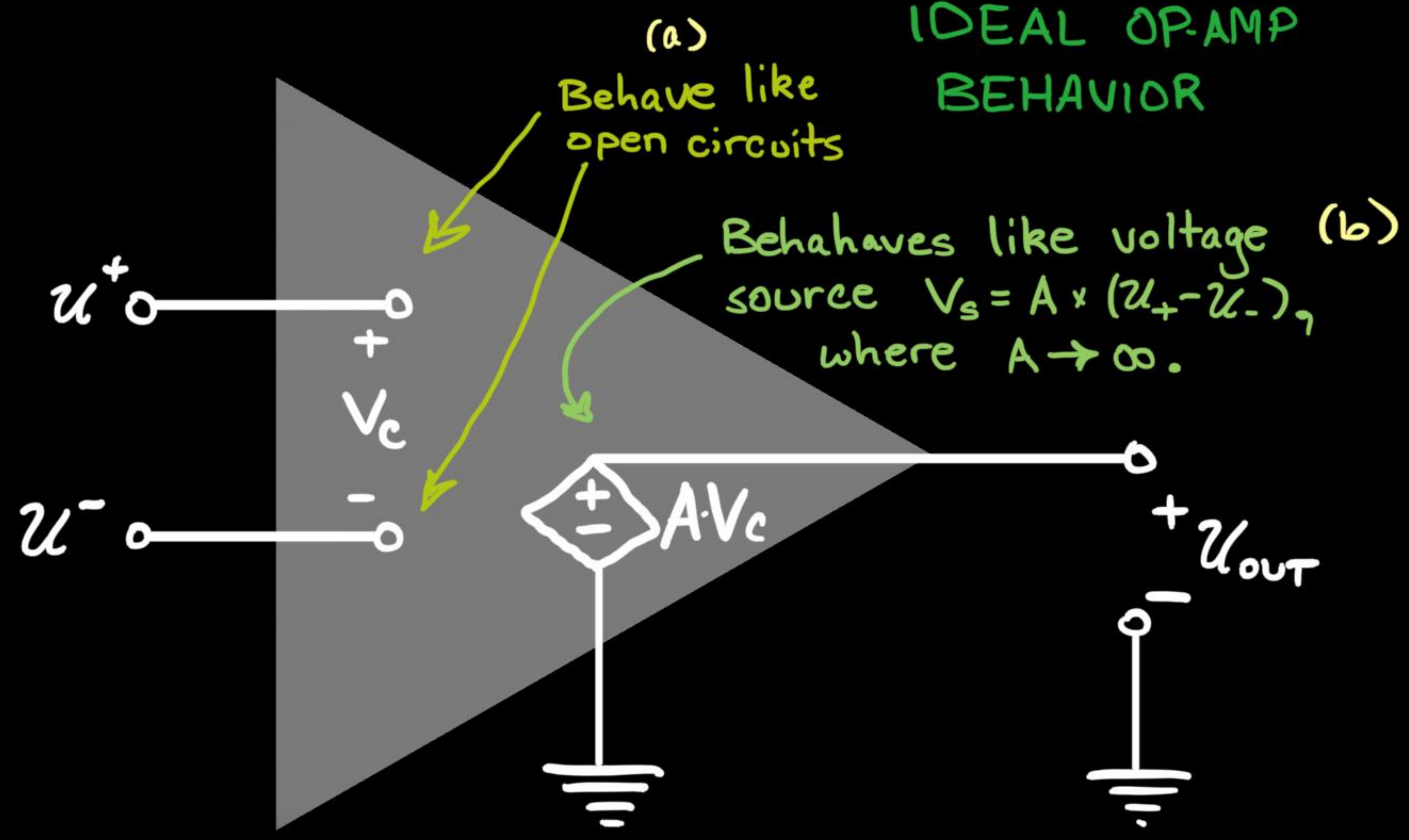
① Op-amp rules:

Equivalent Circuit Model:



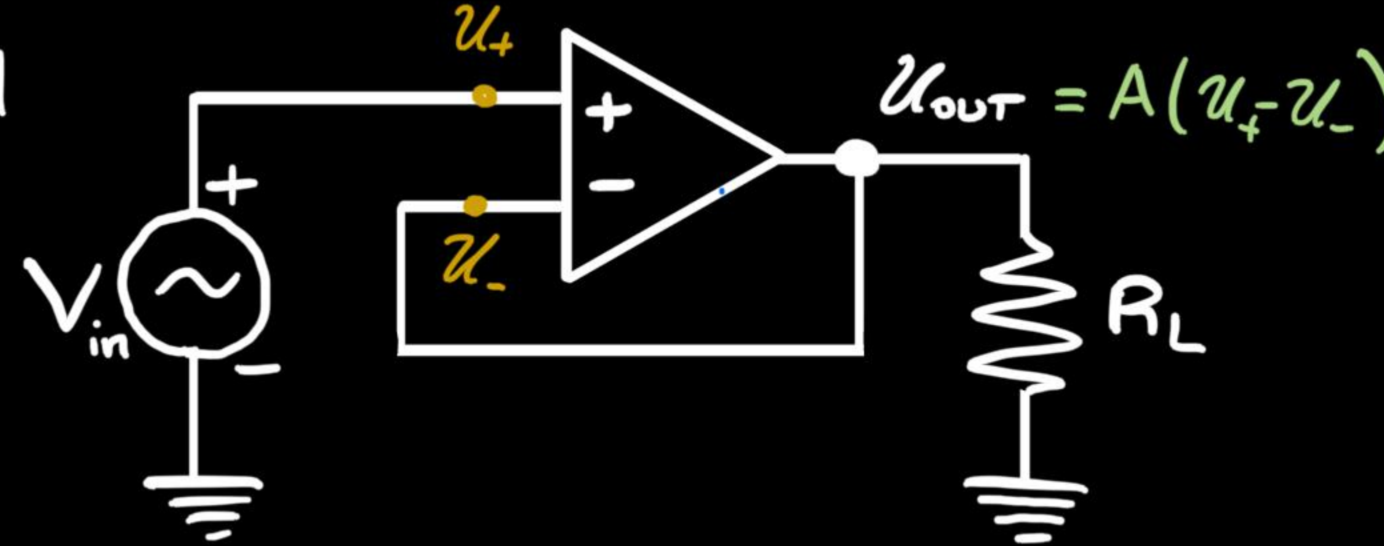
a) What are the currents flowing into the $u^\pm$ terminals?

$$I_{u_+} = I_{u_-} = 0$$

b) If we connect a resistor R_L across u_{OUT}, does u_{OUT} change?

No! u_{OUT} is independent of R_L, since our op-amp model output is a voltage source.

c/d] Consider the circuit:



- What is u_{OUT} for an ideal op-amp ($A \to \infty$)?
- Consider finite A and find u_{OUT}:

Same Node ... Same Node

$$V_{in} = u_+ = u_- = u_{OUT} \implies \boxed{u_{OUT} = V_{in}}$$

"$A \to \infty$ ideal negative-feedback condition":

$$A(u_+ - u_-) = u_{OUT}$$

$A \to \infty$, $(u_+ - u_-) = 0$

$$u_{OUT} = A(u_+ - u_-) \quad (u_+ \to V_{in},\ u_- \to u_{OUT})$$

$$u_{OUT}(1 + A) = A\,V_{in}$$

$$u_{OUT} = \left(\frac{A}{A+1}\right) V_{in}$$

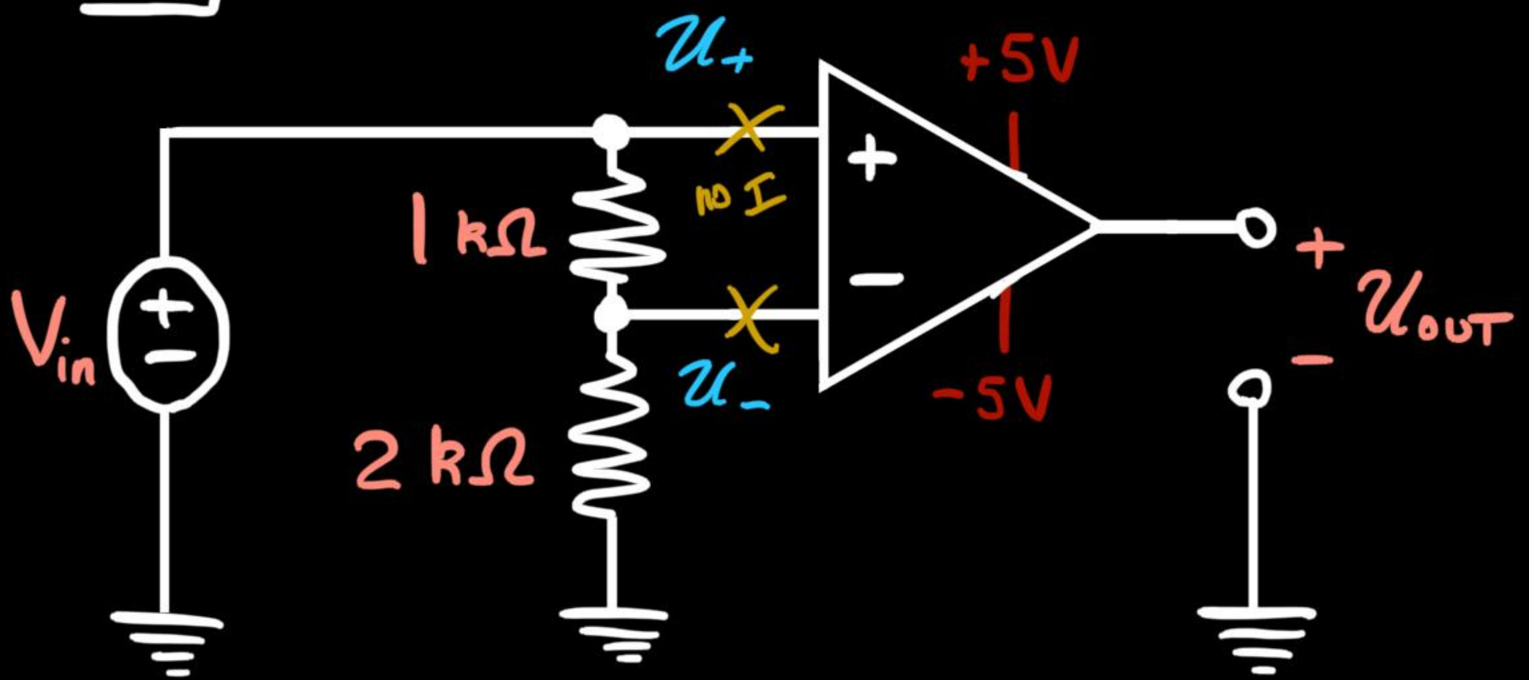
$$\boxed{u_{OUT} = \left(\frac{1}{1+(1/A)}\right) V_{in}}$$

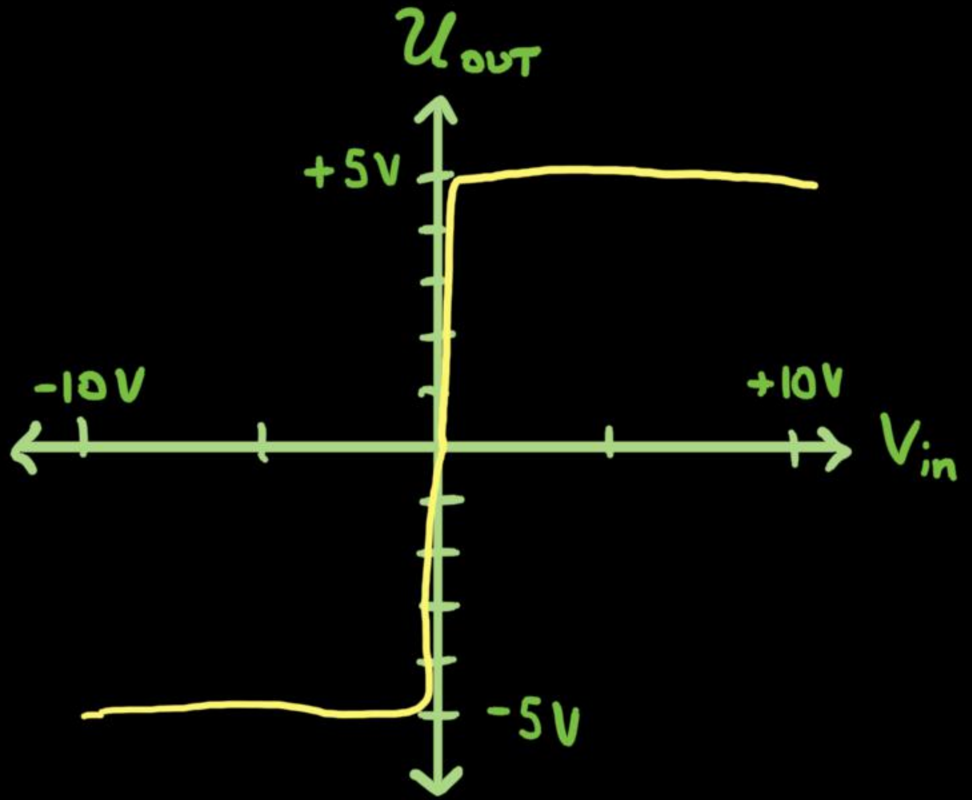
② Comparators

For the following circuits, plot $U_{OUT}(V_{in})$ on the domain $V_{in} \in [-10, +10]$ V:

$A \sim 10^6$

a)



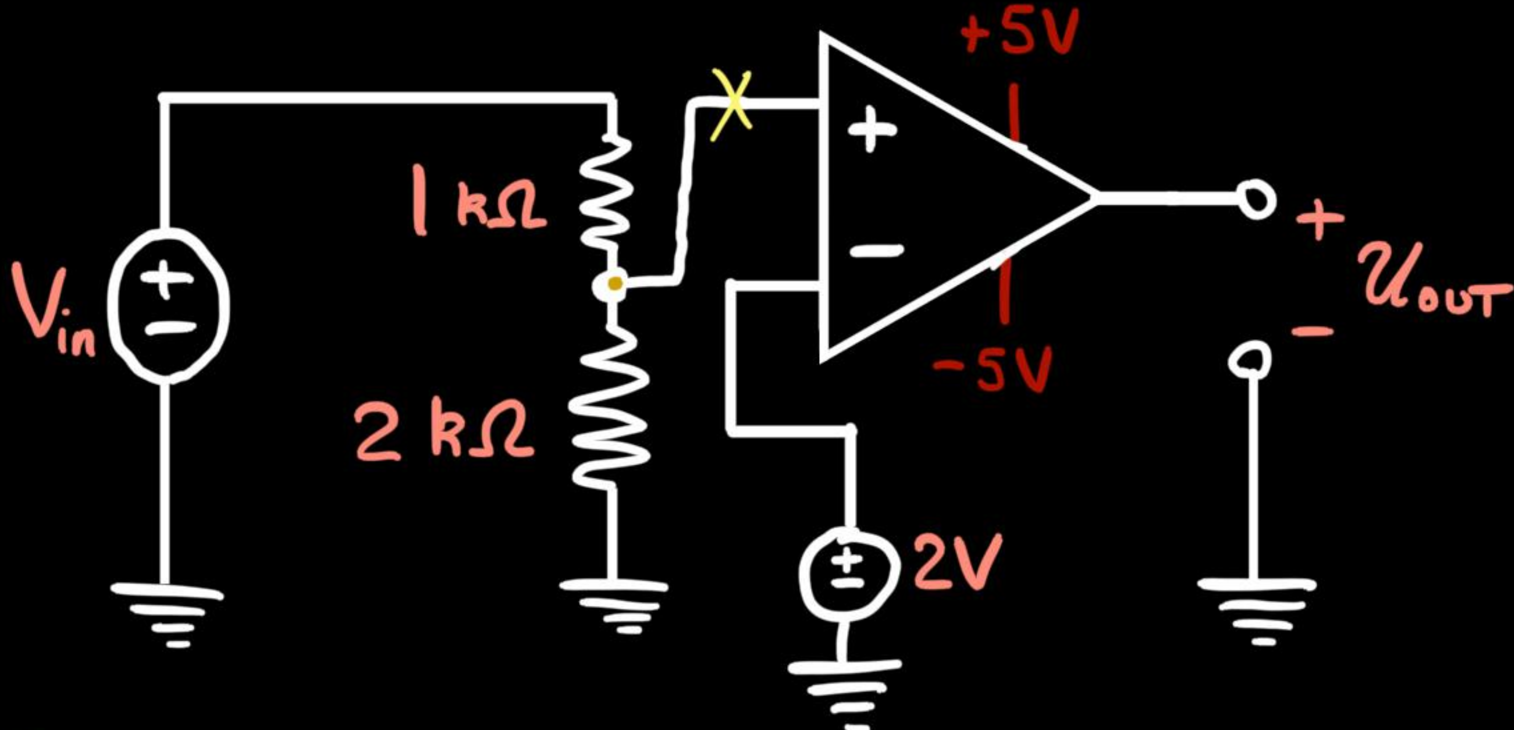


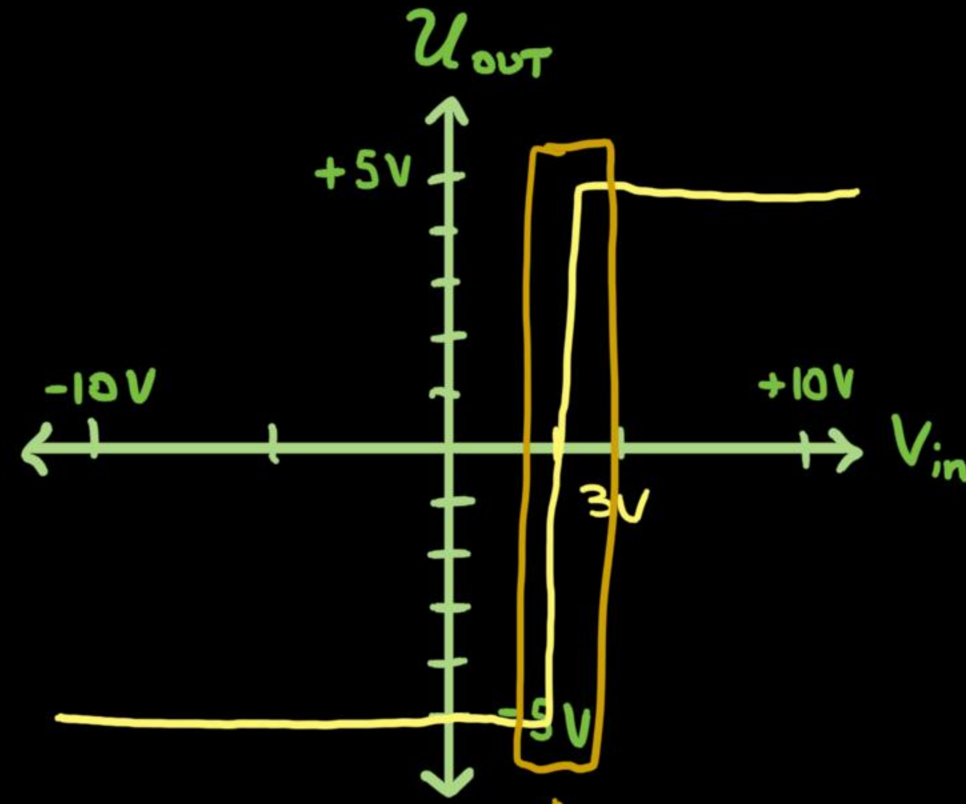
$$U_+ = V_{in}$$

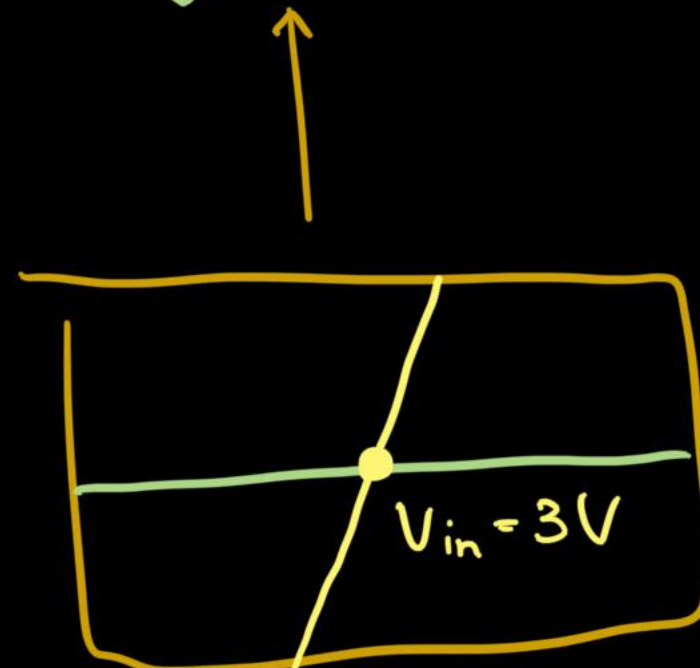
$$U_- = V_{in}\left(\frac{R_2}{R_1+R_2}\right) = \frac{2}{3}V_{in}$$

$$U_{OUT} = A(U_+ - U_-) = A\left(V_{in} - \frac{2}{3}V_{in}\right) = A\,\underline{V_{in}} \cdot \frac{1}{3}$$

b)







$$u_+ = V_{in}\left(\frac{2}{3}\right)$$

$$u_- = 2$$

$$\Longrightarrow \quad u_{OUT} = A \cdot \left(\frac{2}{3}V_{in} - 2\right)$$

$$= \frac{2}{3}A\left(V_{in} - 3\right)$$