EECS 312

EECS 312 - **Electronic** Circuits I

You already understand these **linear** devices:

All useful, but we need other devices to:

1.

2.

Vacuum tubes were once used to achieve this—now engineers use **semiconductor devices**!

Examples of semiconductor devices:

Q: So why semiconductor devices?

A: Orders of magnitude improvement in:

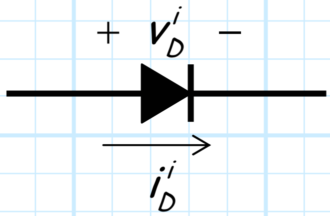
1.
2.
3.
4.

3.1 The Ideal Diode

Reading Assignment: pp.139-141

Diodes:

A) The Ideal Diode Symbol



Note:

1. Device is **not** symmetric!

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

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

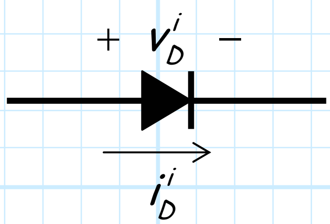
B) Ideal Diode Behavior

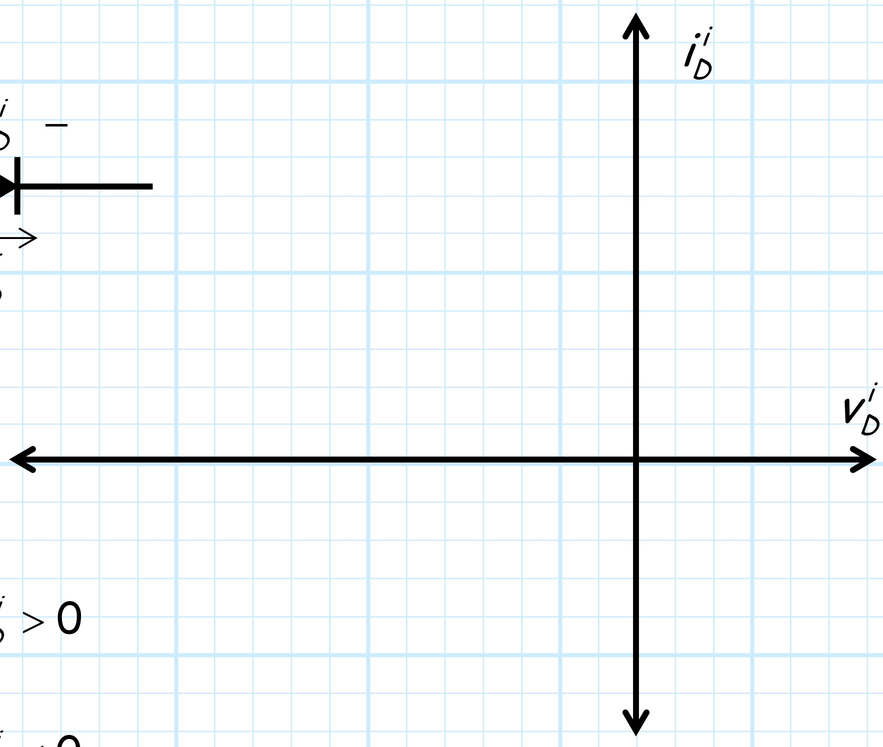
The **ideal** diode →

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 non-linear!

C) Diode Bias Regions

An **ideal** diode operates in one of **two states**:

1) Forward Biased →

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

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

2) Reverse Biased →

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

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

Note: No power is dissipated in either mode!

$$\rightarrow \quad P_D^i =$$

HO: The Ideal Diode

HO: Diode Mechanical Analogy

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

A:

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

Therefore we must preciely follow a set of analysis steps to analyze circuits with these non-linear ideal diodes.

HO: The Ideal Diode Circuit Analysis Guide

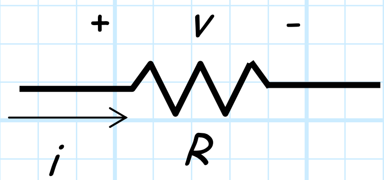
A few examples to help illustrate this procedure:

Example: A Simple Ideal Diode Circuit

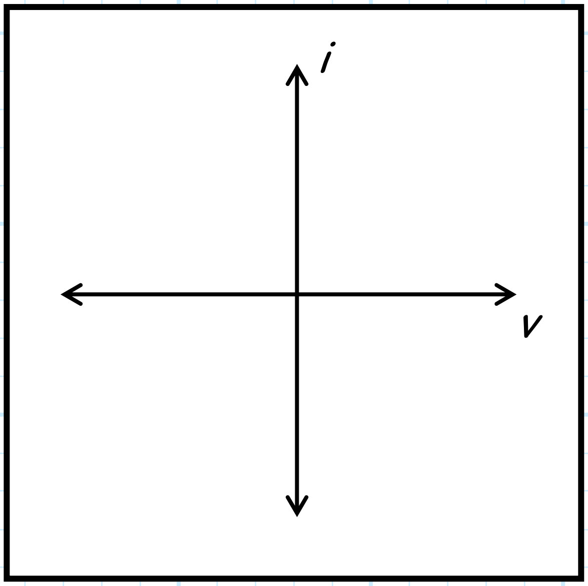
Example: Analysis of a Complex Ideal Diode Circuit

Linear Device Behavior

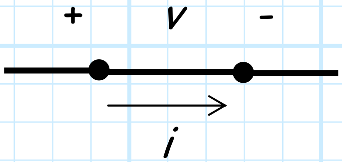
1) Recall the circuit behavior of a **resistor**:



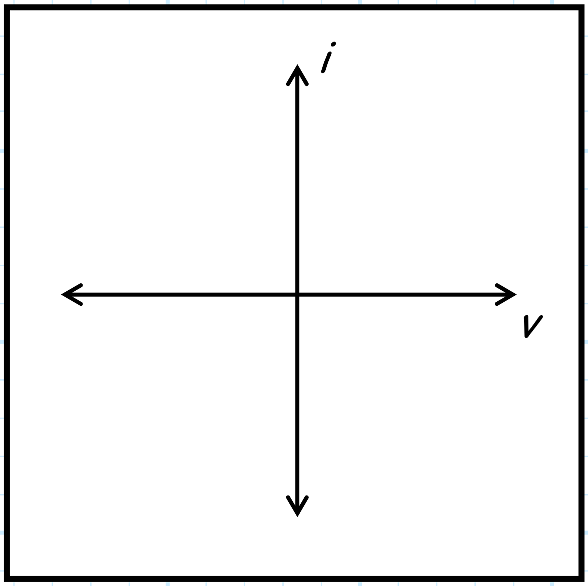
$$i = \frac{v}{R}$$



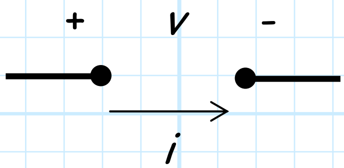
2) If R=0, then we have a **short** circuit:



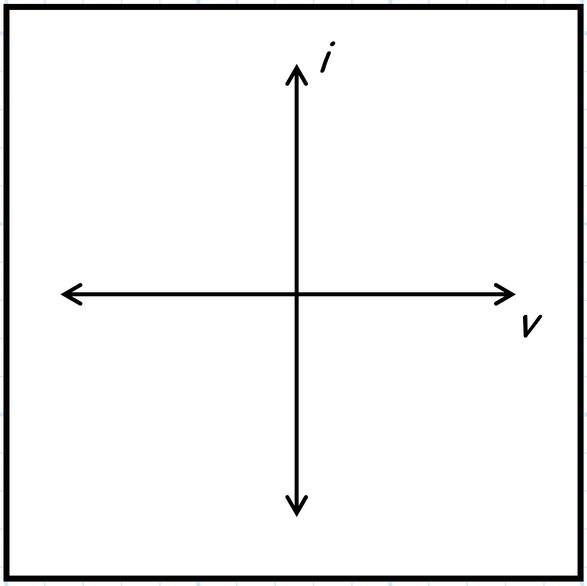
$$v = 0$$



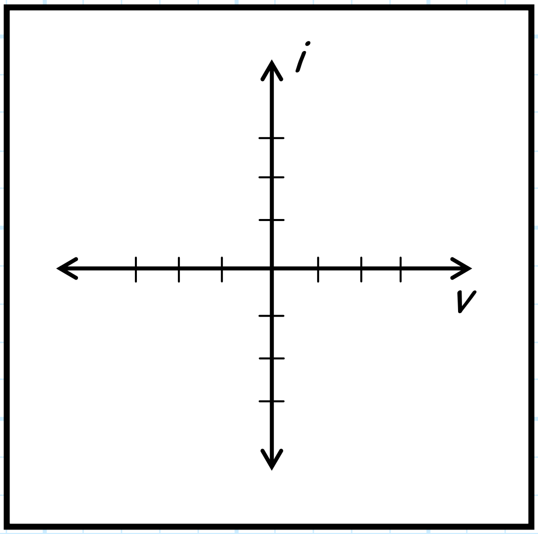
3) If R=∞ , then we have a **open** circuit:

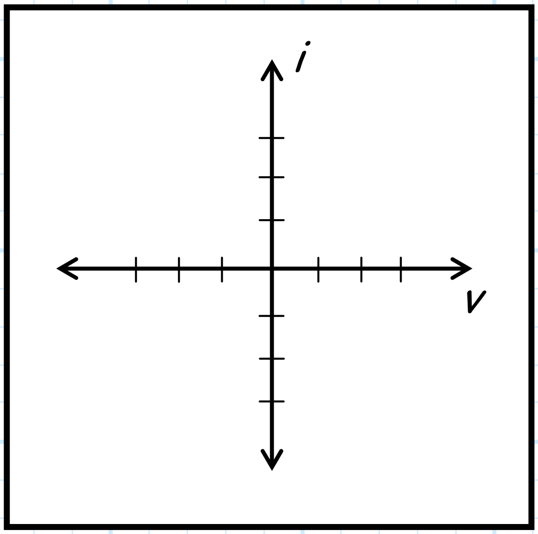


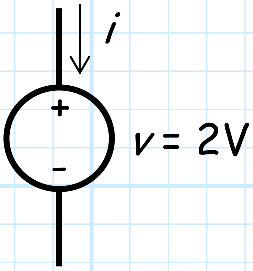
$i = 0$

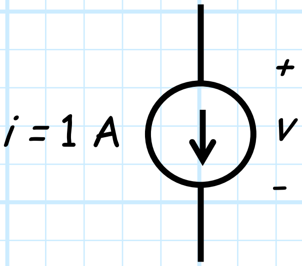


4) We can also plot the behavior of both current and voltage **sources**:

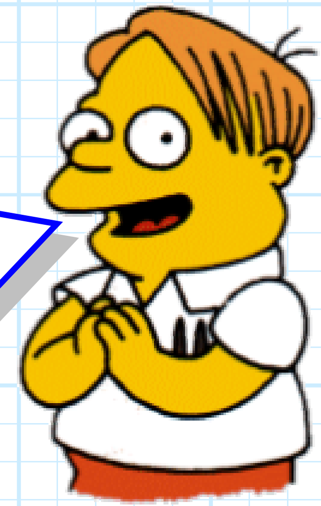






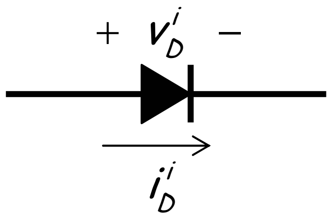


The Ideal Diode



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

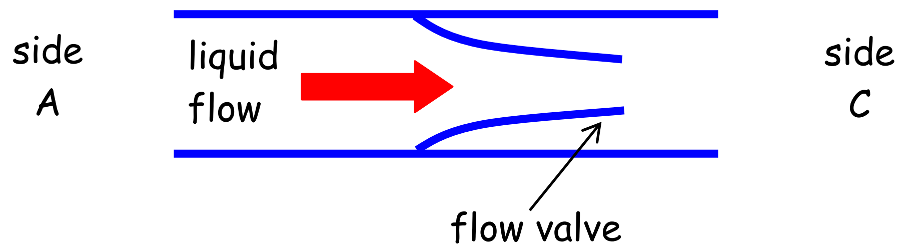
➔ Is it a **short** ? Or is it an **open** ?



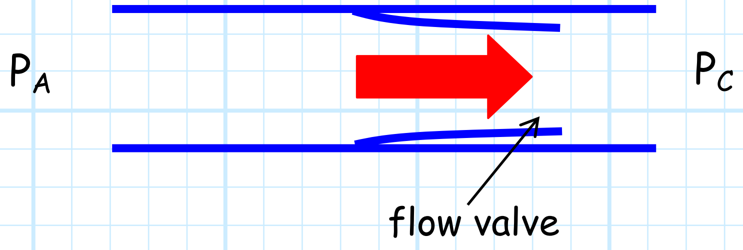
	$v_D^i < 0$	$v_D^i = 0$	$v_D^i > 0$
$i_D^i > 0$	invalid	**forward biased**	invalid
$i_D^i = 0$	**reverse biased**	**no bias**	invalid
$i_D^i < 0$	invalid	invalid	invalid

The Diode Mechanical Analogy

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



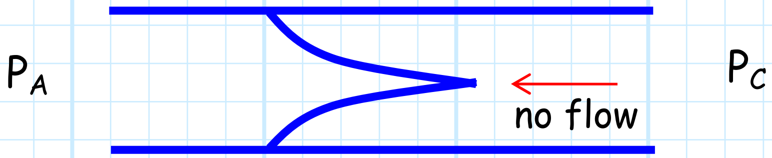
Case 1: Valve allows liquid to flow in pipe from side A to side C.



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

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

Case 2: 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:

$$v_D^i = 0$$

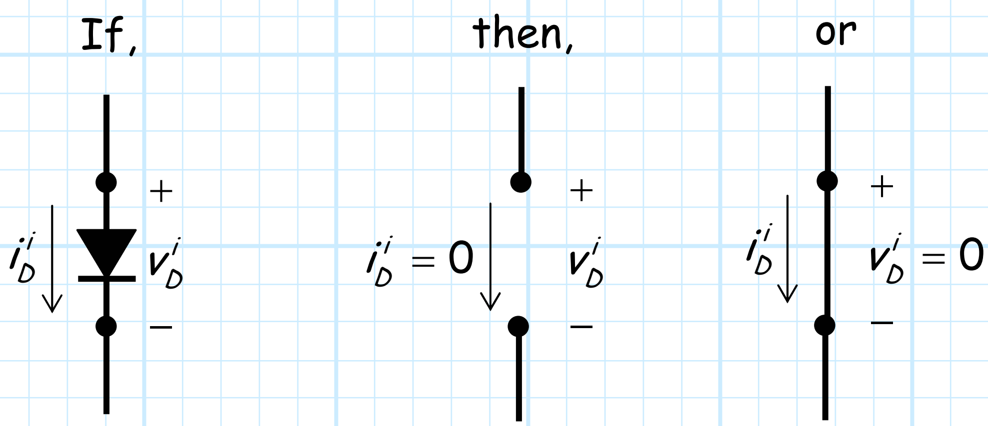
HOW ? ⇨ By replacing the **ideal** diode with a **short** circuit!

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

$$i_D^i = 0$$

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

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



<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.:

$$i_D^i > 0$$

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.:

$$v_D^i < 0$$

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:

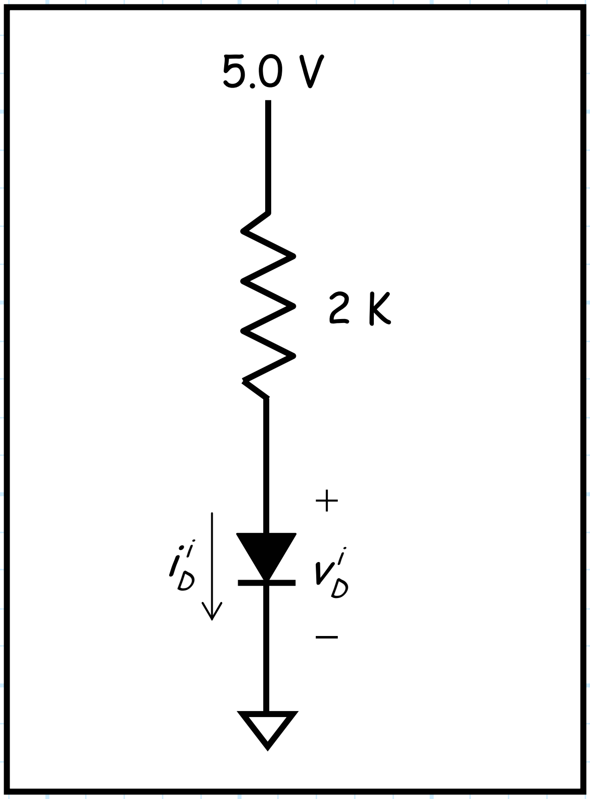
$$i_D^i = 2\ mA > 0 \checkmark \quad \text{or} \quad v_D^i = 2.2 > 0 \ X$$

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:



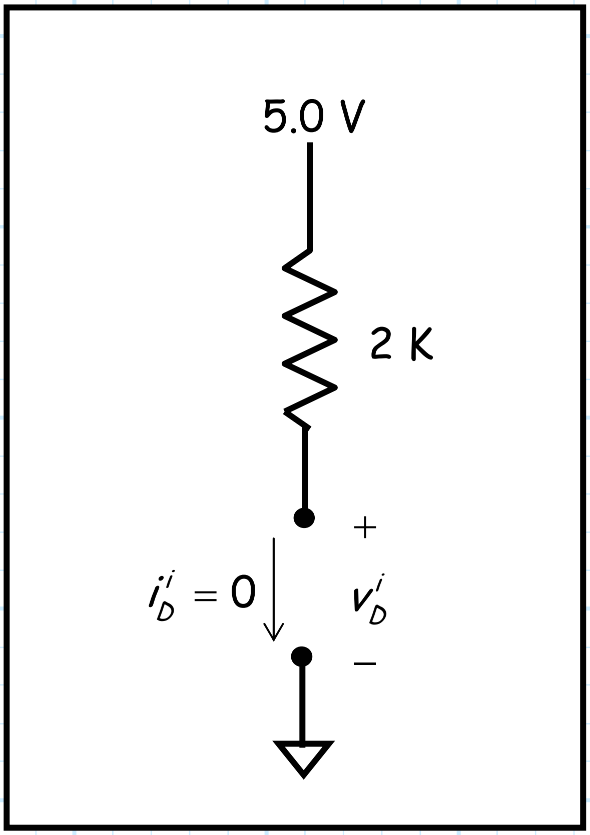
Q: *What are i_D^i and v_D^i?*

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.



(KVL)

$\therefore$

(KCL)

(Ohm's)

(enforced)

$\therefore \; i_R =$

$\therefore \; v_R =$

$\therefore \; v_D^i =$

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

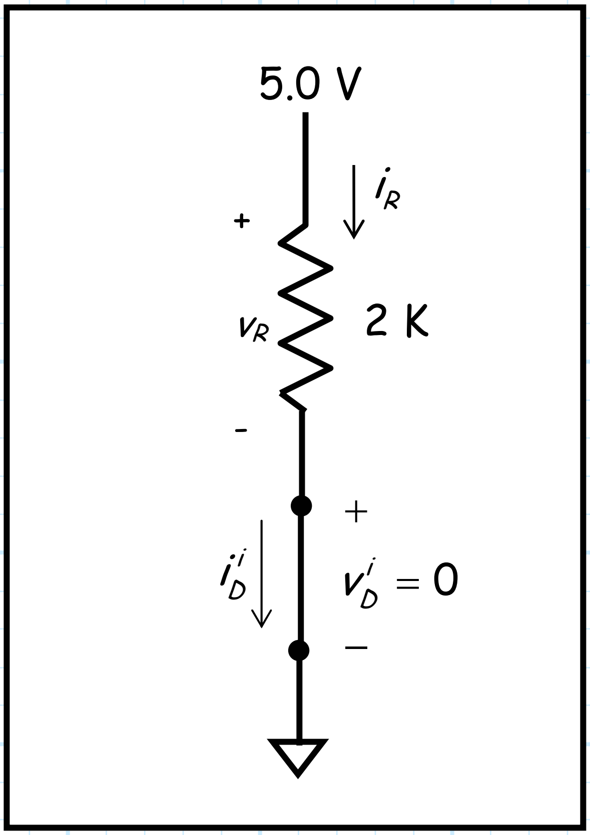
$v_D^i =$ ✗

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.



(KVL)

$\therefore$

(KCL)

(Ohm's)

(enforced)

$\therefore v_R =$

$\therefore \; i_R =$

$\therefore \; i_D^i =$

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

$i_D^i =$ ✓

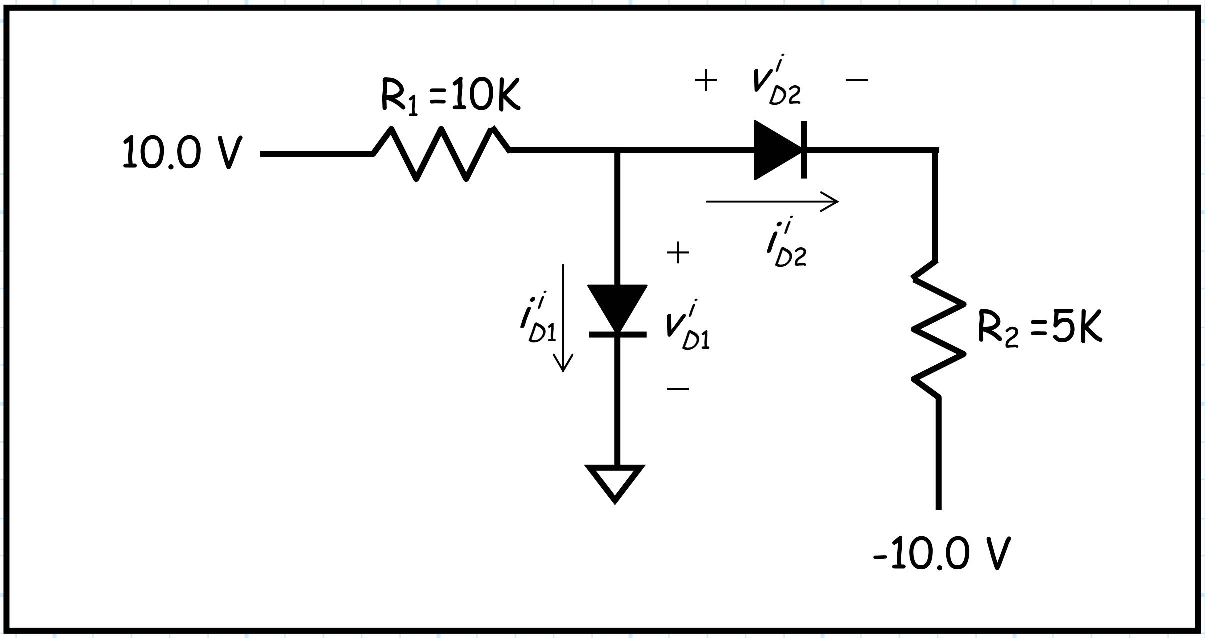
Our assumption is correct !

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

$$v_D^i = 0 \text{ and } i_D^i =$$

Example: Analysis of a Complex Diode Circuit

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



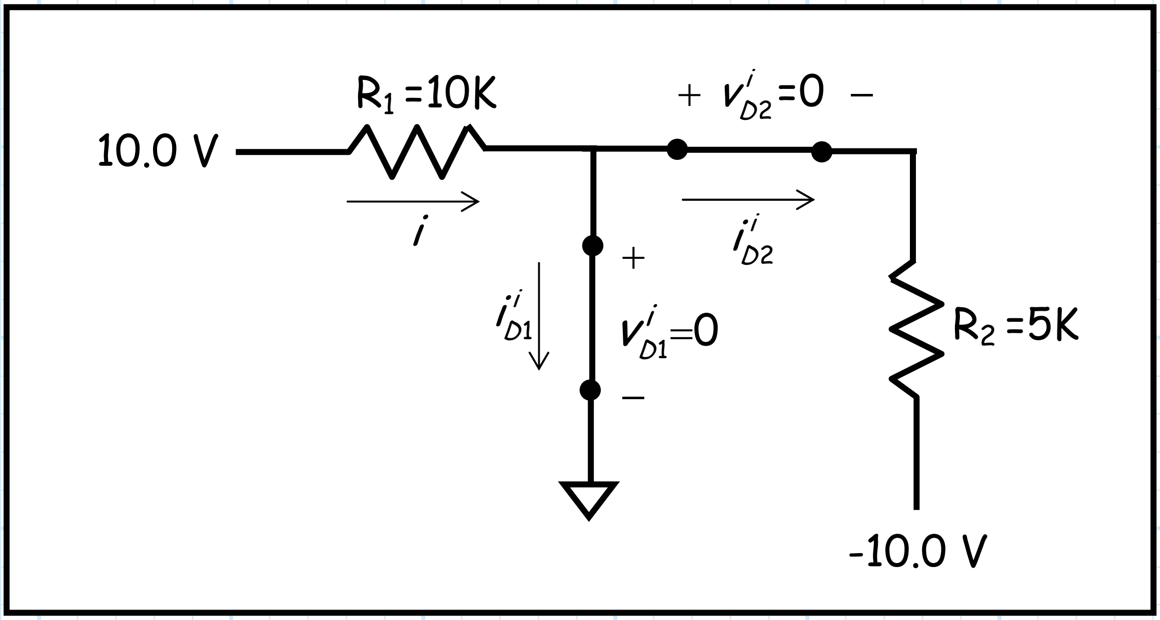
Let's analyze this circuit and find v_{D1}^i, i_{D1}^i, v_{D2}^i, and i_{D2}^i !

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 $i =$

and $i_{D2}^{i} =$

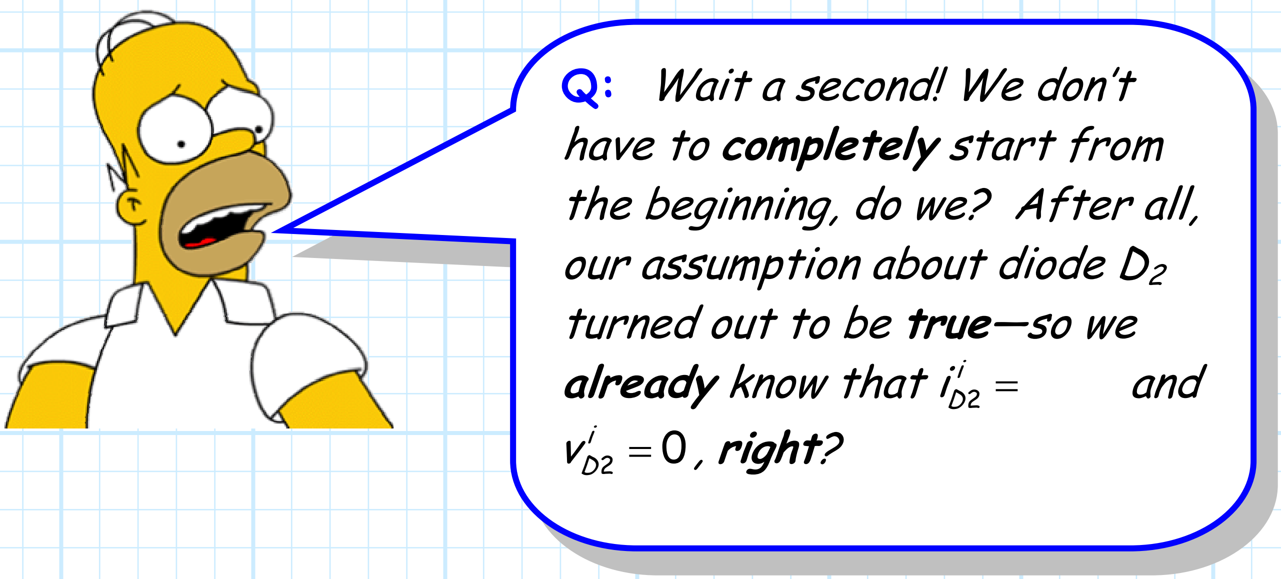
Therefore, $i_{D1}^{i} =$

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

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

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

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



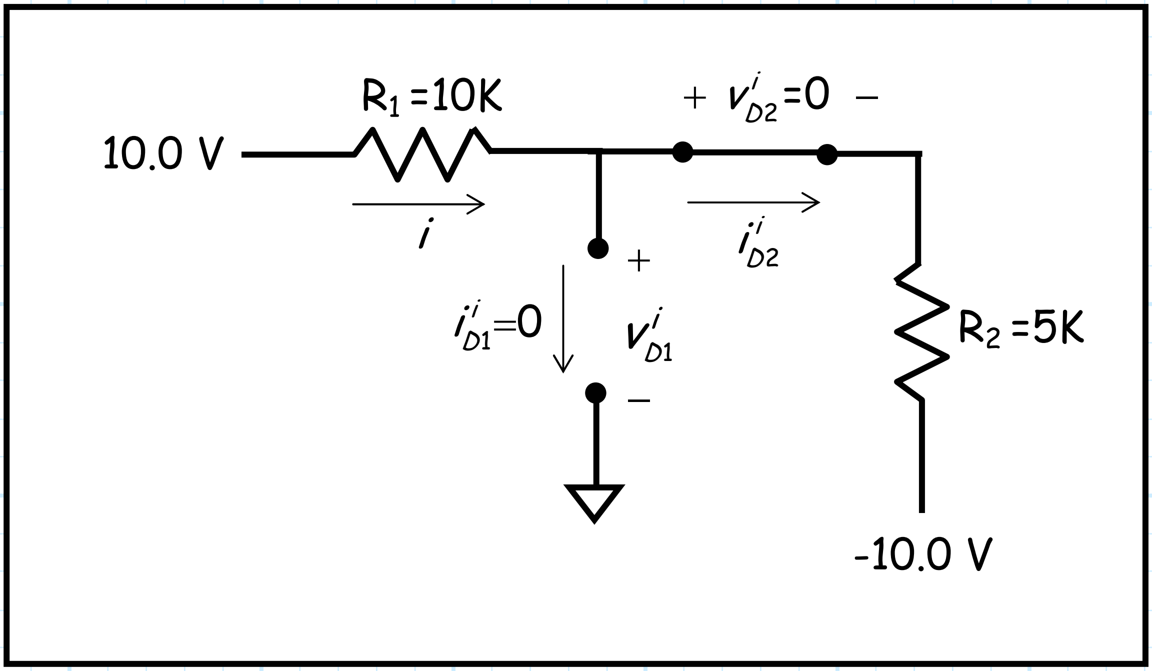
A: **NO!** The solution for diode D_2 is dependent on the state of both diodes D_1 and D_2. If the assumption of just **one** diode turns out to be incorrect, then the solutions for **all** diodes are **wrong**!

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}.



Note $i = i_{D2}^{i} =$

and from KVL:

$\therefore\ v_{D}^{i} =$

4) CHECK our assumptions.

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

$$v_{D1}^{i} =$$

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

$v_{D1}^{i} =$	$i_{D1}^{i} = 0$
$v_{D2}^{i} = 0$	$i_{D2}^{i} =$