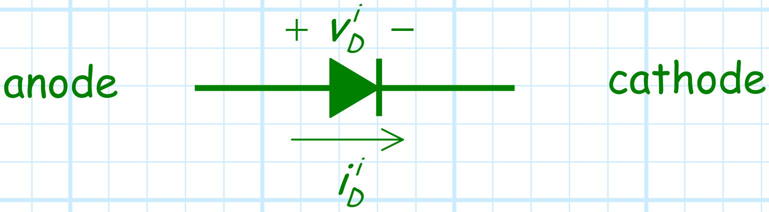
3.1 The Ideal Diode (pp.139-141)

Diodes: The most fundamental non-linear circuit element

A. The Ideal Diode Symbol



Note:

1. Device is not symmetric!

2. Positive current defined as flowing from anode to cathode.

3. Voltage across diode defined as positive when anode voltage > cathode voltage.

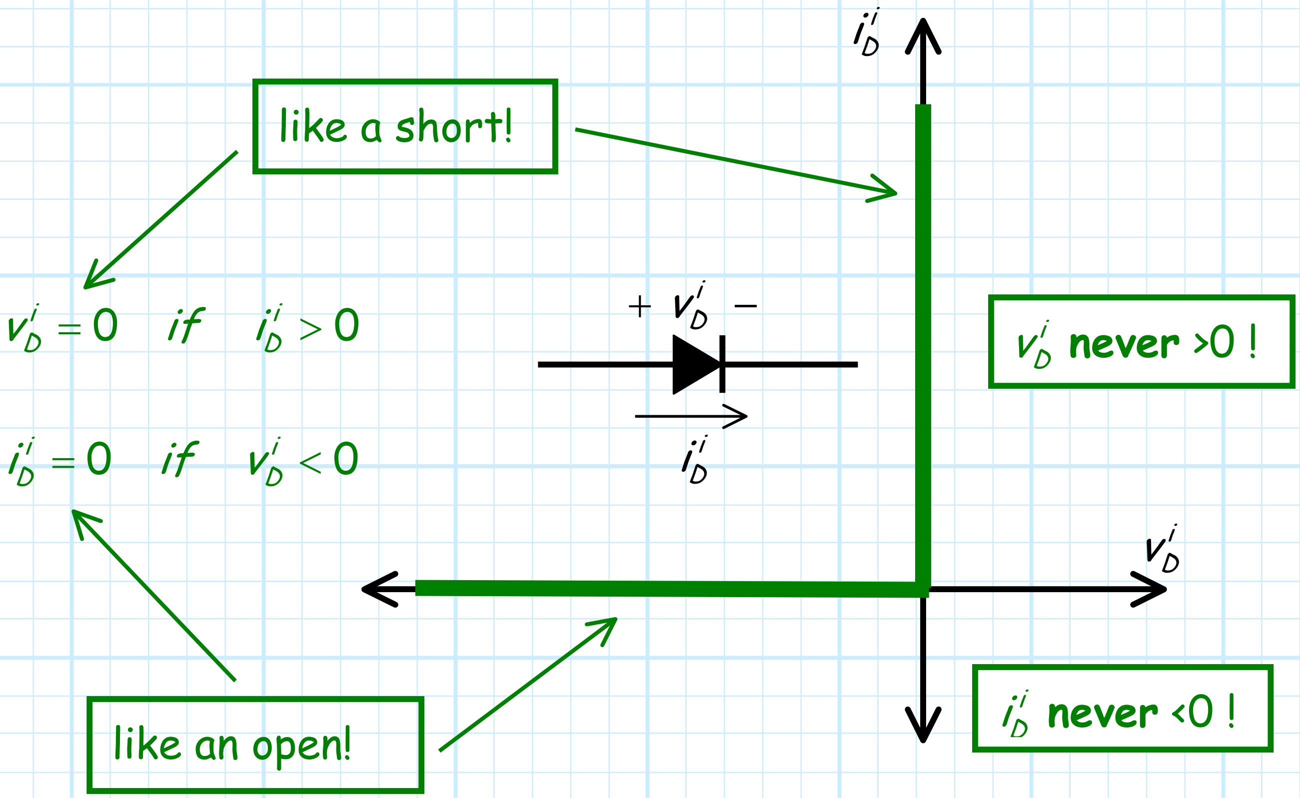
B. Ideal Diode Behavior

The ideal diode → a close approx. of a physical diode.

First, let's recall linear device behavior!

HO: Linear Device Behavior

For an ideal diode:



$$v_D^i = 0 \quad if \quad i_D^i > 0$$

$$i_D^i = 0 \quad if \quad v_D^i < 0$$

The Ideal Diode is <u>non-linear</u>!

C. Diode Bias Regions

Ideal diode operates in one of two states:

1) Forward Biased → "on" or "active"

$$v_D^i = 0 \quad if \quad i_D^i > 0$$

i.e., acts as a short, IF current is positive.

2) Reverse Biased → "off" or "inactive"

$$i_D^i = 0 \quad if \quad v_D^i < 0$$

i.e., acts as a open, IF voltage is negative.

Note: No power is dissipated in either mode!

$$\rightarrow \quad P_D^i = v_D^i \, i_D^i = 0 \quad \text{always!}$$

HO The Ideal Diode

HO Diode Mechanical Analogy

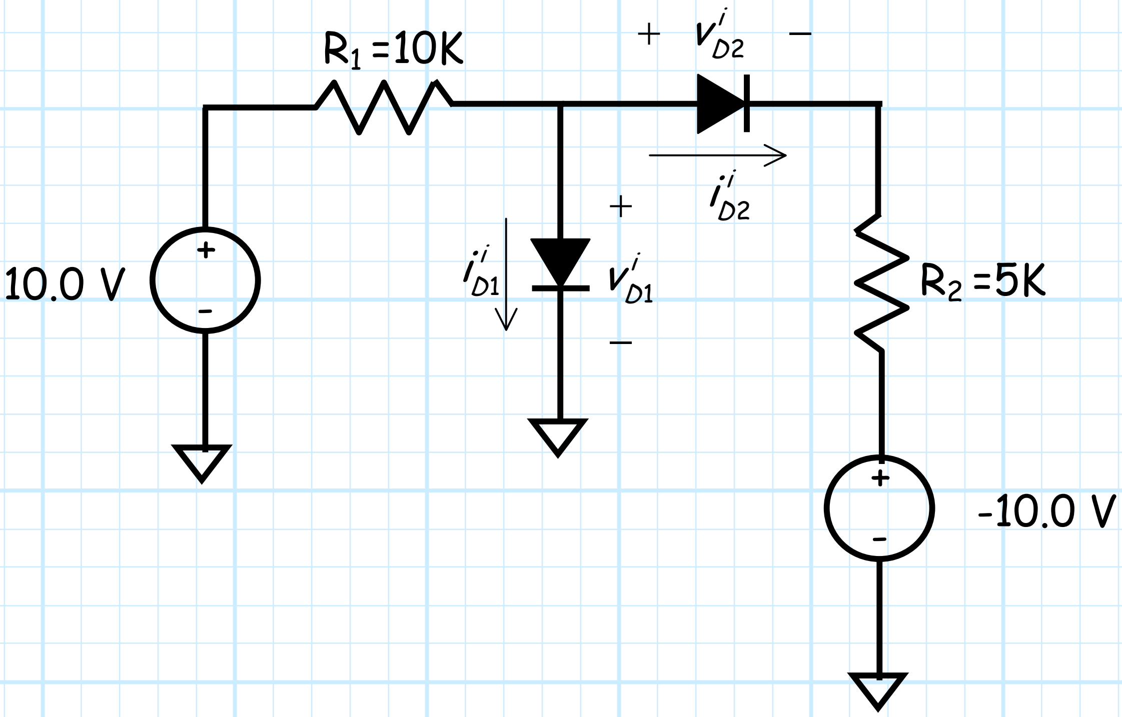
Q: What turns a diode "on" or "off"?

A: The circuit attached to it!

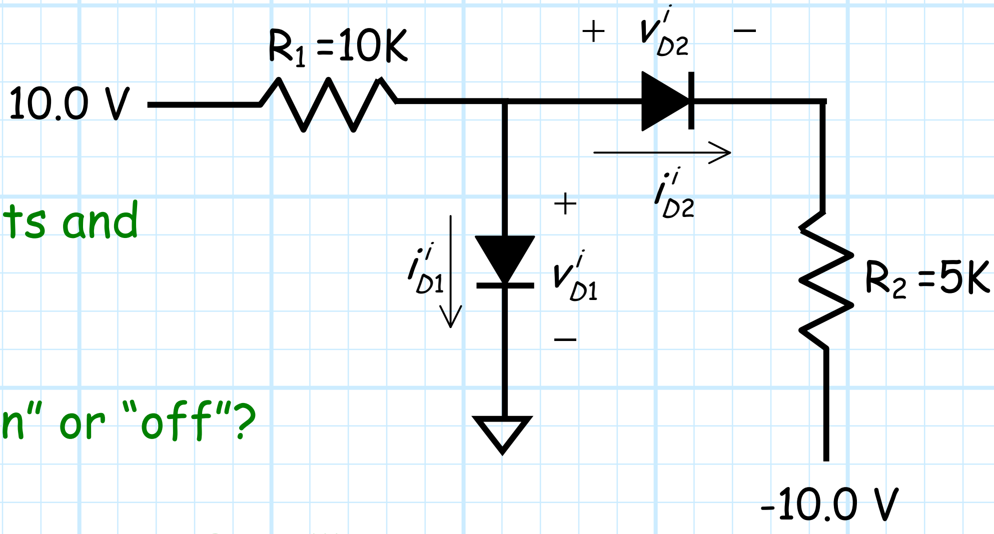
Problem: It is very difficult to determine what the circuit is trying to do!

D. Ideal Diode Circuit Analysis

Consider this ideal diode circuit:



Which we more compactly write as:



What are currents and Voltages ?

Q: Are diodes "on" or "off"?

A: Can't tell! We must GUESS !!!

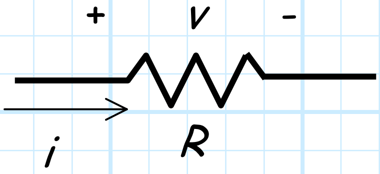
HO: The Ideal Diode Circuit Analysis Guide

HO: Example: A Simple Ideal Diode Circuit

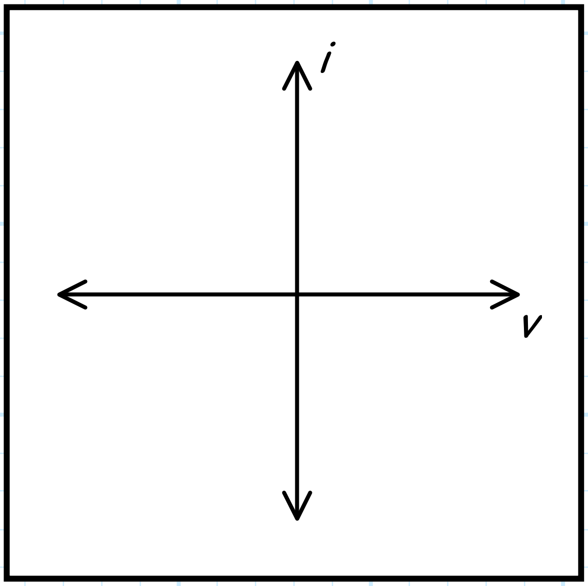
HO: Example: Analysis of a Complex Diode Circuit

Linear Device Behavior

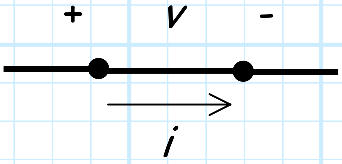
1) Recall the circuit behavior of a **resistor**:



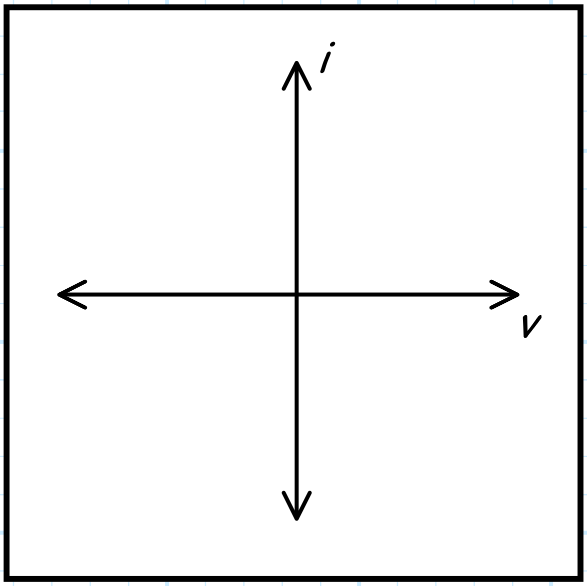
$$\boxed{i = \frac{v}{R}}$$



2) If R=0, then we have a **short** circuit:



$$\boxed{v = 0}$$



Linear Device Behavior

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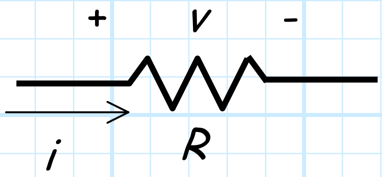
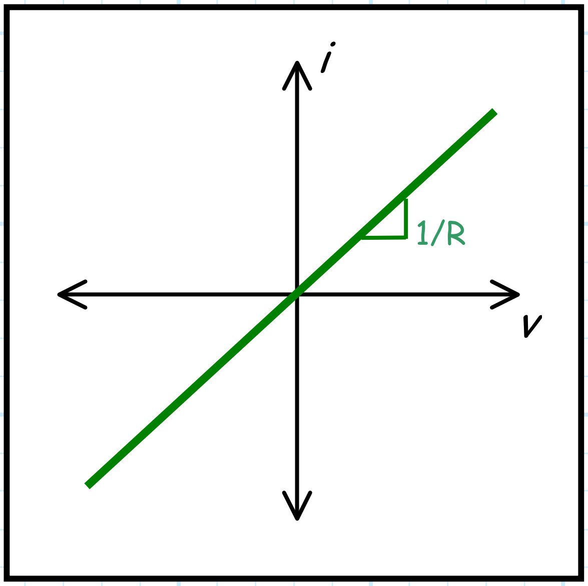


$$\boxed{i = \frac{v}{R}}$$



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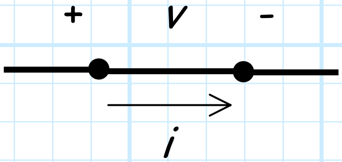
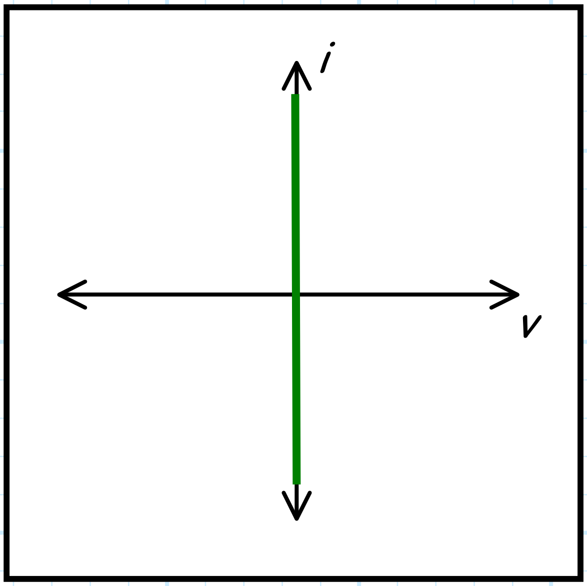
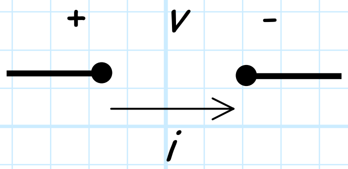


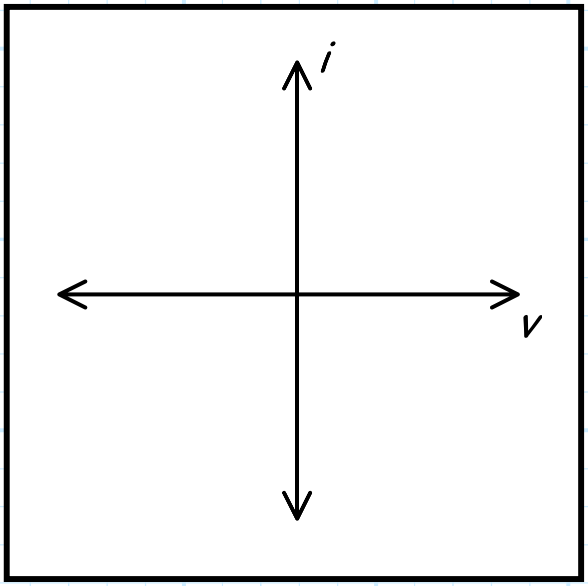
$$\boxed{v = 0}$$



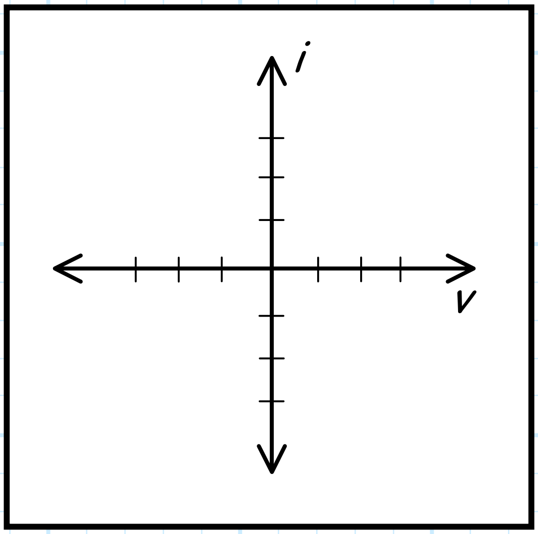
3) If R=∞, then we have a **open** circuit:

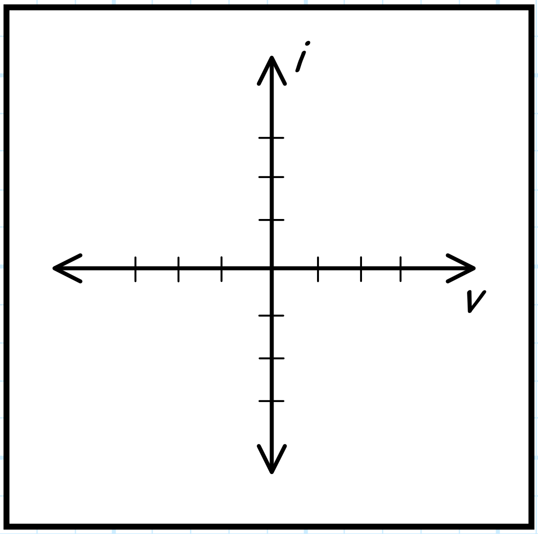


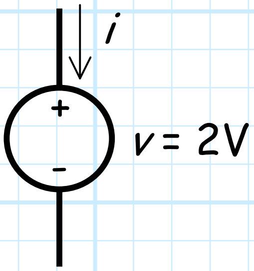
$\boxed{i = 0}$

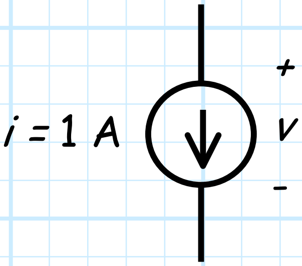


4) We can also plot the behavior of both current and voltage **sources**:

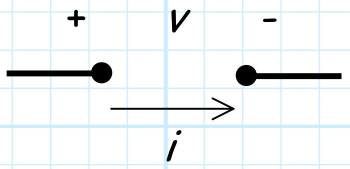




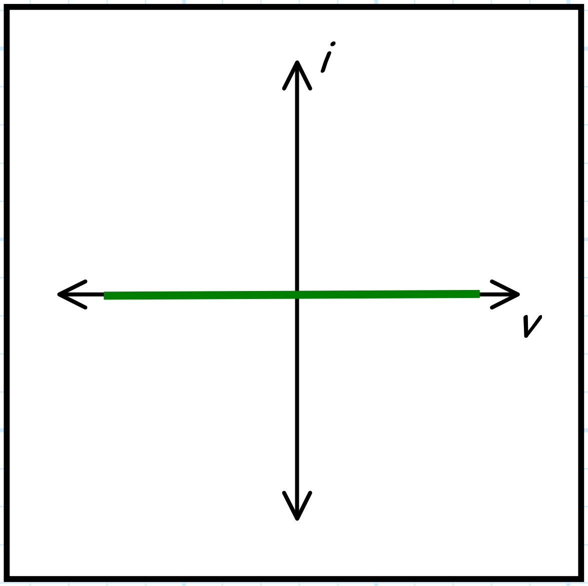




3) If $R=\infty$, then we have a **open** circuit:



$\boxed{i = 0}$



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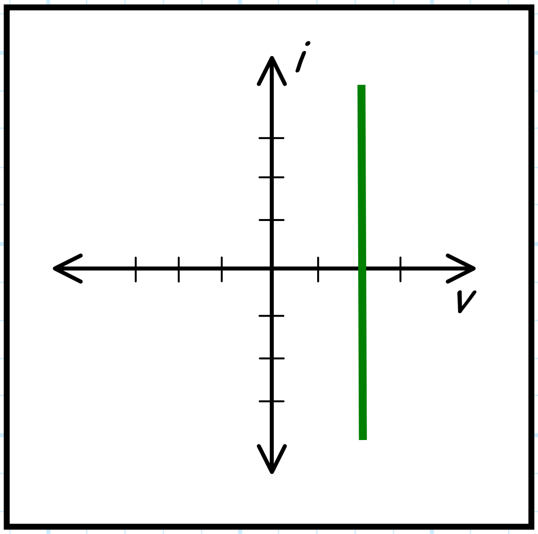
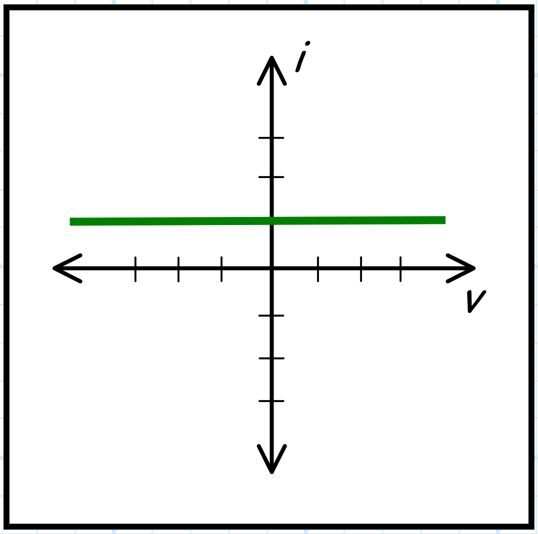
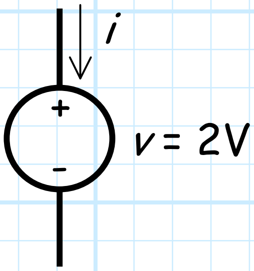
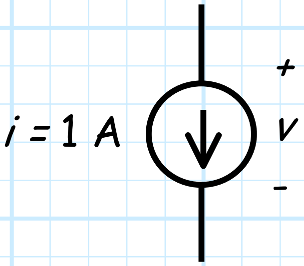




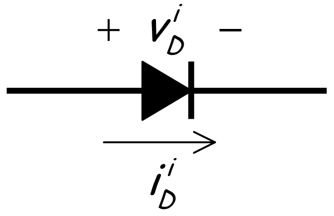


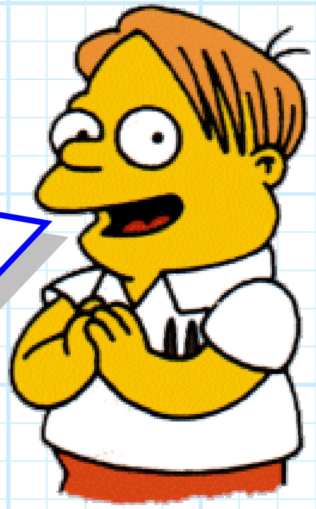


The Ideal Diode

An **ideal diode**—the circuit device with a split personality!

→ Is it a **short** ? Or is it an **open** ?

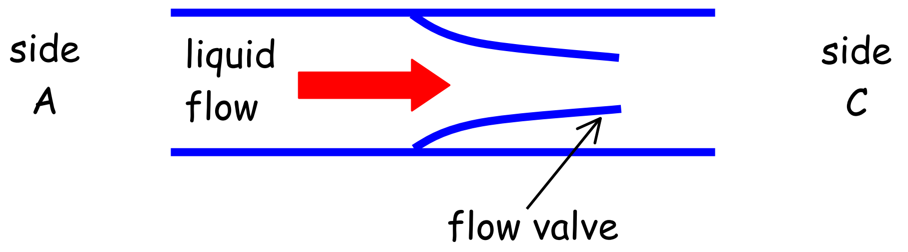




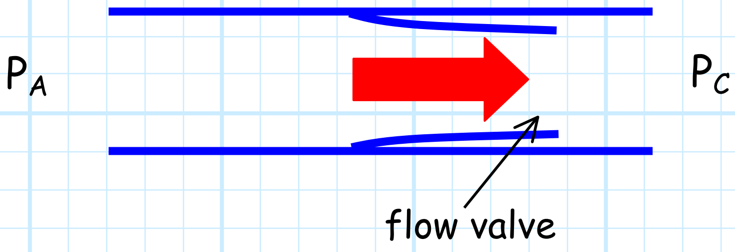
	$v_D^i < 0$	$v_D^i = 0$	$v_D^i > 0$
$i_D^i > 0$	invalid	**forward biased**	invalid
$i_D^i = 0$	**reverse biased**	**no bias**	invalid
$i_D^i < 0$	invalid	invalid	invalid

The Diode Mechanical Analogy

An ideal diode is sort of like a mechanical **valve** !



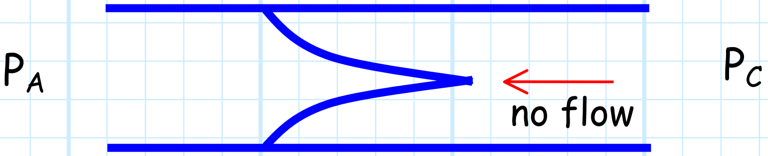
Case 1: Valve allows liquid to flow in pipe from side A to side C.



There is no drop in pressure (P) from side A to side C.

$$\Rightarrow \quad P_A - P_C = 0$$

<u>Case 2</u>: Valve prevents liquid from flowing **back** from side C to side A.



No flow occurs when pressure P_C is greater than pressure P_A

$$\rightarrow \qquad P_A - P_C < 0$$

Note the **analogies** with an ideal diode:

Valve	**Diode**
Pressure	Voltage
Liquid Flow	Current
Side A	Anode
Side C	Cathode
Case 1	Forward Bias
Case 2	Reverse Bias

The Ideal Diode Circuit Analysis Guide

Follow these easy steps to successfully analyze a circuit containing one or more **ideal** diodes !

Step 1: *ASSUME* a bias state for each ideal diode.

⇨ In other words, **GUESS** !!

Either,

a) *ASSUME* an **ideal** diode is **forward biased**, or

b) *ASSUME* it is **reversed biased**.

Step 2: *ENFORCE* the **equality** condition consistent with your assumption.

a) If you assume an ideal diode is **f.b.**, then *ENFORCE* the equality:

$$\boxed{v_D^i = 0}$$

HOW ? ⇨ By replacing the **ideal** diode with a **short** circuit!

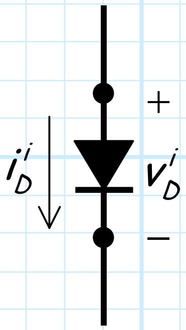
b) If you assumed an ideal diode was **r.b.**, then *ENFORCE* the condition that:

$$\boxed{i_D^i = 0}$$

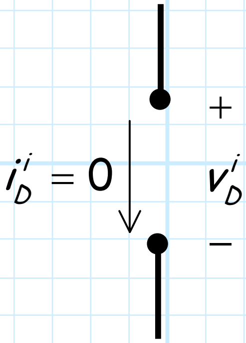
HOW ? ⇨ By replacing the ideal diode with an **open** circuit.

IMPORTANT !!! Retain the **same** current and voltage definitions when you replace the ideal diode!

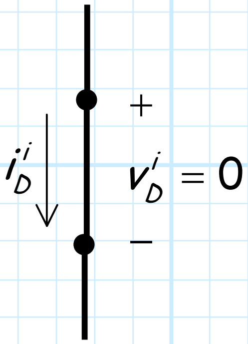
If,



then,



or



<u>Step 3:</u> *ANALYZE* the circuit.

After the all **ideal** diodes have been replaced with either shorts or opens:

a) Determine **all** desired (required) circuit values.

b) Determine i_D^i through each **short** circuit and v_D^i across each **open** circuit.

Step 4: *CHECK* the **inequality** consistent with your assumption to see **if** this assumption is correct.

HOW ??

a) An **ideal** diode cannot have negative current flowing through it. If you ASSUMED the ideal diode was **forward biased**, *CHECK* to see if the **short** circuit current is positive, i.e.:

$$\boxed{i_D^i > 0}$$

If true, you *ASSUMED* correctly ! If **not**, your **f.b.** assumption is wrong.

b) An **ideal** diode cannot have positive voltage across it. If you ASSUMED the ideal diode was **reversed biased**, *CHECK* to see if the **open** circuit voltage is negative, i.e.:

$$\boxed{v_D^i < 0}$$

If true, you *ASSUMED* correctly ! If **not**, your **r.b.** assumption is wrong.

Step 5: If you ASSUMED incorrectly, then change your assumptions and return to step 1 !

Notes on ideal diode circuit analysis:

1) You **must** check all assumptions in this form:

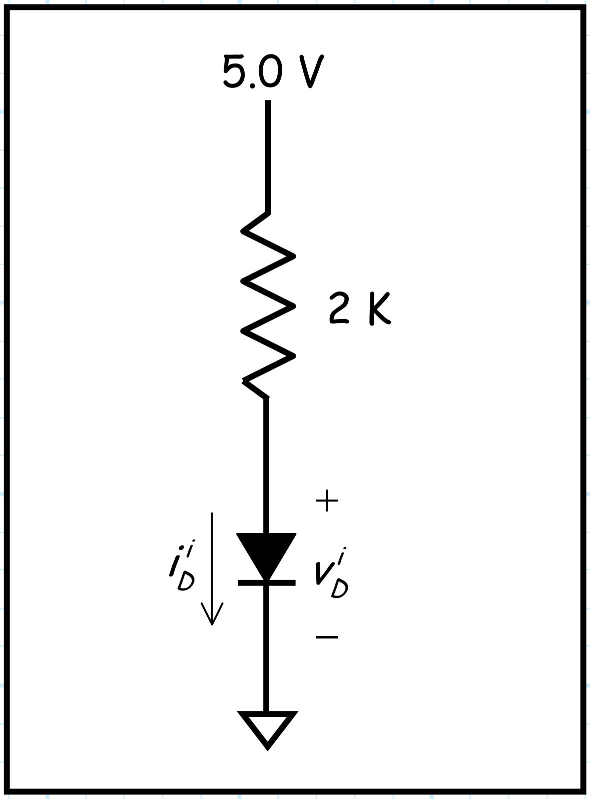
$$i_D^i = 2\ mA > 0 \checkmark \qquad \text{or} \qquad v_D^i = 2.2 > 0 \ \text{✗}$$

2) Do **not** check the condition that you enforced !

3) For **every** circuit, one and only one assumption will be valid.

Example: A Simple Ideal Diode Circuit

Consider this simple circuit that includes an **ideal** diode:



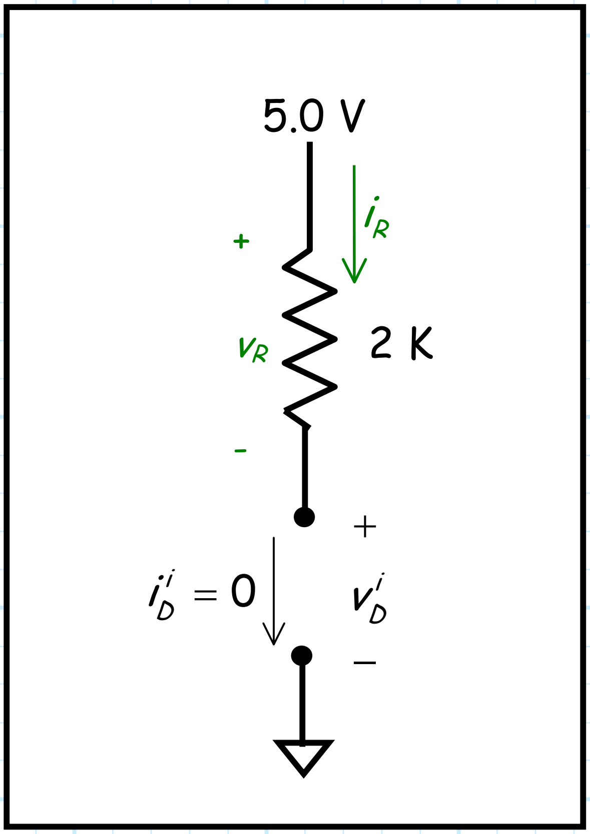
Q: *What are* i_D^i *and* v_D^i *?*

A: Follow the five easy analysis steps !

Step 1: Let's *ASSUME* the ideal diode is **reverse biased** (we're just guessing!).

Step 2: We therefore *ENFORCE* $i_D^i = 0$ by replacing the ideal diode with an **open** circuit.

Step 3: Now we *ANALYZE* the circuit; finding the value of v_D^i.



$$5.0 - v_R - v_D^i = 0 \quad \text{(KVL)}$$

$$\therefore \; v_D^i = 5.0 - v_R$$

$$i_R = i_D^i \quad \text{(KCL)}$$

$$v_R = 2\, i_R \quad \text{(Ohm's)}$$

$$i_D^i = 0 \quad \text{(enforced)}$$

$$\therefore \; i_R = 0$$

$$\therefore \; v_R = 2(0) = 0$$

$$\therefore \; v_D^i = 5.0 - 0 = 5.0\,V$$

Step 4: Now let's CHECK our result. ⇨ **Is** $v_D^i < 0$??

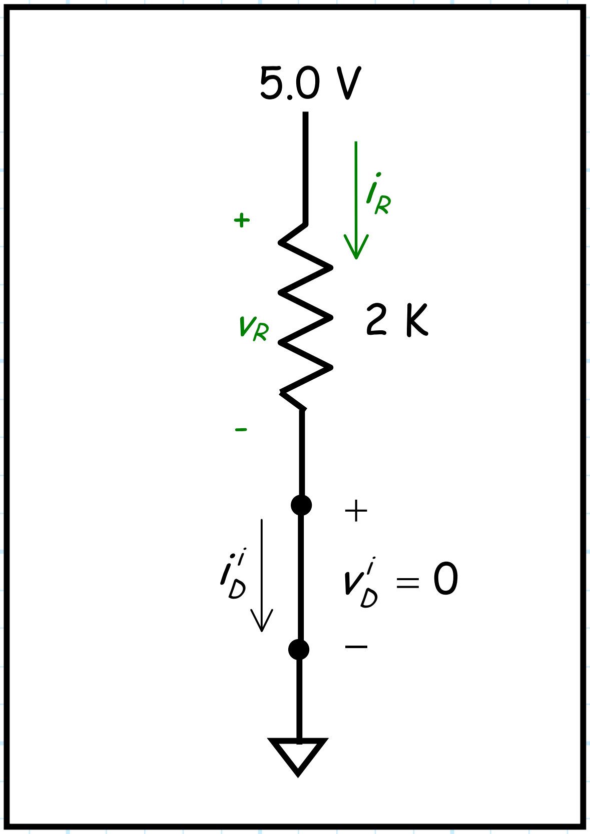
$v_D^i = 5.0 > 0$ ✗

We must change our assumption, and then **start over** (Doh!).

1) Now *ASSUME* the ideal diode is **forward biased** (what's left?).

2) We therefore *ENFORCE* $v_D^i = 0$ by replacing the ideal diode with an **short** circuit.

3) Now we *ANALYZE* the circuit; finding the value of i_D^i.



$$5.0 - v_R - v_D^i = 0 \quad \text{(KVL)}$$

$$\therefore \; v_R = 5.0 - v_D^i$$

$$i_D^i = i_R \quad \text{(KCL)}$$

$$i_R = v_R / 2 \quad \text{(Ohm's)}$$

$$v_D^i = 0 \quad \text{(enforced)}$$

$$\therefore v_R = 5.0 - 0 = 5.0\,V$$

$$\therefore \; i_R = 5.0 / 2 = 2.5\,mA$$

$$\therefore \; i_D^i = 2.5\,mA$$

4) Now, let's CHECK our result. ⇨ **Is** $i_D^i > 0$??

$$i_D^i = 2.5\,mA \quad > \quad 0 \;\; ✓$$

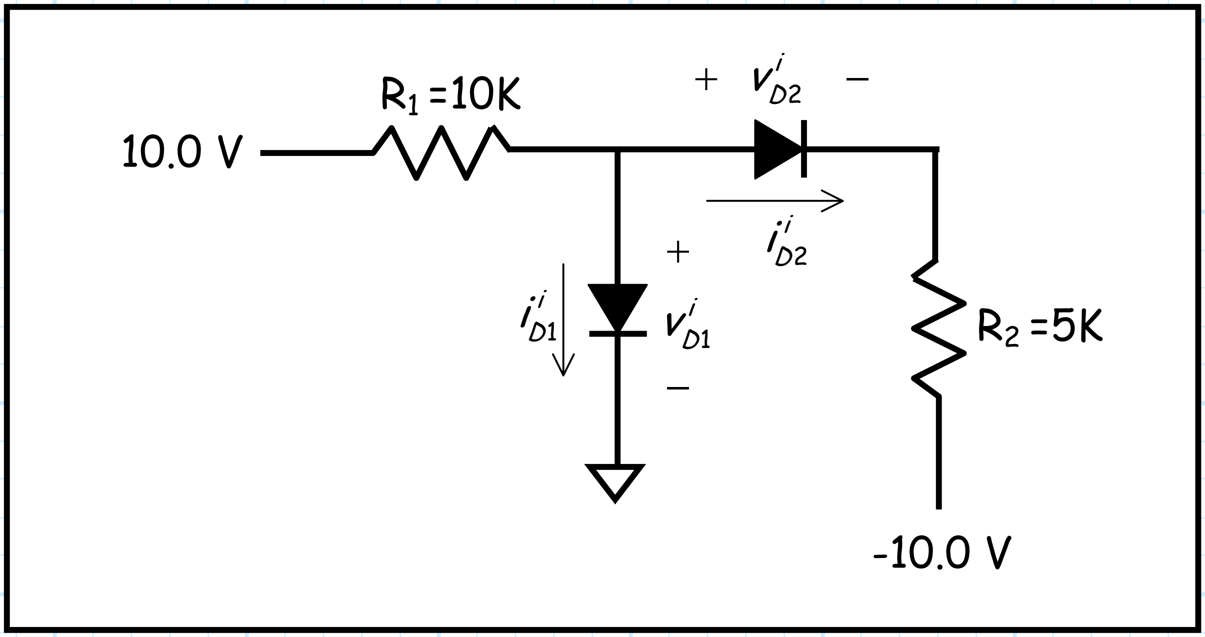
Our assumption is correct !

Therefore, in this circuit, we now **know** that:

$$v_D^i = 0 \;\text{ and }\; i_D^i = 2.5\,mA$$

Example: Analysis of a Complex Diode Circuit

Consider this circuit with **two ideal diodes**:



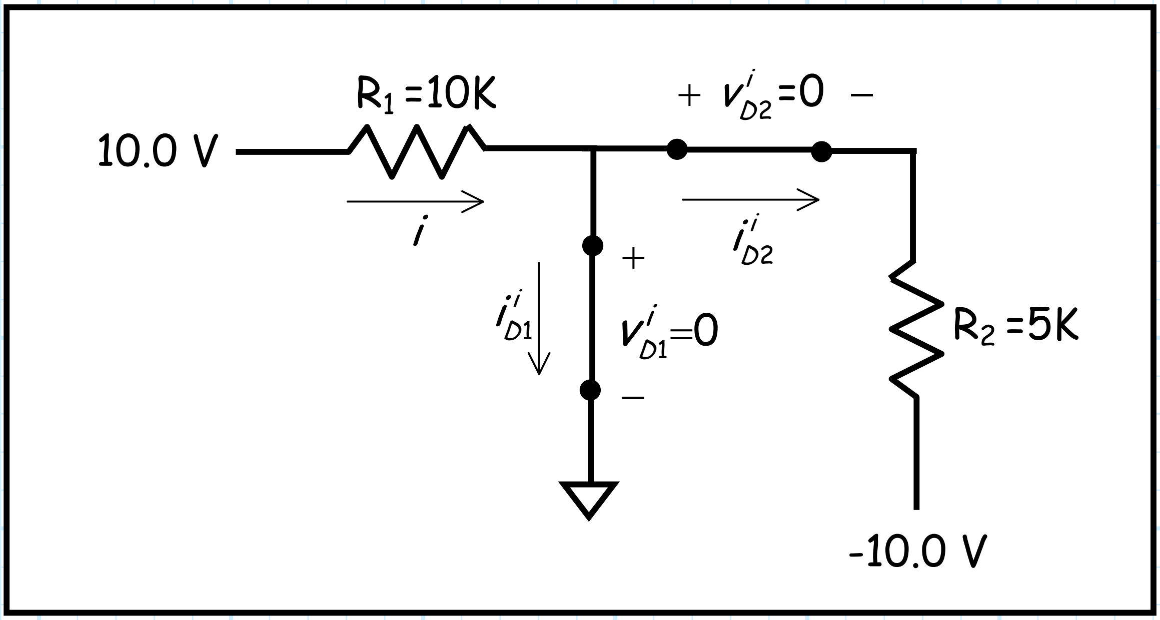
Let's analyze this circuit and find v_{D1}^{i}, i_{D1}^{i}, v_{D2}^{i}, and i_{D2}^{i} !

Remember, we must accomplish each of the **five** steps:

Step 1: *ASSUME* that both D_1 and D_2 are **"on"** (might as well!).

Step 2: *ENFORCE* the **equalities** $v_{D1}^{i} = 0 = v_{D2}^{i}$, by replacing each ideal diode with a **short** circuit.

Step 3: *ANALYZE* the resulting circuit, and find i_{D1}^{i} and i_{D2}^{i}.



Begin with **KCL**:

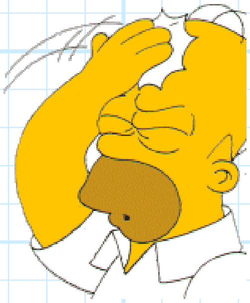
$$i = i_{D1}^{i} + i_{D2}^{i}$$

where $$i = \frac{10.0-0}{10} = 1.0\ mA$$

and $$i_{D2}^{i} = \frac{0-(-10)}{5} = \frac{10}{5} = 2.0\ mA$$

Therefore, $$i_{D1}^{i} = i - i_{D2}^{i} = 1.0 - 2.0 = -1.0\ \ mA$$

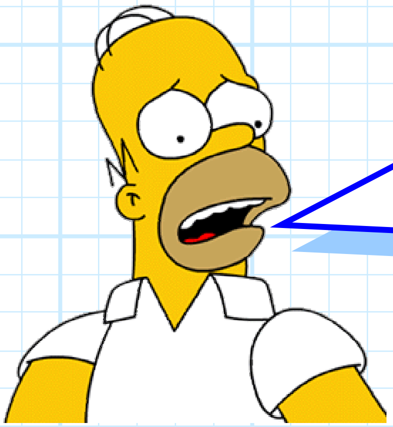
Step 4: Now we must *CHECK* **inequalities** to see if our assumptions are correct!



$$i_{D1}^{i} = -1.0 \; mA \; < \; 0$$ ✗

$$i_{D2}^{i} = 2.0 \; mA \; > \; 0$$ ✓

One assumption is therefore **INCORRECT**. We must proceed to **step 5**—change our assumptions and **completely** start again!



Q: *Wait a second! We don't have to **completely** start from the beginning, do we? After all, our assumption about diode D_2 turned out to be **true**—so we **already** know that $i_{D2}^{i} = 2.0$ and $v_{D2}^{i} = 0$, **right?***

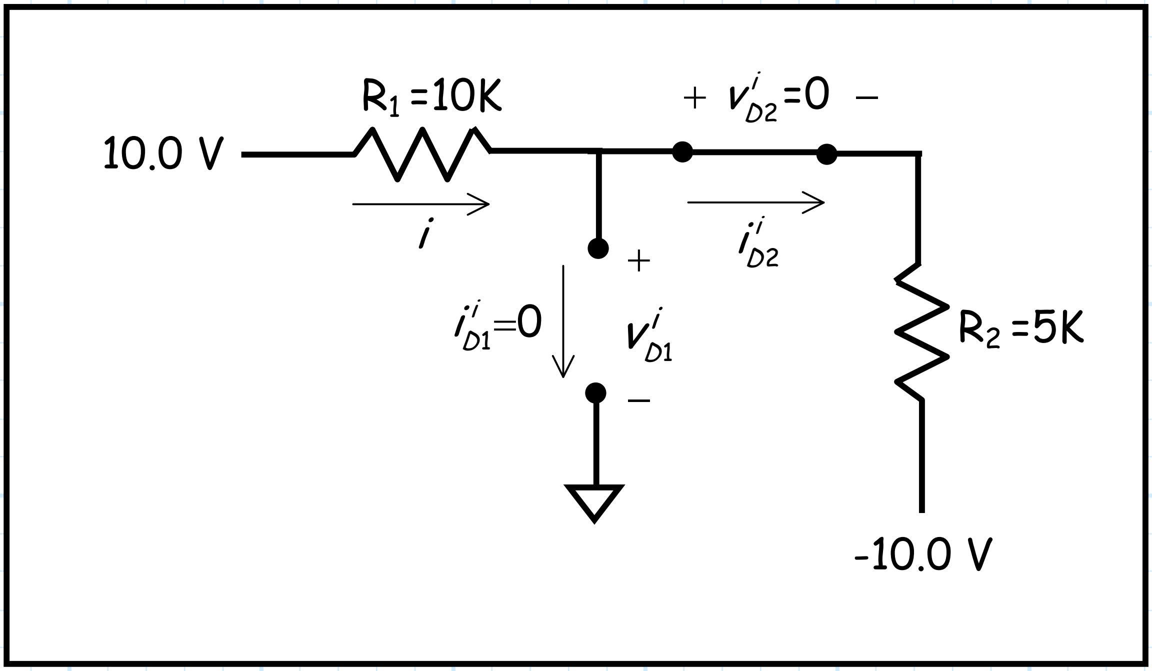
A: **NO!** The solution for diode D_2 is dependent on the state of both diodes D_1 and D_2. If the assumption of just **one** diode turns out to be incorrect, then the solutions for **all** diodes are **wrong**!

So, let's change our assumption and start all over again!

Step 1: Now *ASSUME* that D_1 is **"off"** and D_2 is **"on"**.

Step 2: *ENFORCE* $i_{D1}^i = 0$ (D_1 open) and $v_{D2}^i = 0$ (D_2 short).

Step 3: *ANALYZE* resulting circuit, and find v_{D1}^i and i_{D2}^i.



$$\text{Note } i = i_{D2}^i = \frac{10.0-(-10.0)}{10+5} = \frac{20.0}{15} = 1.33\, mA$$

and from KVL:

$$10.0 - 10i - v_D^i = 0$$

$$10.0 - 10(1.33) - v_D^i = 0$$

$$\therefore \; v_D^i = 10.0 - 10(1.33) = -3.33\, V$$

4) CHECK our assumptions.

$$i_{D2}^{i} = 1.33\ mA \quad > \quad 0 \quad \checkmark$$

$$v_{D1}^{i} = -3.33\ V \quad < \quad 0 \quad \checkmark$$

$\therefore$ Assumptions are **correct**! We are finished!

$$\boxed{\begin{array}{ll} v_{D1}^{i} = -3.33\ V & \qquad i_{D1}^{i} = 0 \\[2em] v_{D2}^{i} = 0 & \qquad i_{D2}^{i} = 1.33\ mA \end{array}}$$