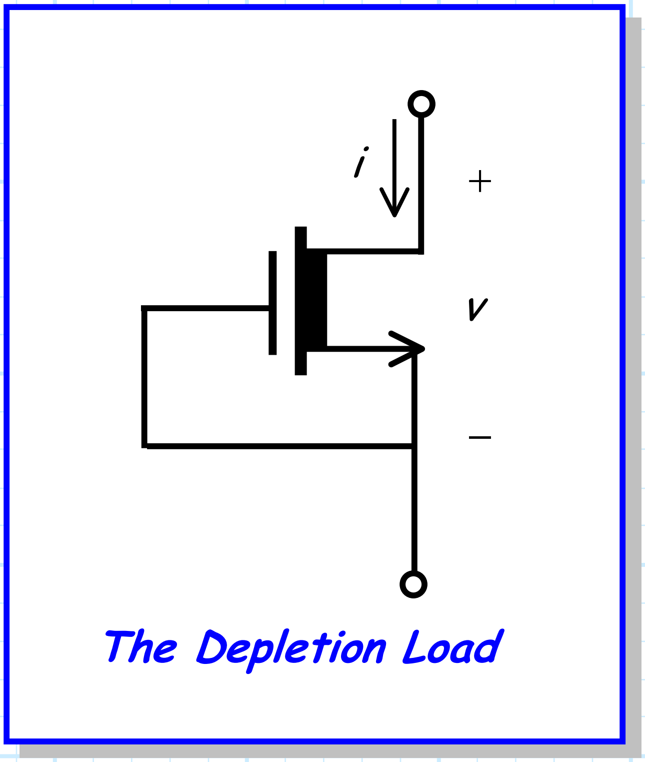
The Depletion Load

Say we connect the gate of a **depletion** NMOS to its source—we now have a **two-terminal device**!

This device is called a **depletion load**.



The Depletion Load

Since the depletion load is a two-terminal device, its **behavior** is defined by the relationship between the **voltage** v across the device and the **current** i through it.

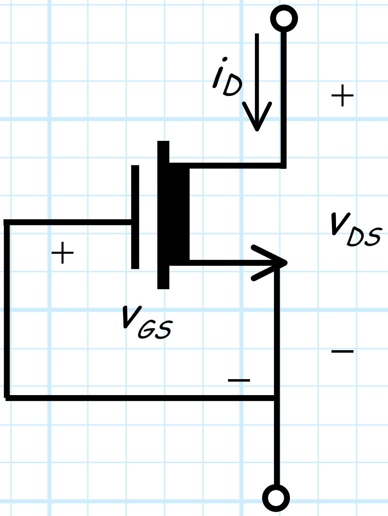
For example, a **resistor** is a two terminal device whose behavior (i.e., its relationship between i and v) is defined by **Ohm's Law** ($i = v/R$).

Although the **depletion load** is decidedly **not** a resistor, its i-v relationship does have **some** similarities with Ohm's Law.

Q: *So what **is** "Ohm's Law" for a **depletion load** (i.e., what is* $i = f(v)$*)?*

A: A result easily found by implementing our knowledge of **depletion** MOSFETs!

For a **depletion load**, we find that:



$$i_D = i$$
$$v_{GS} = 0$$
$$v_{DS} = v$$
$$v_{GS} - V_t = -V_t$$

Q: *But since $v_{GS} = 0$, isn't the NMOS device in **cutoff**?*

A: **Nope!** Notice that this is a depletion MOSFET, and a depletion MOSFET **will** conduct when $v_{GS} = 0$!

Thus the MOSFET in a depletion load will always be either in: **a)** triode or **b)** saturation.

a) Depletion load MOSFET is in **triode** if:

$$v_{DS} < v_{GS} - V_t$$
$$v < 0 - V_t$$
$$v < -V_t$$

Therefore, the **current** will be:

$$\begin{aligned} i_D &= K\left[2\left(v_{GS}-V_t\right)v_{DS}-v_{DS}^2\right] \\ i &= K\left[2\left(0-V_t\right)v-v^2\right] \\ i &= K\left[-2V_t\, v-v^2\right] \end{aligned}$$

b) Depletion load MOSFET is in **saturation** if:

$$\begin{aligned} v_{DS} &> v_{GS}-V_t \\ v &> 0-V_t \\ v &> -V_t \end{aligned}$$

Therefore, the **current** will be:

$$i_D = K\left(v_{GS}-V_t\right)^2+\frac{v_{DS}}{r_o}$$

$$i = K\left(0-V_t\right)^2+\frac{v}{r_o}$$

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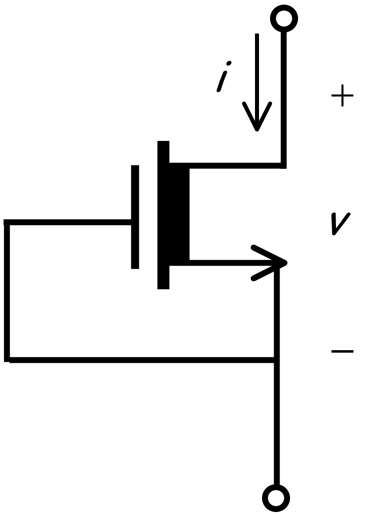
$$i = K\left(-V_t\right)^2+\frac{v}{r_o}$$

$$i = K\,V_t^2+\frac{v}{r_o}$$

where in this case:

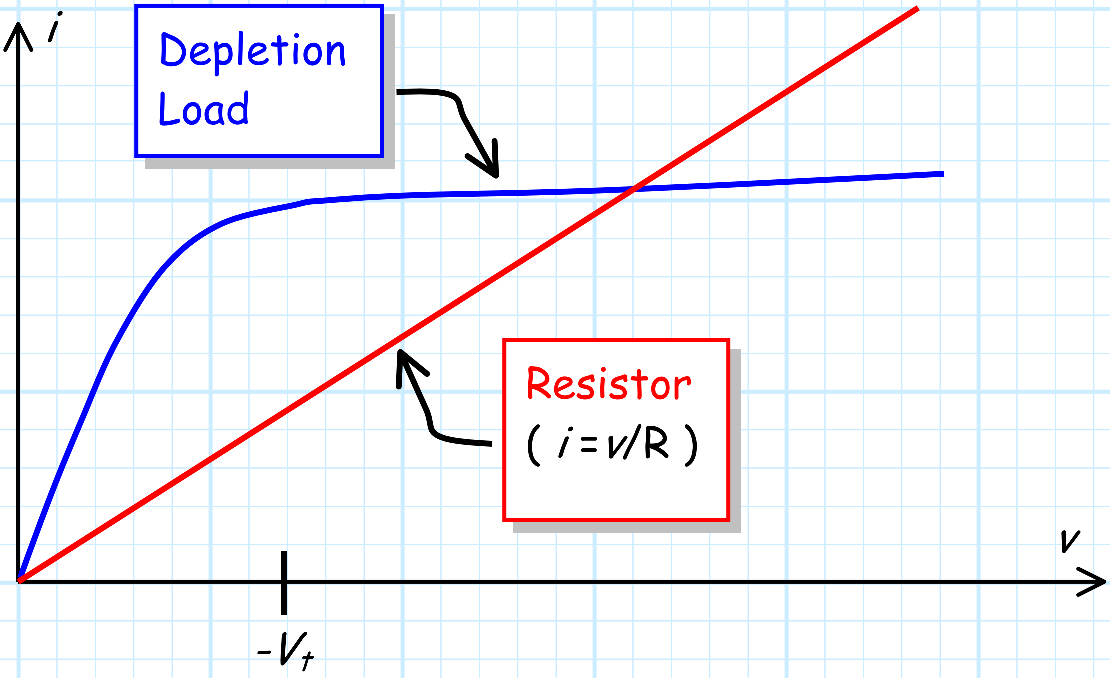
$$r_o=\frac{1}{\lambda K\left(v_{GS}-V_t\right)^2}=\frac{1}{\lambda K\left(0-V_t\right)^2}=\frac{1}{\lambda\,V_t^2}$$

Combining the two results, we find that "Ohm's Law" for a depletion load is:



$$i = \begin{cases} K\left[-2V_t\, v - v^2\right] & \text{if } \; 0 < v < -V_t \\ K\,V_t^2 + \dfrac{v}{r_o} & \text{if } \; v > -V_t \end{cases}$$

Plotting this function, we find something like this:



Note that the behavior of a Depletion Load and a resistor are **very different**—however they are precisely the **same** in two key ways:

1. When the voltage across each device (i.e., resistor and depletion load) is **zero**, the current through each device is likewise **zero** (and vice versa!).

2. As the voltage across each device **increases**, the current through each device **increases**.

As a result, we can use a depletion load as the "**pull-up resistor**" in our integrated circuit NMOS logic!