VOLTAGE REGULATOR

POWER SUPPLY BUILDING BLOCKS

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TOPIC OUTLINE

Zener Diode

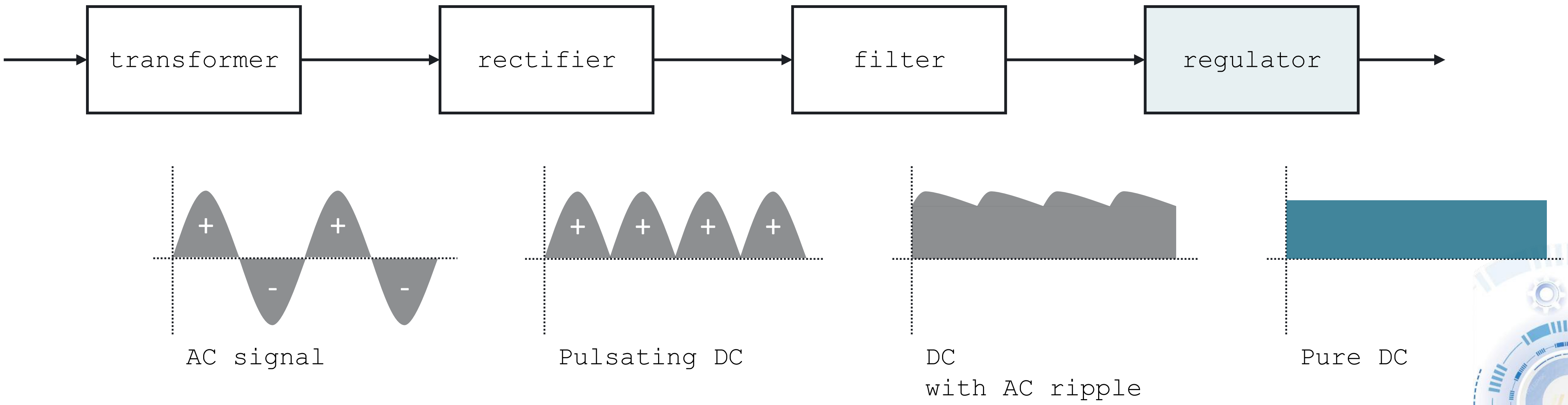
Linear Voltage Regulator IC

ZENER DIODE

VOLTAGE REGULATOR

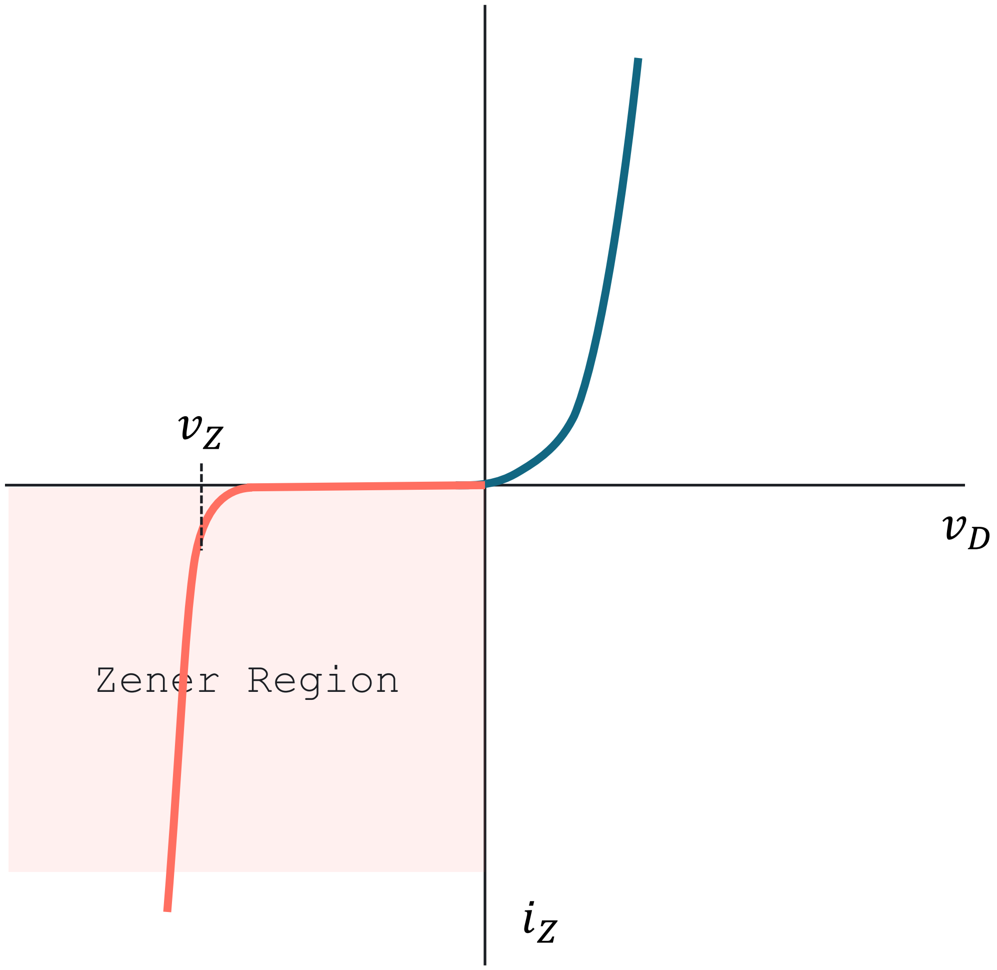
Voltage regulator provides a **constant** DC output voltage by adjusting their internal resistance to compensate for input voltage or load variations.

Power Supply Block Diagram



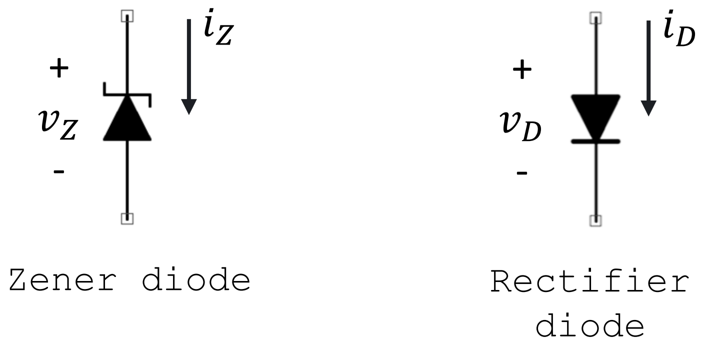
ZENER DIODE

Characteristic Curve



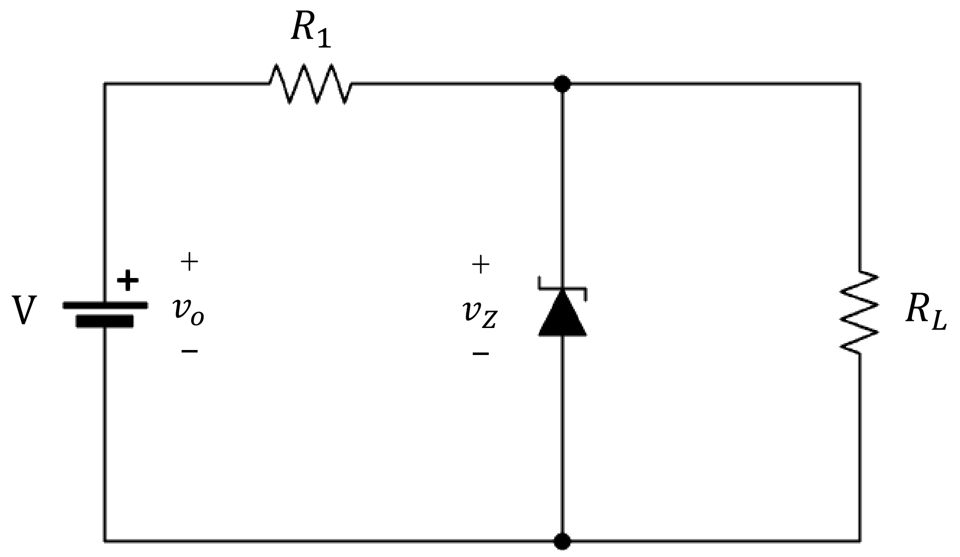
Zener diode operates in the **reverse bias** region, where it allows current to flow once the reverse voltage reaches a specific value known as the **Zener voltage** (v_Z).

Conduction direction



STATE OF ZENER DIODE

Determine the state of Zener diode by **removing** it from the network and calculating the voltage across the resulting open circuit.



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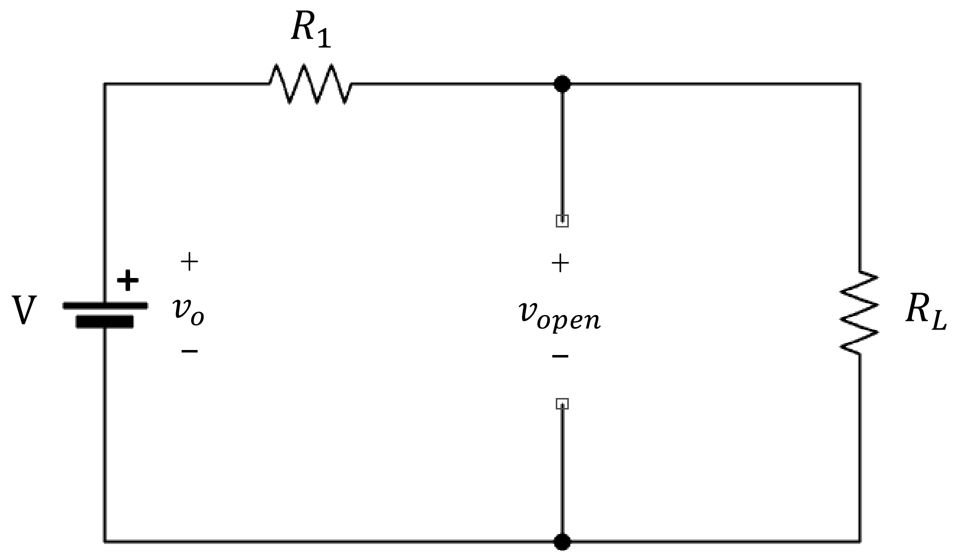
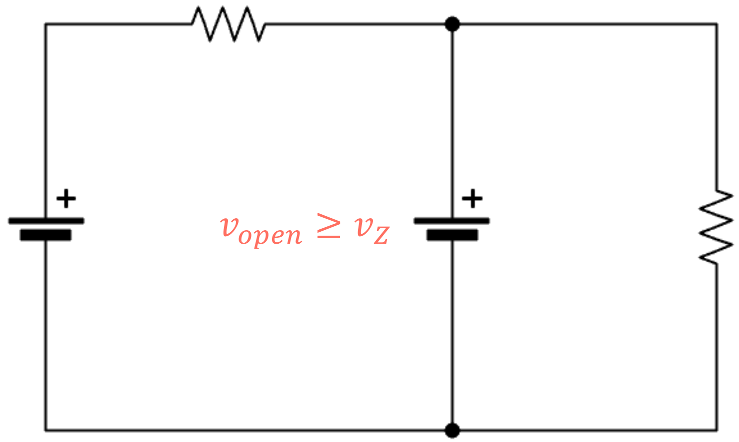
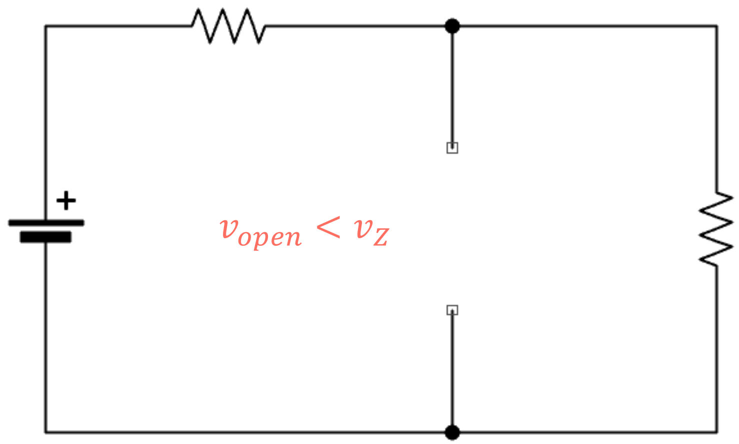


$$v_{open} = v_o \frac{R_L}{R_1 + R_L}$$

"ON" state equivalent circuit



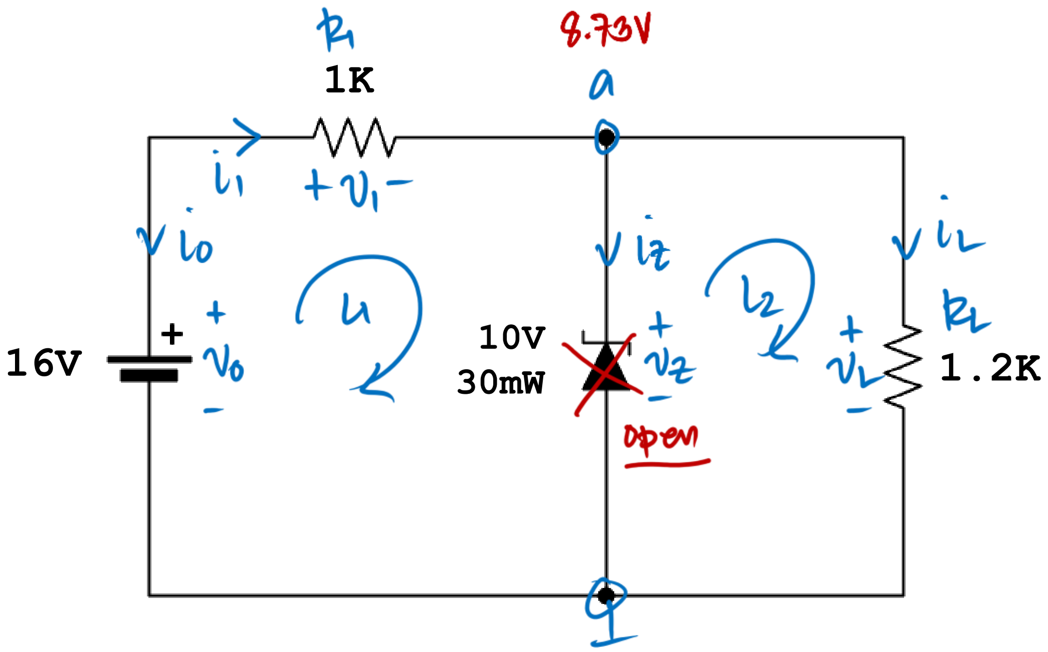
"OFF" state equivalent circuit



EXERCISE

For the given circuit, determine the voltage across the load, the voltage across $1K\Omega$ resistor, the current flowing through the Zener diode, and the power dissipated by the Zener diode.

v_L v_1 i_Z P_Z



Solution

For open zener

$$v_Z(\text{open}) = v_o \frac{R_L}{R_1 + R_L}$$

$$v_Z(\text{open}) = 16 \frac{1.2K}{1K + 1.2K}$$

$$v_Z(\text{open}) = 8.73\text{ V}$$

Since $8.73\text{V} < 10\text{V}$, Zener is OFF

$$v_L = v_a = v_Z(\text{open})$$

$$\boxed{v_L = 8.73\text{V}}$$

ans

EXERCISE

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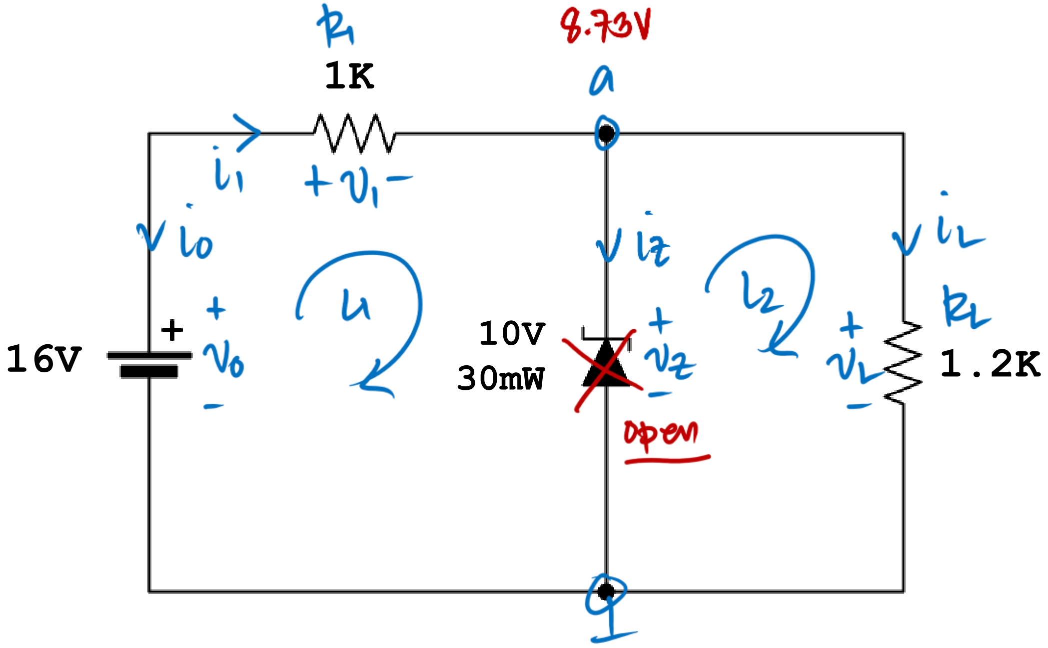


Solution

$$v_1 = v_0 - v_a$$

$$v_1 = 16 - 8.73$$

$$\boxed{v_1 = 7.27\,V}$$

ans

$$\boxed{i_Z = 0}$$

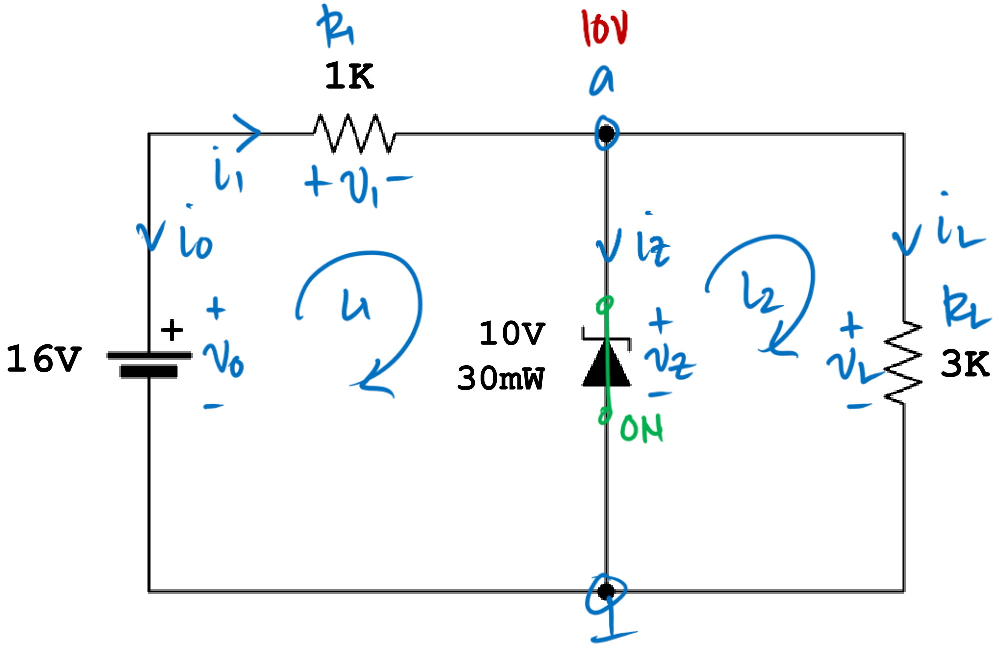
ans

$$\boxed{P_Z = 0}$$

ans

EXERCISE

In reference to the previous problem, assume the load resistance is changed to $3K\Omega$.



Solution

For open zener

$$v_z(\text{open}) = v_o \frac{R_L}{R_1 + R_L}$$

$$v_z(\text{open}) = 16 \frac{3K}{1K + 3K}$$

$$v_z(\text{open}) = 12V$$

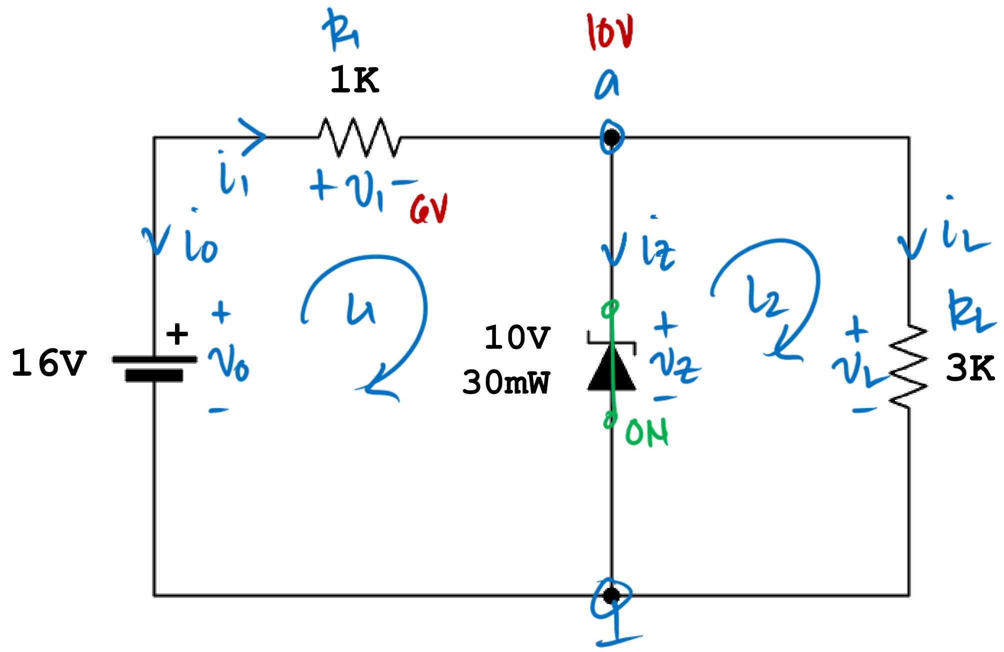
since $12V \geq 10V$, zener is ON

$$\therefore \boxed{v_L = 10V}$$

ans

EXERCISE

In reference to the previous problem, assume the load resistance is changed to $3K\Omega$.



Solution

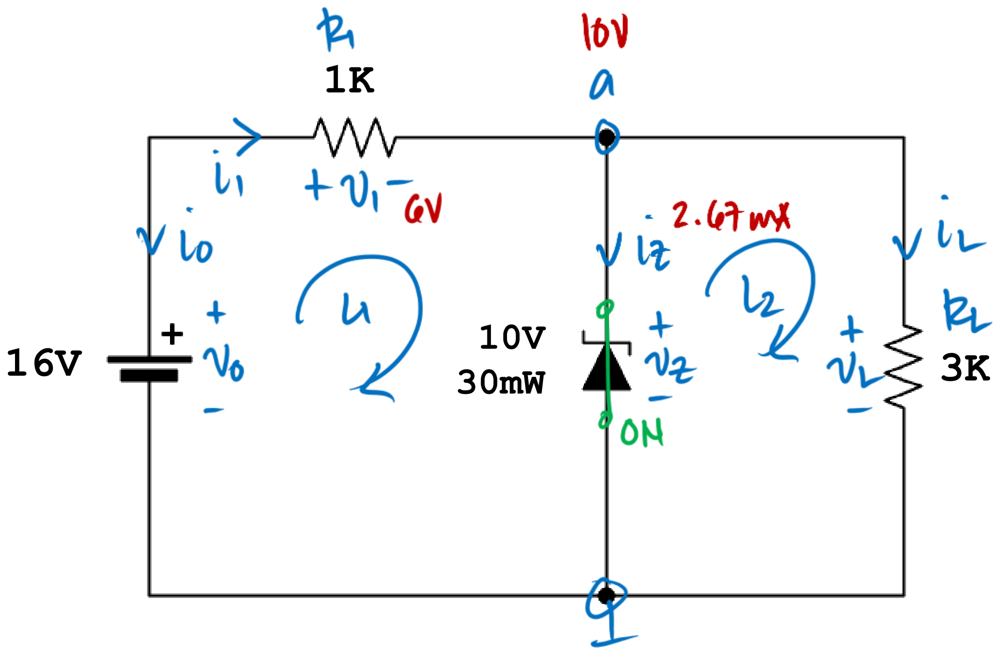
$v_1 = v_0 - v_a$

$v_1 = 16 - 10$

$\boxed{v_1 = 6V}$ ans

EXERCISE

In reference to the previous problem, assume the load resistance is changed to $3K\Omega$.



Solution

KCL @ a

$$-i_1 + i_z + i_L = 0$$

$$i_z = i_1 - i_L$$

$$i_z = \frac{v_1}{R_1} - \frac{v_L}{R_L}$$

$$i_z = \frac{6}{1K} - \frac{10}{3K}$$

$$\boxed{i_z = 2.67\,mA}$$

ans

$$P_z = i_z v_z$$

$$P_z = 2.67m(10)$$

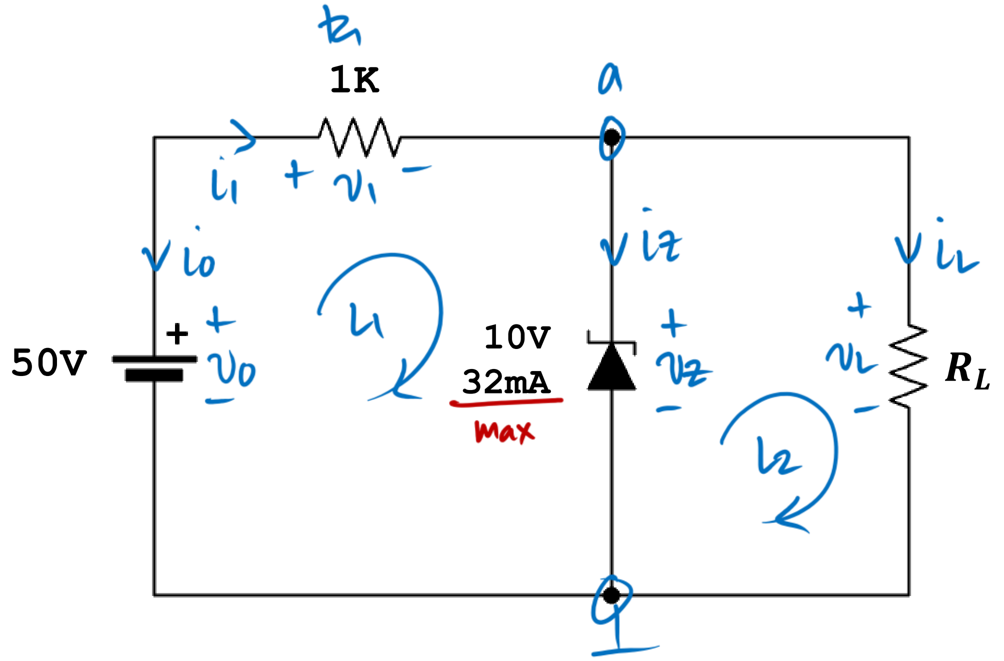
$$\boxed{P_z = 26.7\,mW}$$

ans

EXERCISE

For the given circuit, determine the range of load resistance and load current that will ensure the load voltage remains regulated at 10V.

min, max



Solution

For min R_L

$$v_{Z(open)} = v_0 \frac{R_L}{R_1 + R_L}$$

$$\frac{v_{Z(open)}}{v_0} = \frac{R_L}{R_1 + R_L} \rightarrow \frac{v_0}{v_{Z(open)}} = \frac{R_1 + \cancel{R_L}}{\cancel{R_L}}$$

$$\frac{v_0}{v_{Z(open)}} - 1 = \frac{R_1}{R_L}$$

$$R_L = \frac{R_1}{\frac{v_0}{v_{Z(open)}} - 1} \rightarrow R_L = \frac{1K}{\frac{50}{10} - 1}$$

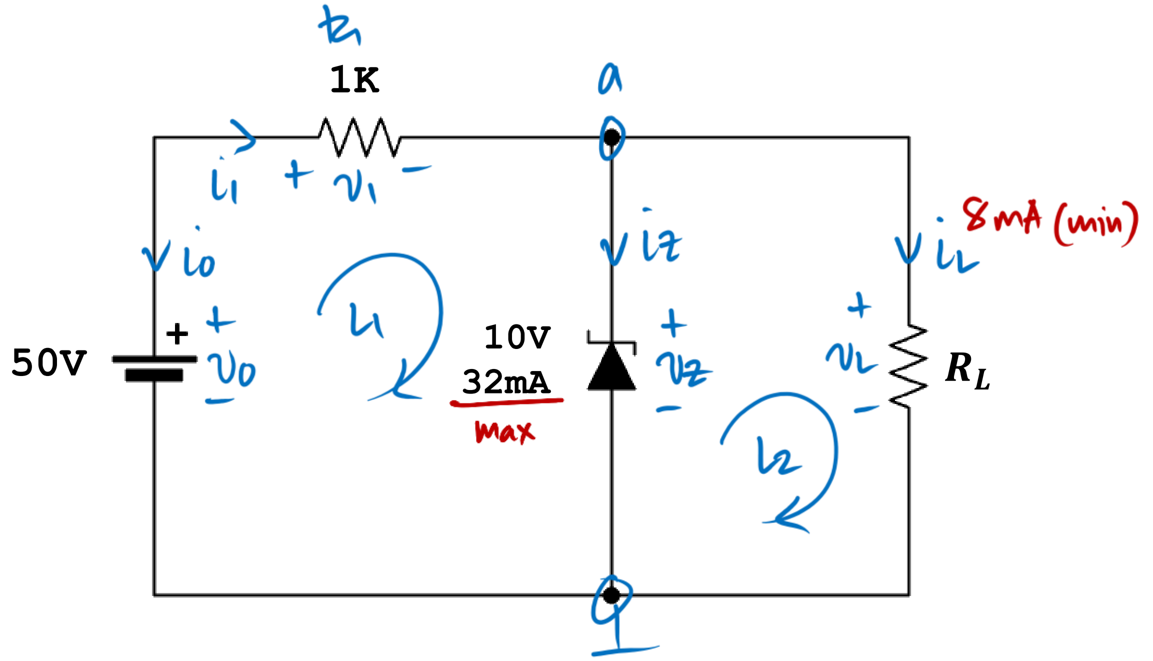
$$\boxed{R_{L(min)} = 250\ \Omega}$$

ans

EXERCISE

min, max

For the given circuit, determine the range of load resistance and load current that will ensure the load voltage remains regulated at 10V.



Solution

For max R_L

KCL @ a

$$-i_1 + i_Z + i_L = 0$$

$$i_L = i_1 - i_Z$$

$$i_L = \frac{v_1}{R_1} - i_Z$$

$$i_L = \frac{v_0 - v_a}{R_1} - \cancel{i_Z} \rightarrow \text{max}$$

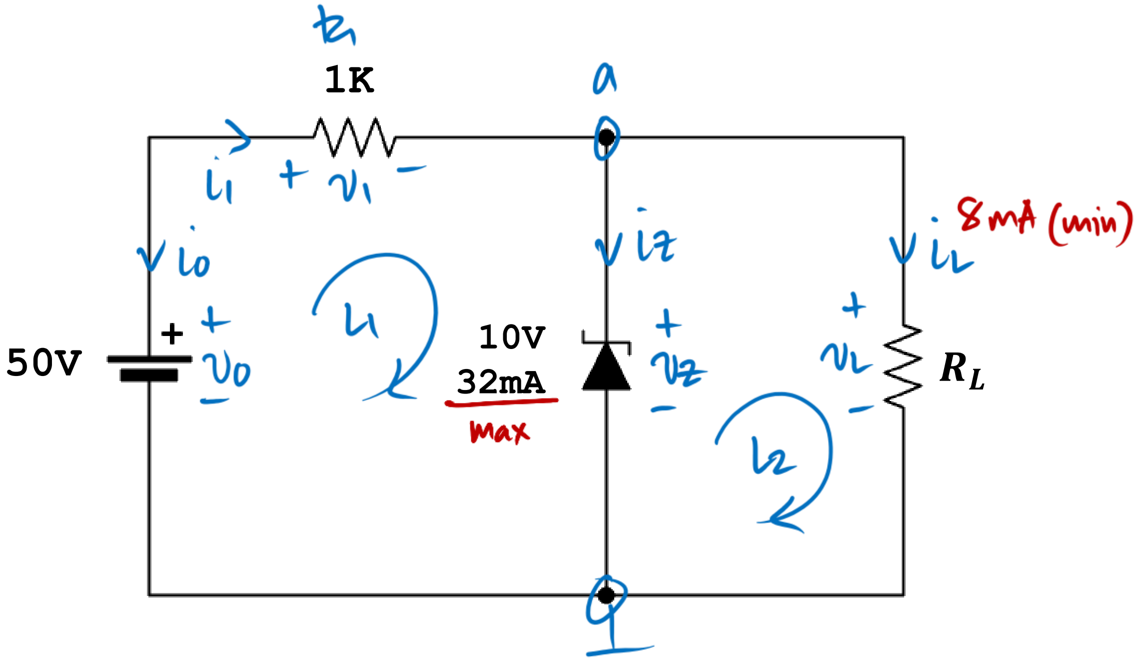
$$i_L = \frac{50 - 10}{1k} - 32m$$

$$i_L = 8mA$$

EXERCISE

For the given circuit, determine the range of load resistance and load current that will ensure the load voltage remains regulated at 10V.

min, max



Solution

For max R_L

$$R_L = \frac{v_L}{i_L}$$

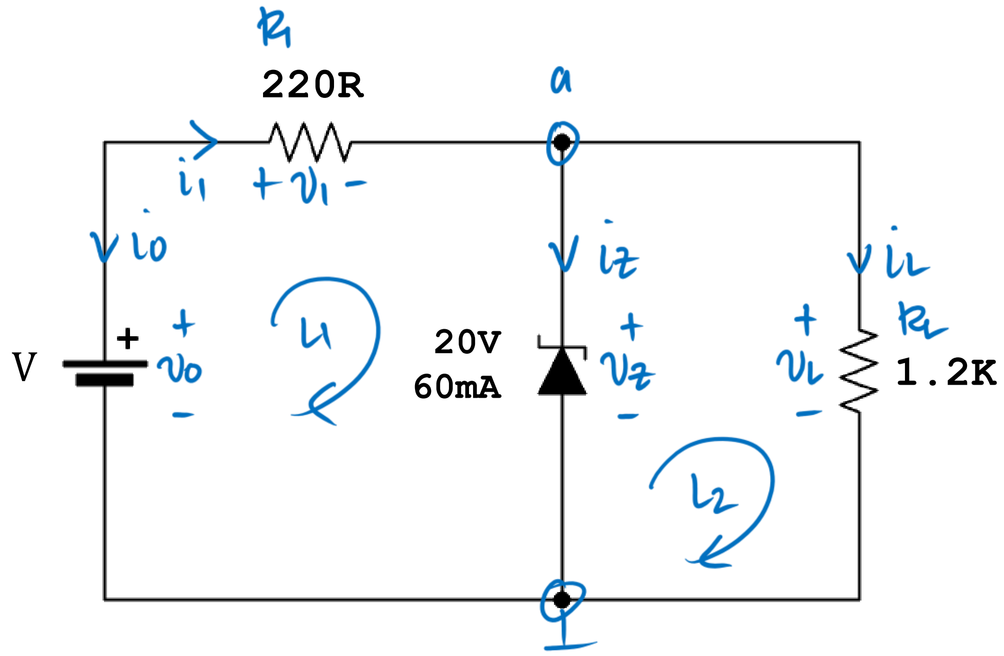
$$R_L = \frac{10}{8m}$$

$$\boxed{R_{L(max)} = 1.25\ k\Omega}$$

ans

EXERCISE

Determine the range of input (source) voltage for which the Zener diode remains in its conducting state in the given circuit.



Solution

For min vo

$$v_{z(open)} = v_o \frac{R_L}{R_1 + R_L}$$

$$v_o = \frac{v_{z(open)}(R_1 + R_L)}{R_L}$$

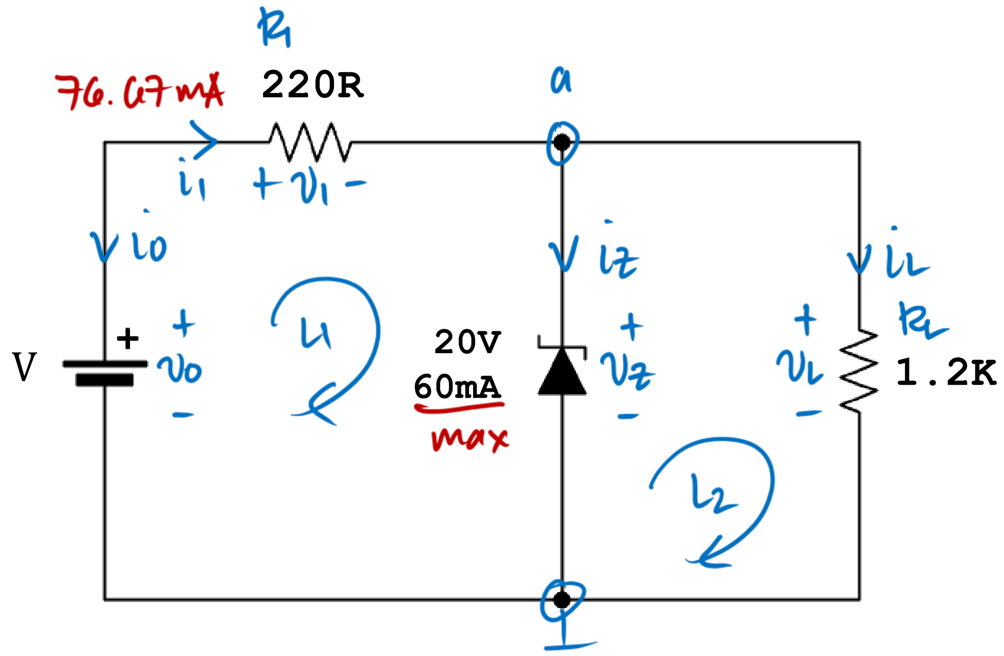
$$v_o = \frac{20(220 + 1.2K)}{1.2K}$$

$$\boxed{v_{o(min)} = 23.67\,V}$$

ans

EXERCISE

Determine the range of input (source) voltage for which the Zener diode remains in its conducting state in the given circuit.



Solution

For max v_0

KCL @ a

$$-i_1 + i_z + i_L = 0$$

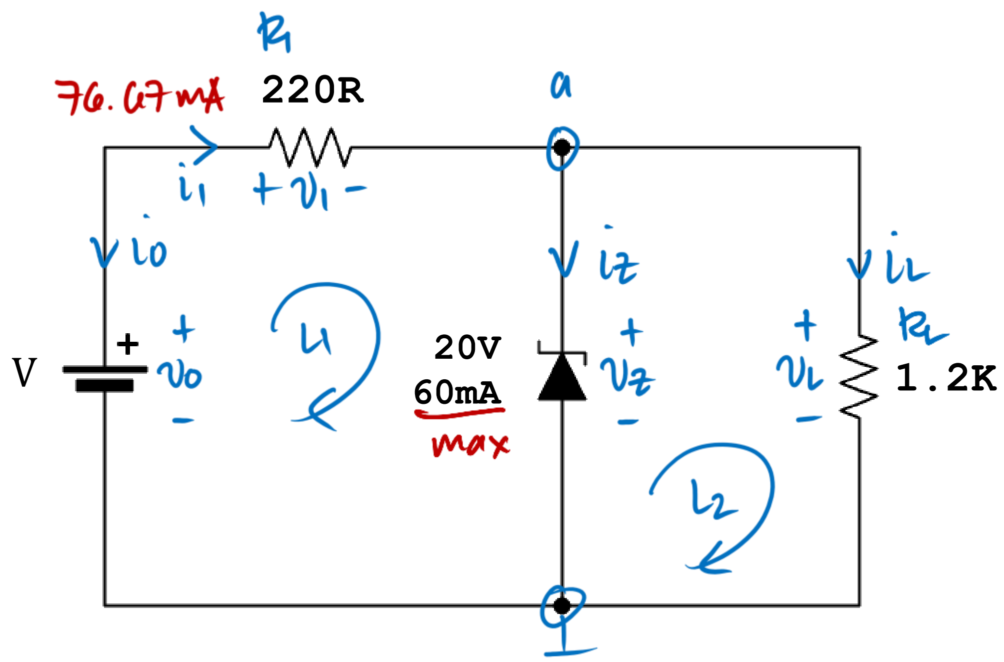
$$i_1 = \overset{max}{i_z} + i_L \quad v_L/R_L$$

$$i_1 = 60m + \frac{20}{1.2K}$$

$$i_1 = 76.67\,mA$$

EXERCISE

Determine the range of input (source) voltage for which the Zener diode remains in its conducting state in the given circuit.



Solution

For max Vo

KVL @ L1

$$-v_o + v_1 + v_z = 0$$

$$v_o = v_1 + v_z$$

$$v_o = i_1 R_1 + v_z$$

$$v_o = 76.67m(220) + 20$$

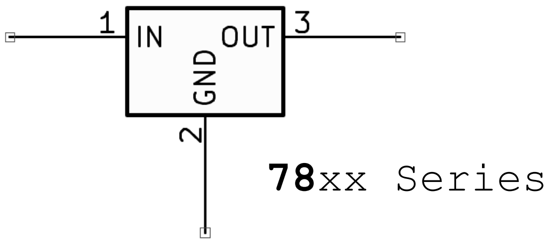
$$\boxed{v_{o(max)} = 36.87\,V}$$

ans

LINEAR VOLTAGE REGULATOR IC

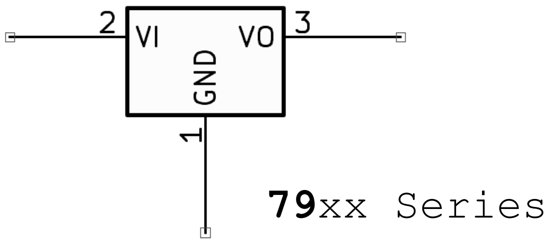
LINEAR VOLTAGE REGULATOR

Positive voltage regulator



A **linear voltage regulator** compares the output to a reference voltage and adjusts a pass transistor (BJT or MOSFET) to maintain a steady output.

Negative voltage regulator



DROPOUT VOLTAGE

The **dropout voltage**, typically 2V, is the **minimum** amount of voltage across input–output terminals that must be maintained if the IC is to operate as regulator.

Positive voltage regulator

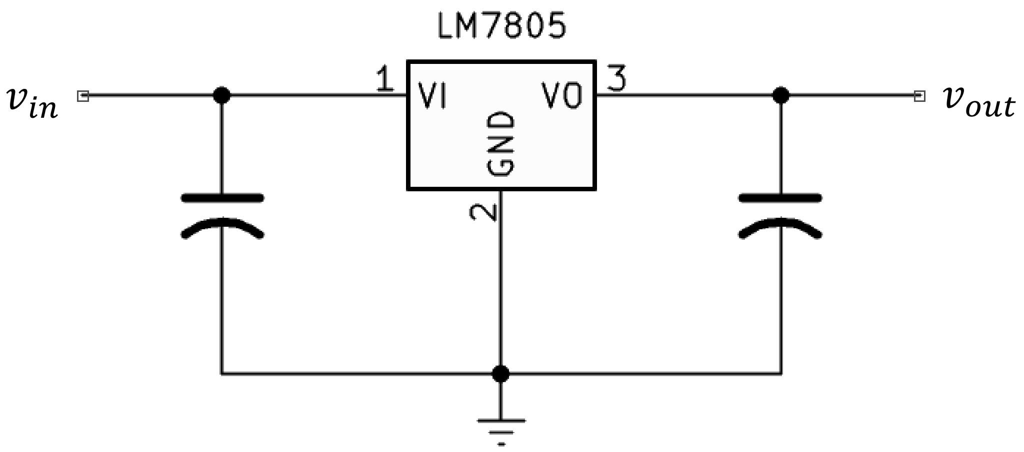
IC	Output Voltage (V)	Minimum Input Voltage (V)
7805	+5	7.3
7810	+10	12.5
7812	+12	14.6

Negative voltage regulator

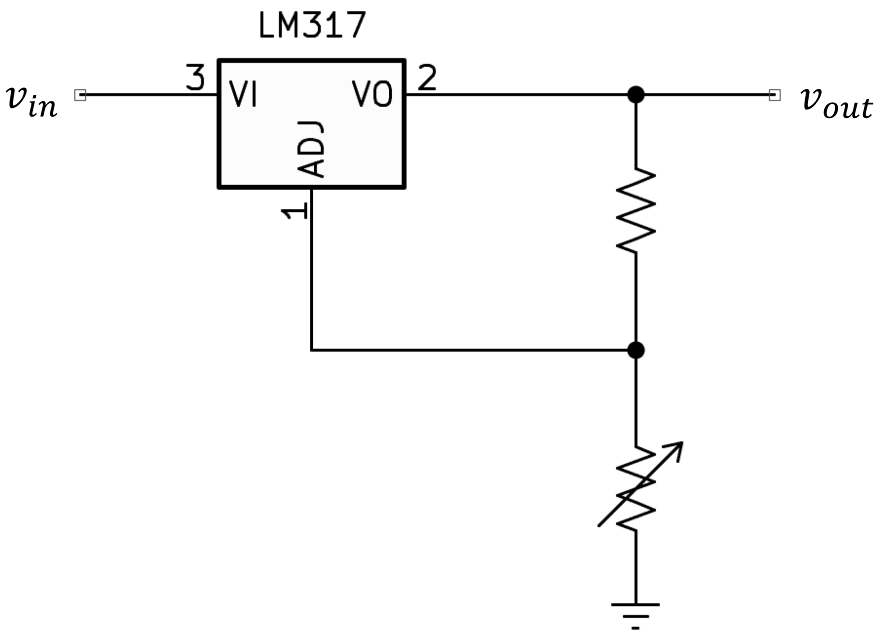
IC	Output Voltage (V)	Minimum Input Voltage (V)
7906	-6	-8.4
7909	-9	-11.5
7915	-15	-17.7

VOLTAGE REGULATOR CONNECTION

Fixed Voltage Regulator



Adjustable Voltage Regulator



LABORATORY