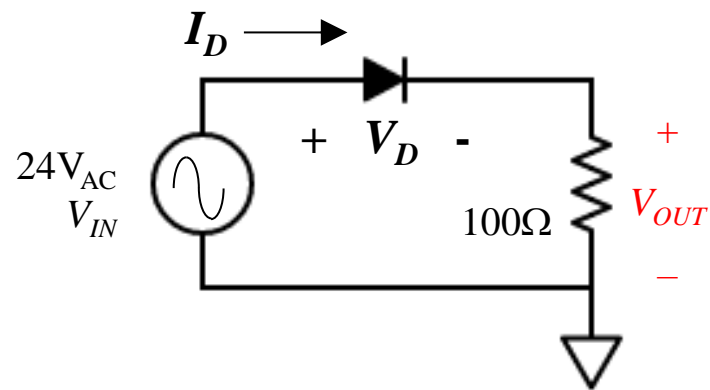
Diode Full-Wave Rectifier



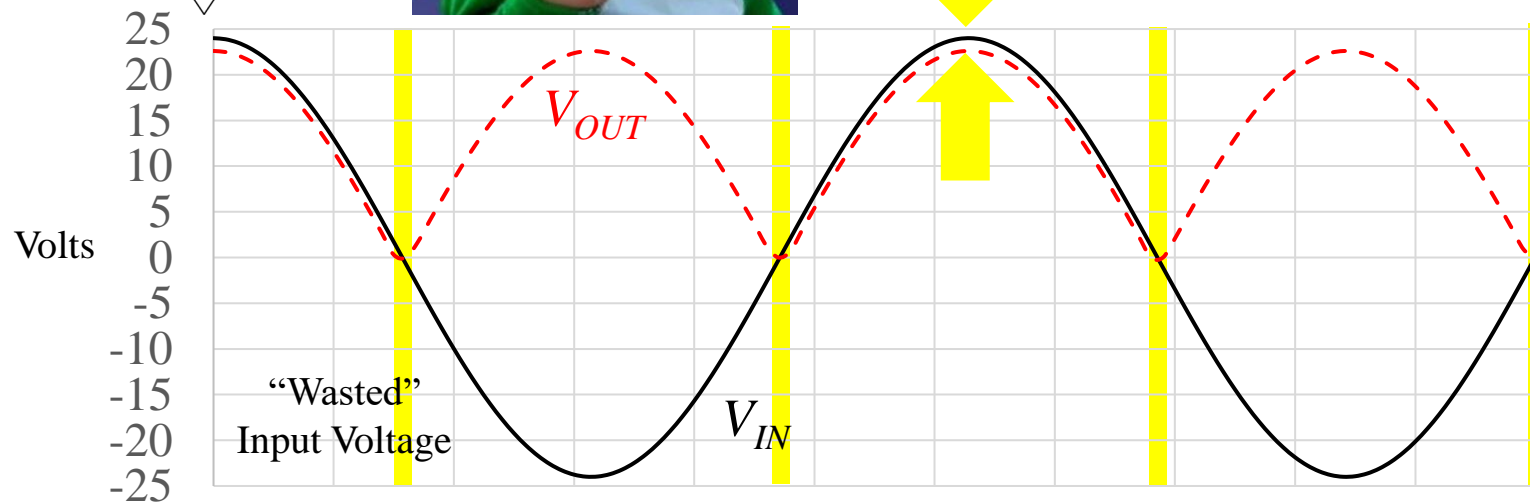
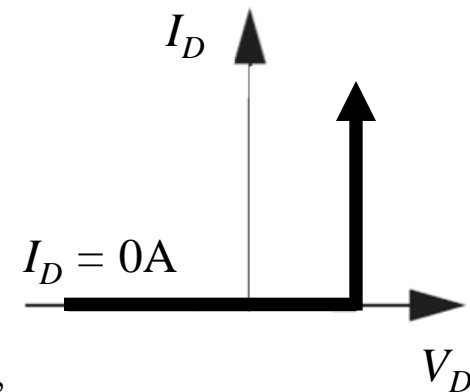
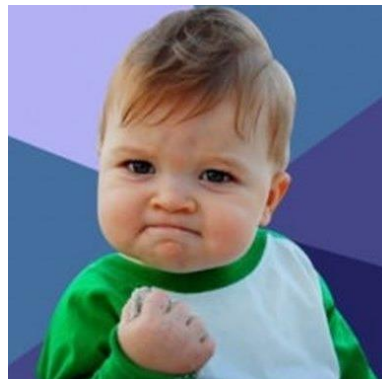
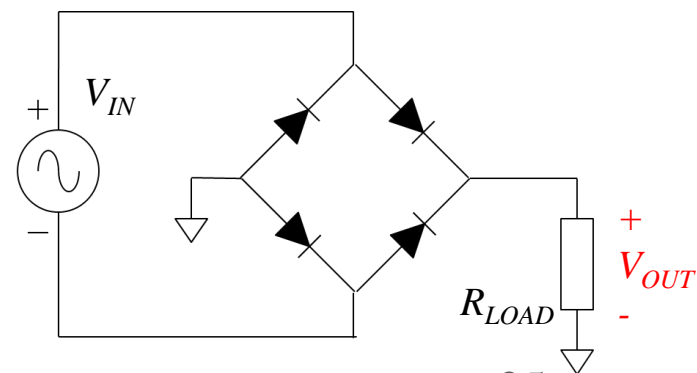
Diode Full-Wave Rectifier



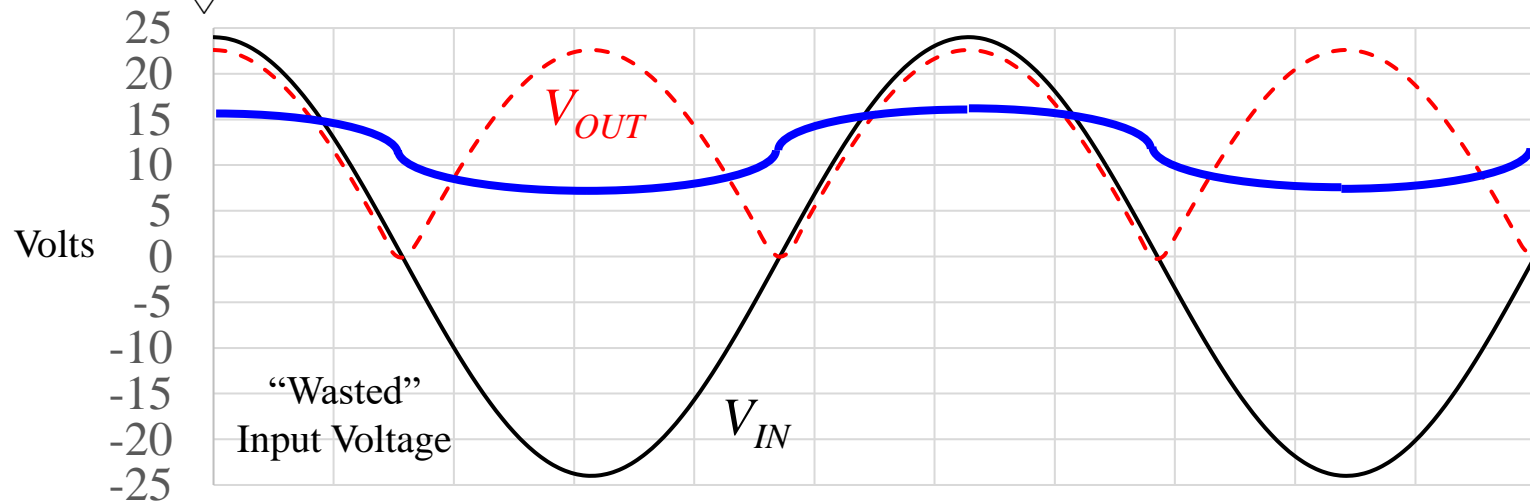
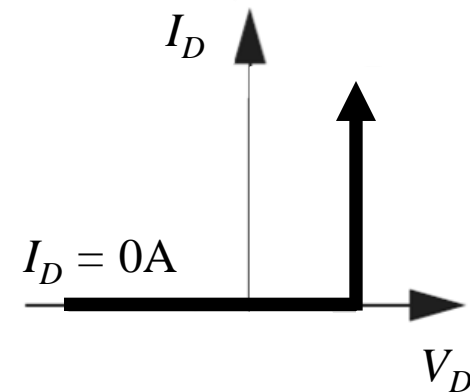
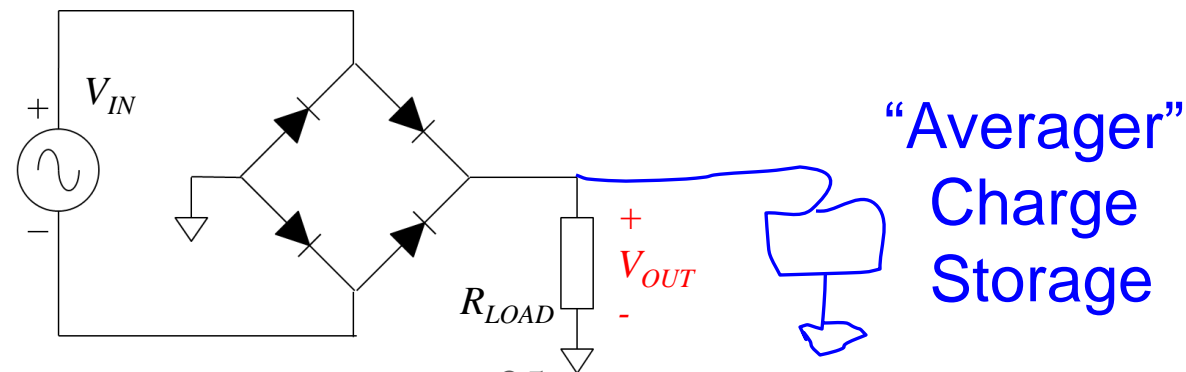
Diode Half-Wave Rectifier (Knee Model)



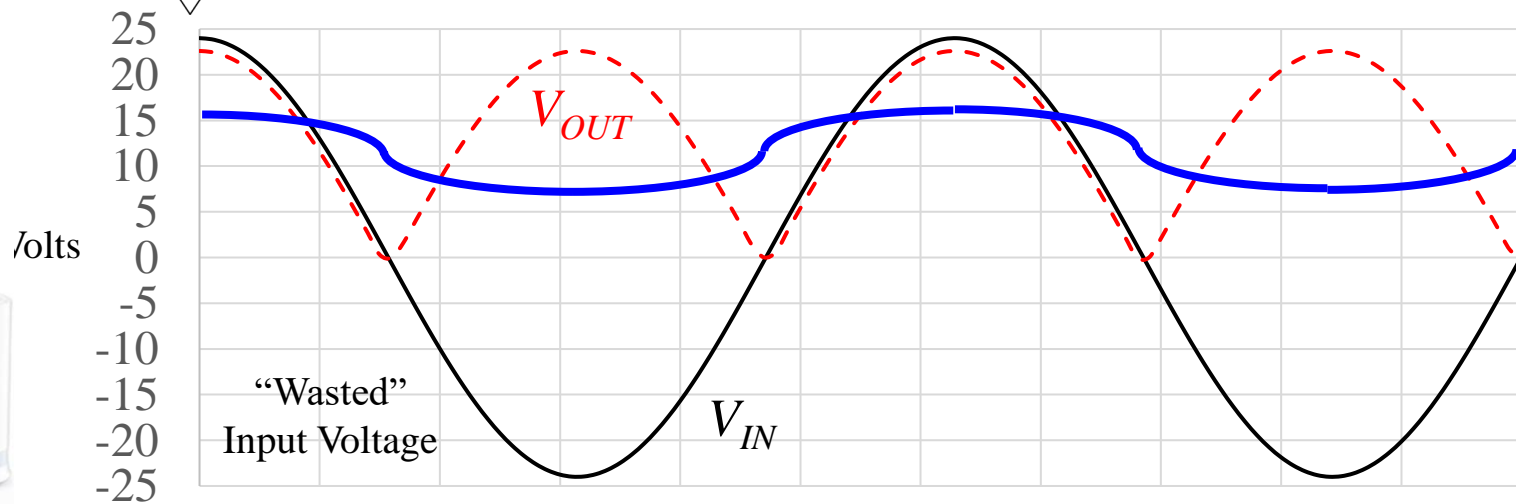
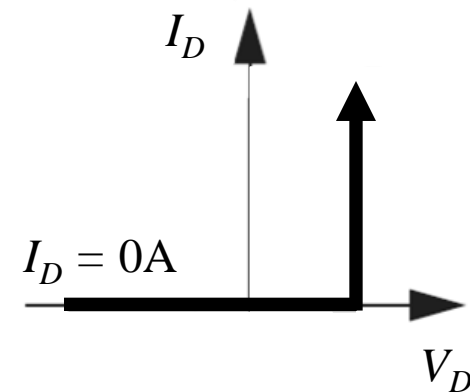
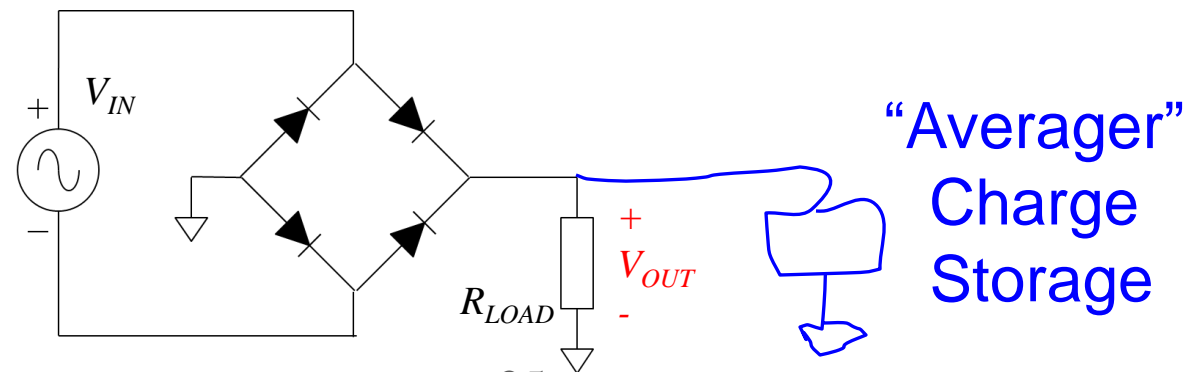
Diode Full-Wave Rectifier



Diode Full-Wave Rectifier

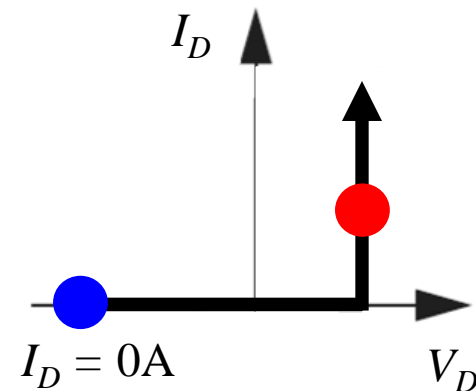
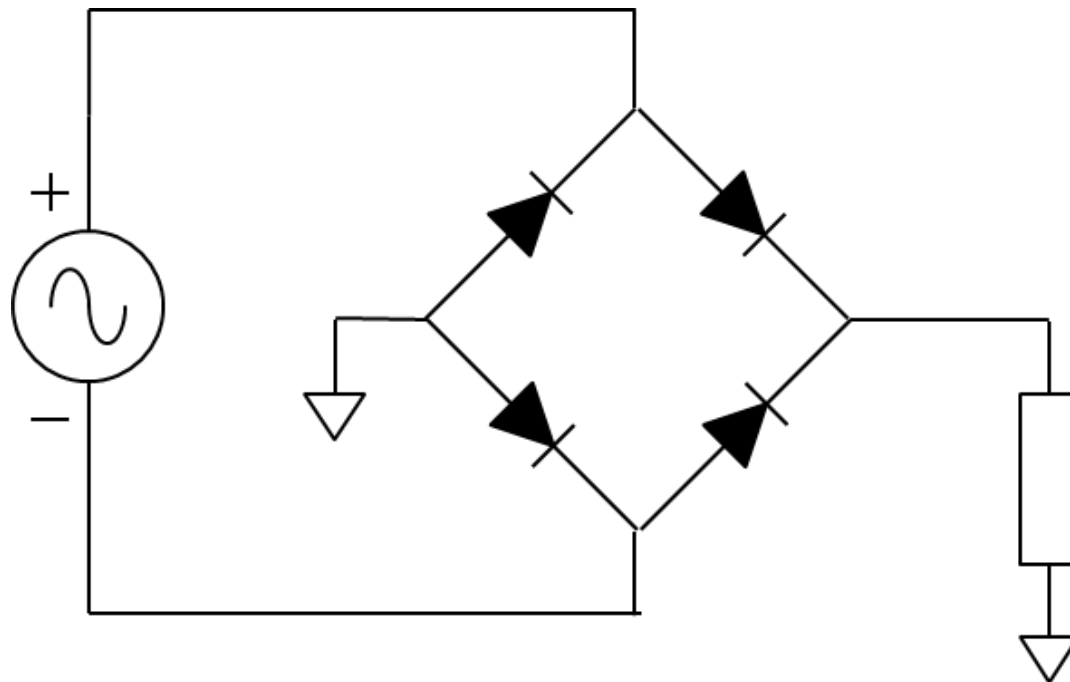


Diode Full-Wave Rectifier



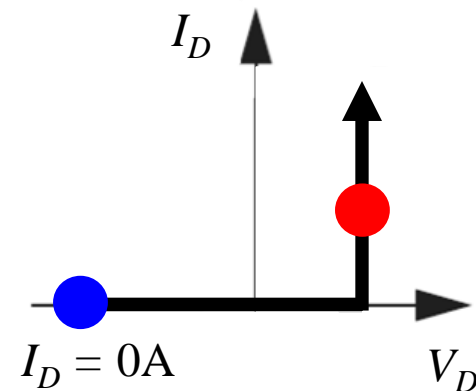
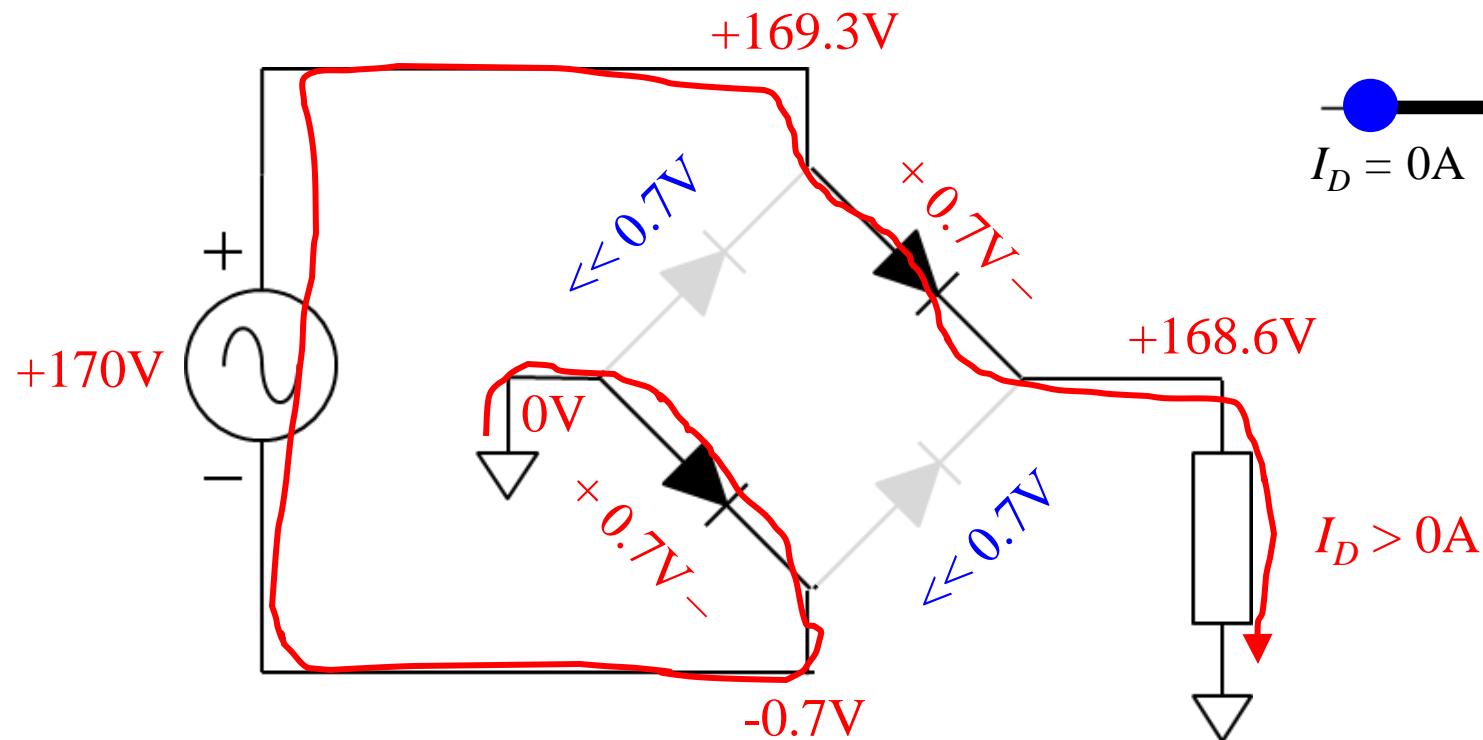
Diode Full-Wave Rectifier

- Two diodes conduct, two diodes act as open circuits



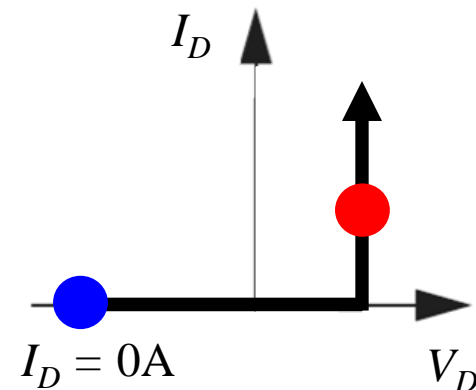
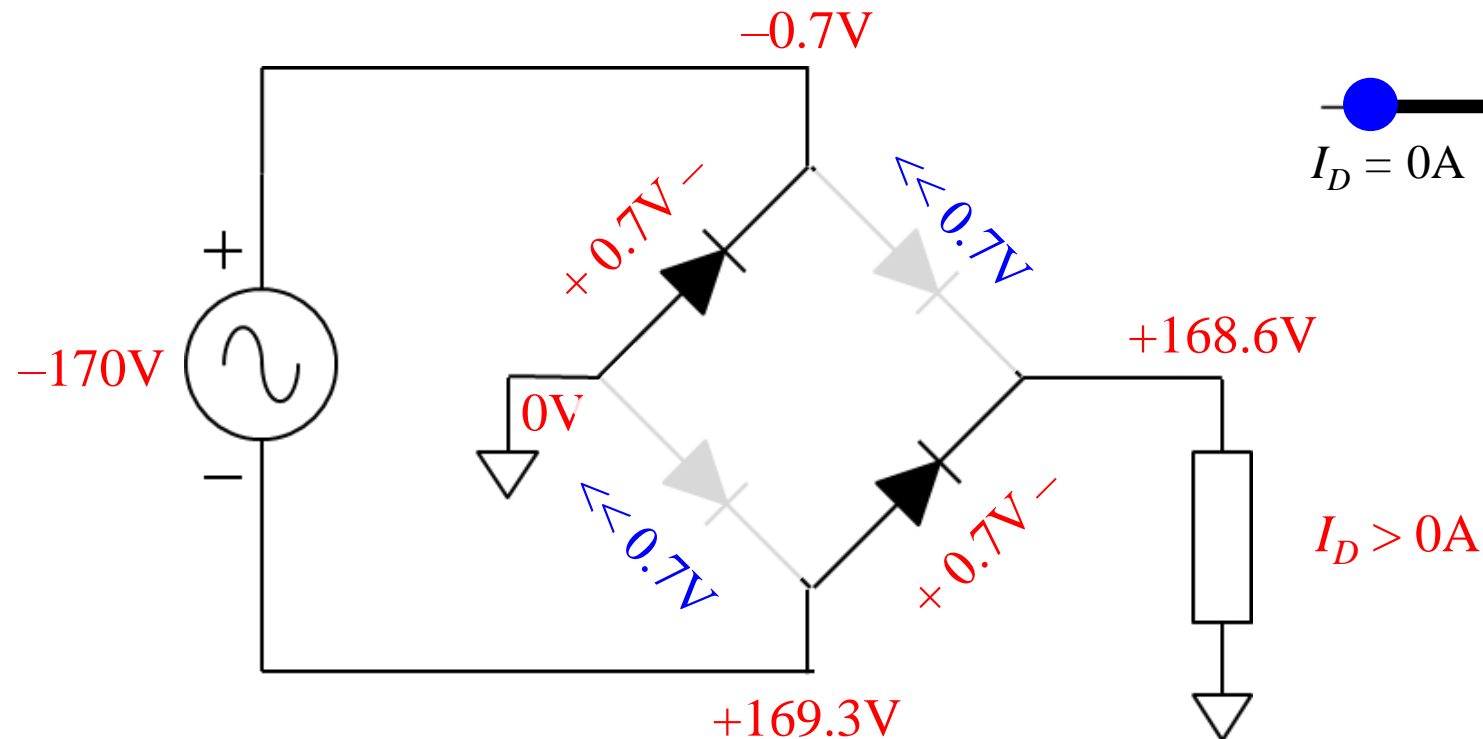
Diode Full-Wave Rectifier

- Two diodes conduct, two diodes act as open circuits



Diode Full-Wave Rectifier

- Two diodes conduct, two diodes act as open circuits



What Do You Need to Do Next?

1. Take the **Lecture 4 Quiz** on canvas!
2. Check out Piazza and Gradescope

The screenshot displays the Canvas LMS interface for Carnegie Mellon University. The left sidebar contains navigation links: Account, Dashboard, Courses, Calendar, Inbox, History, and Studio. The main content area shows the course path '18100 > Quizzes' and a search bar labeled 'Search for Quiz'. A list of 'Assignment Quizzes' is shown, including Quiz 01 through Quiz 04, each with availability and due dates.

Quiz	Available until	Due	Pts	Questions
Quiz 01	May 7 at 10pm	Jan 14 at 10pm	3 pts	3 Questions
Quiz 02	May 7 at 10pm	Jan 16 at 10pm	3 pts	3 Questions
Quiz 03	May 7 at 10pm	Jan 24 at 10pm	3 pts	3 Questions
Quiz 04	May 7 at 10pm	Jan 28 at 10pm	3 pts	3 Questions