Voltage Dividers and Analog-to-Digital Conversion

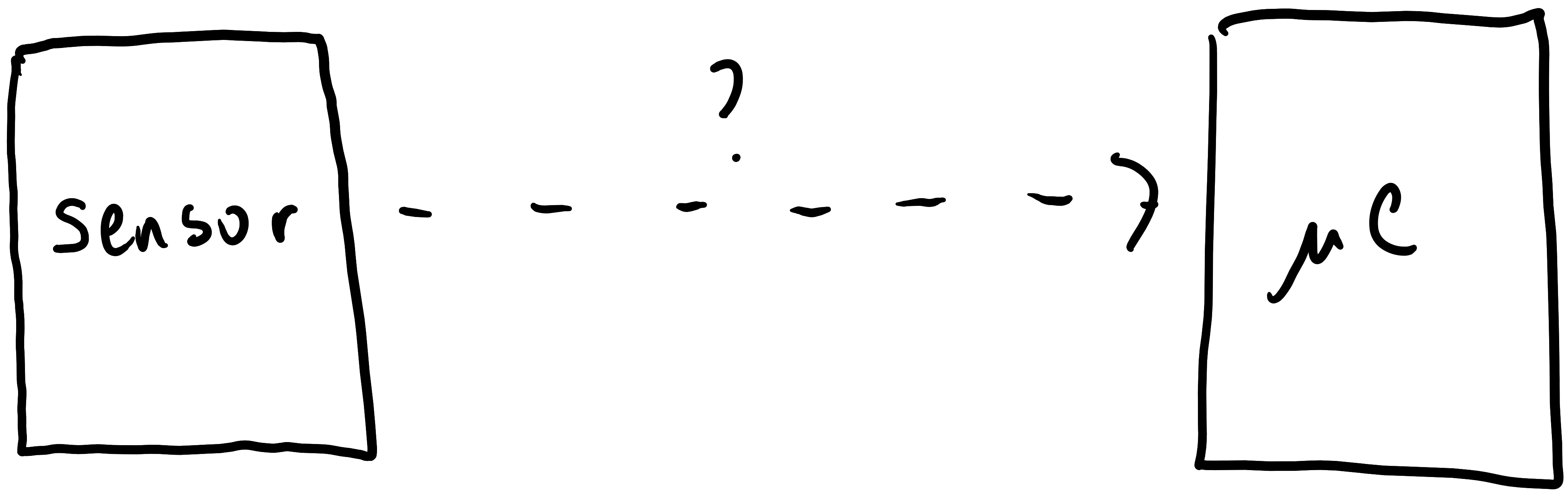
How hot is it?

Hint: it’s 2173

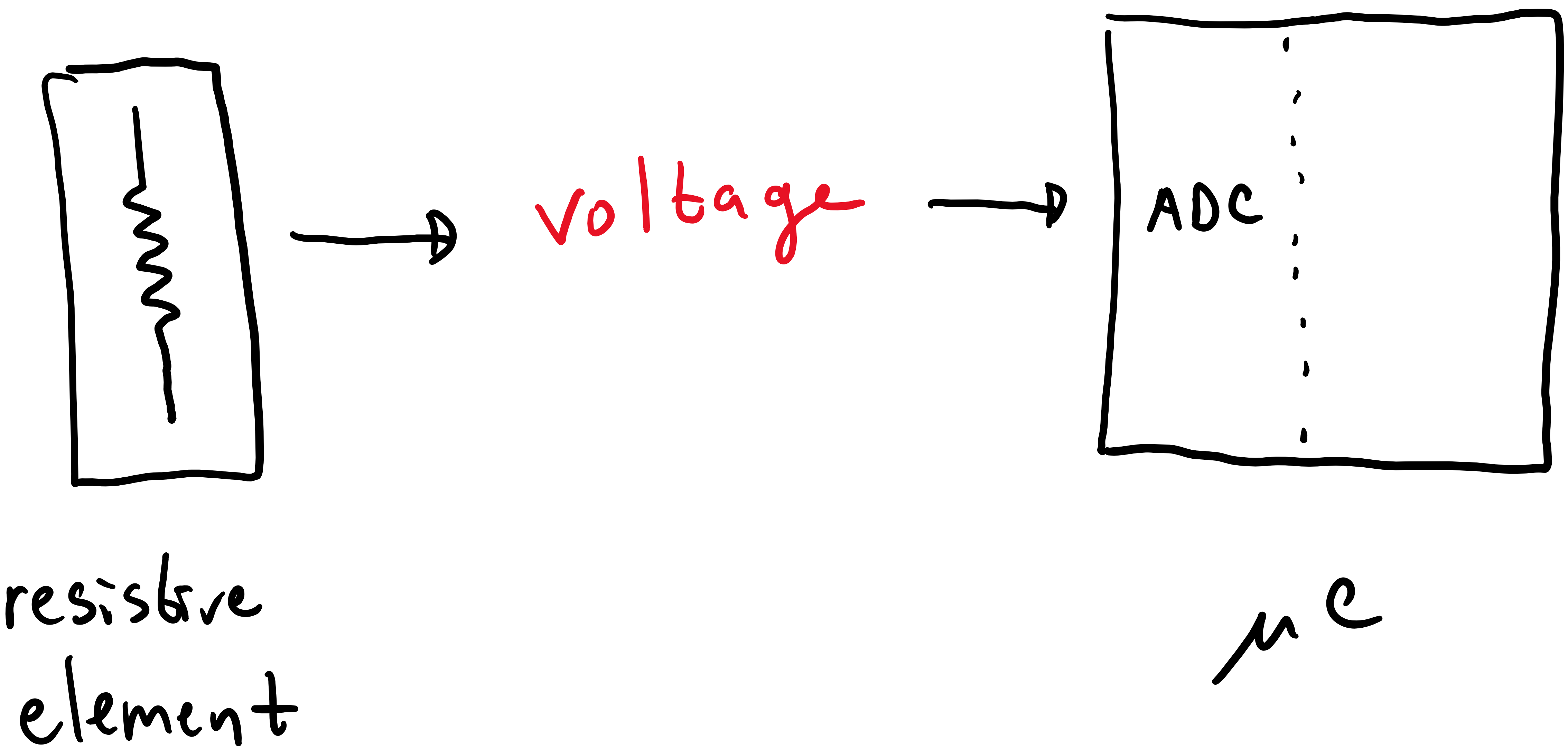
Agenda

- Review voltage dividers
- Show a useful example related to sensing
- Analog-to-digital conversion

Sensor interfaces



Sensor interfaces



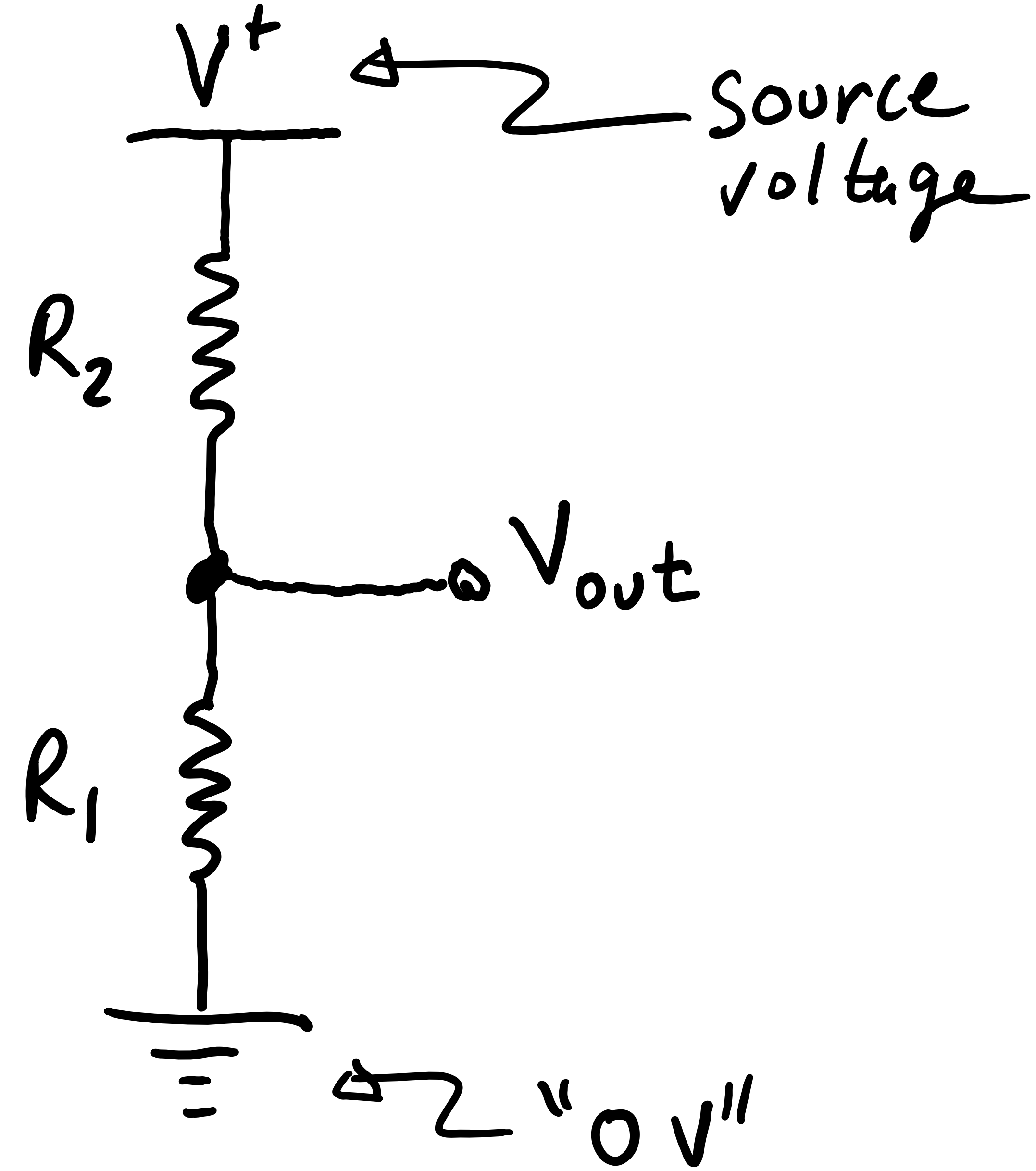
The voltage divider

(The simplest case)

- When no current flows from the junction, for the "simple" voltage divider shown, the *output voltage* is:

$$V_{out} = \frac{R_1}{R_1 + R_2} \cdot V^+$$

That is, the output voltage is just a linear interpolation of the source voltage



The voltage divider

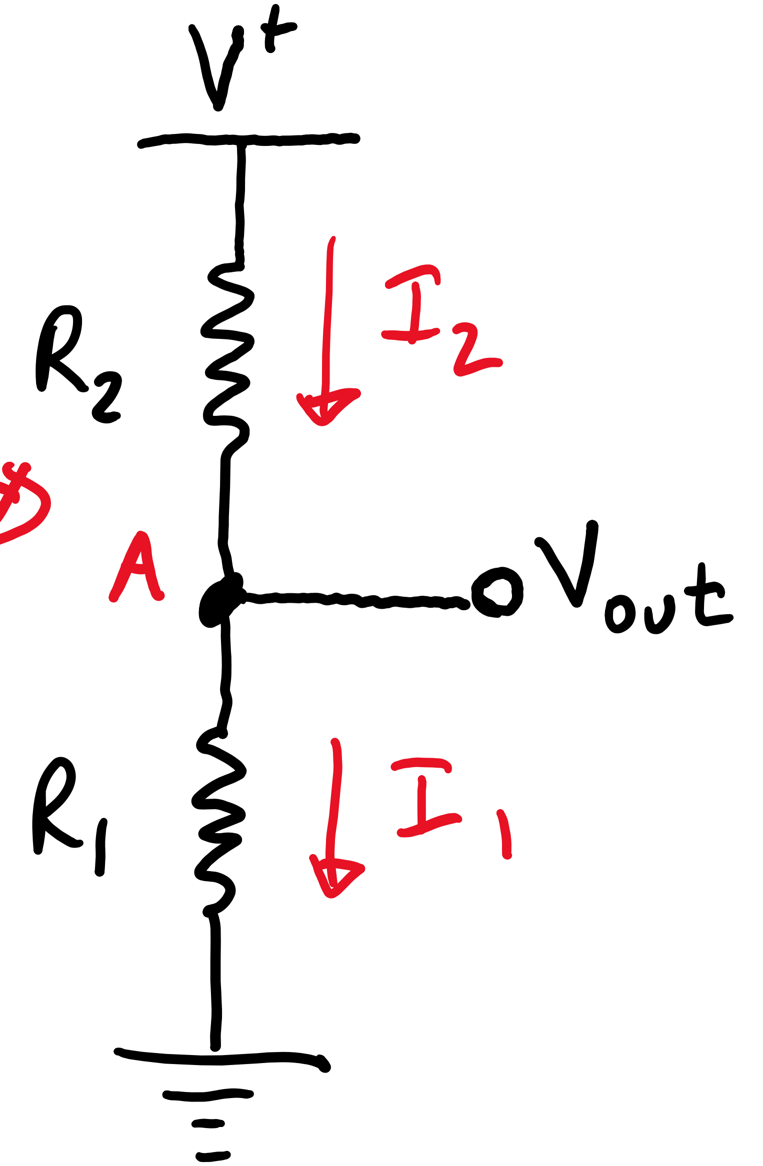
(The simplest case)

$$\Sigma I_A = 0$$

$$\therefore I_1 = I_2$$

$$\frac{V_{out}}{R_1} = \frac{V^+ - V_{out}}{R_2}$$

$$V_{out} = \frac{R_1}{R_1 + R_2} \cdot V^+$$

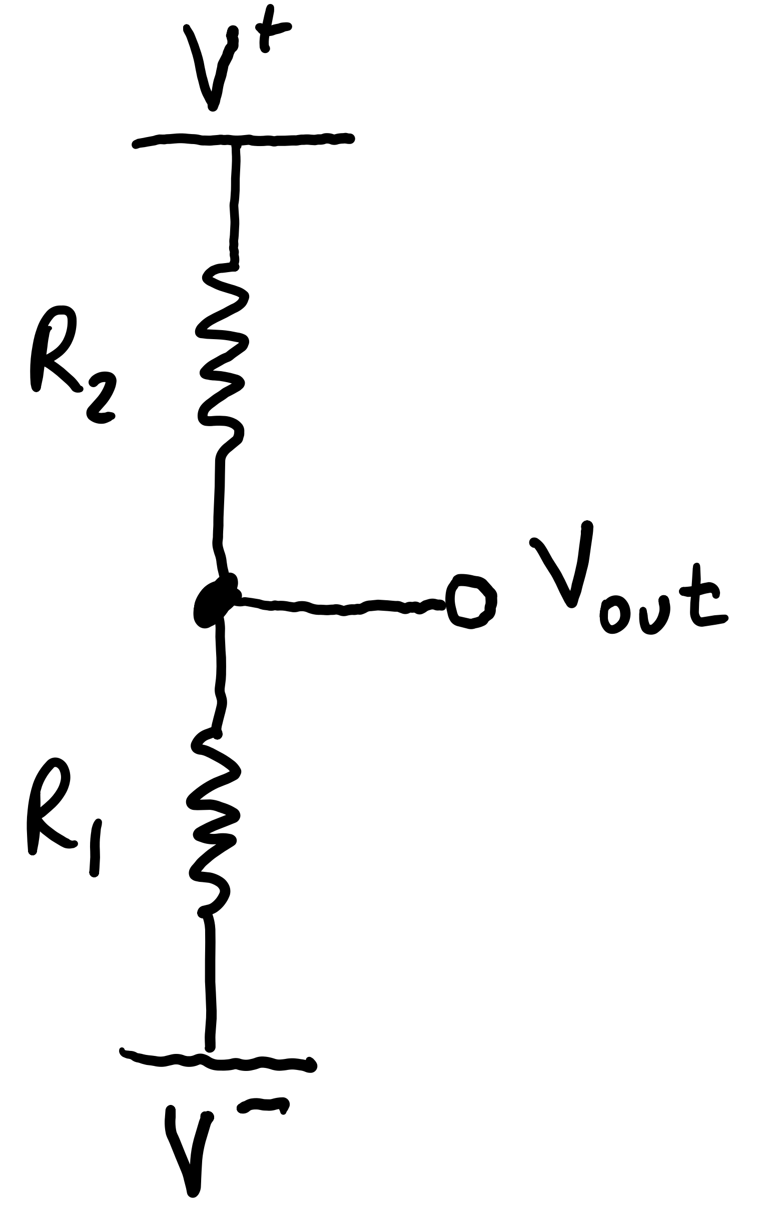


The voltage divider

- Be careful if the low voltage side is not ground!

$$\boldsymbol{V_{out}} = \boldsymbol{V^-} + \frac{\boldsymbol{R_1}}{\boldsymbol{R_1} + \boldsymbol{R_2}} \cdot (\boldsymbol{V^+} - \boldsymbol{V^-})$$

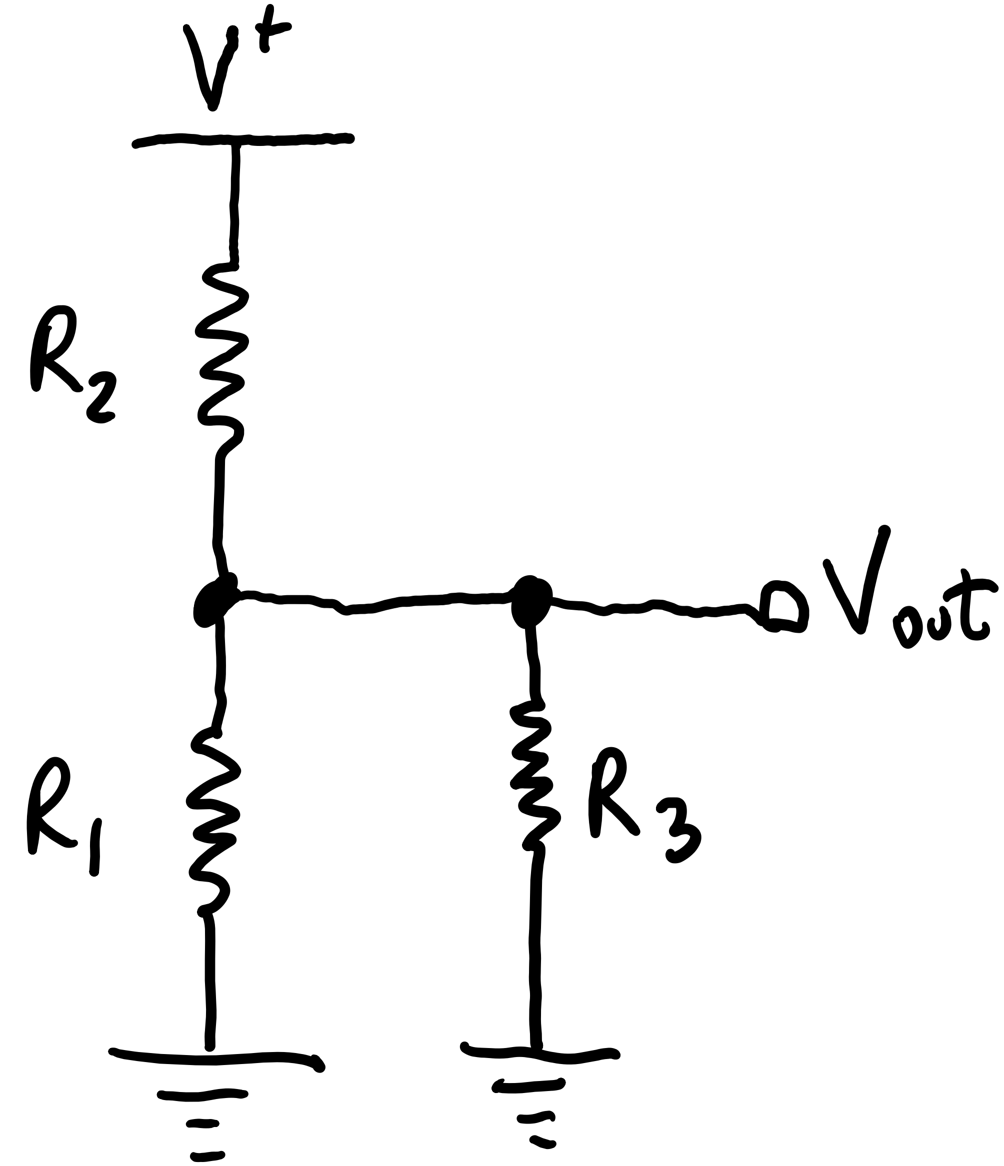
(This will show up later this week, but it's generally best to go back to the current analysis.)



The voltage divider

- Be careful that no current flows out at the junction!

$$V_{out} = \frac{R_1}{R_1 + R_2} \cdot V^+$$

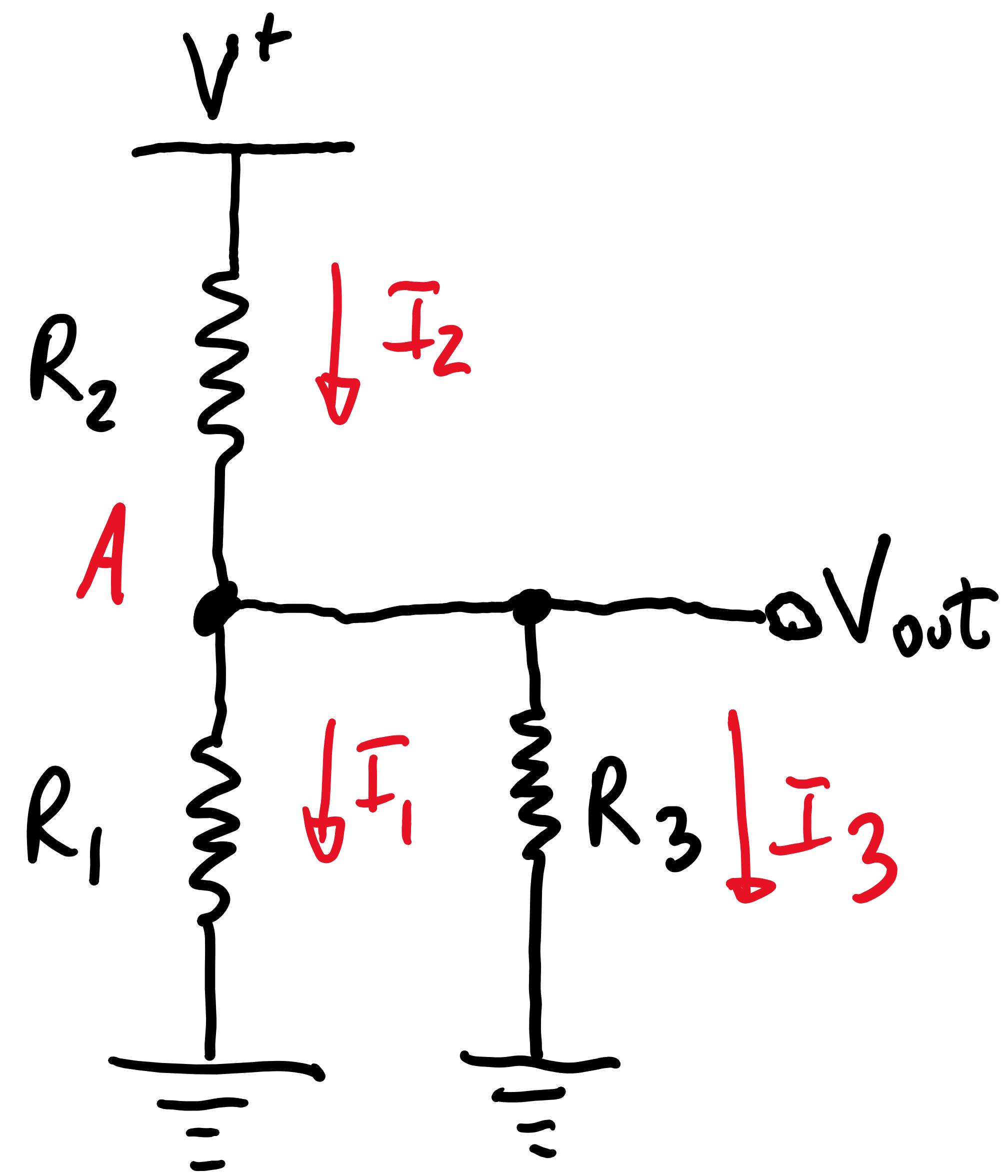


The voltage divider

$\sum I_A = 0$

$\therefore I_2 = I_1 + I_3$

$$\cancel{V_{out} = \frac{R_1}{R_1 + R_2} \cdot V^+}$$



You can always find the voltage at point A, but be careful not to apply the standard equation without verifying the assumptions!

How is this useful?

- Many sensors react to their environment by changing resistance
  - Photoresistors
  - Humidity sensors
  - Thermistors
  - Accelerometers
  - Many, many more

Thermistors

- The resistance of a thermistor is a function of temperature, for example,

$$R = R_0 e^{-B\left(\frac{1}{T_0} - \frac{1}{T}\right)}$$

where the temperatures are in Kelvin and B is some constant specified by the manufacturer. R_0 is the nominal resistance at the reference temperature, T_0.

How is this useful?

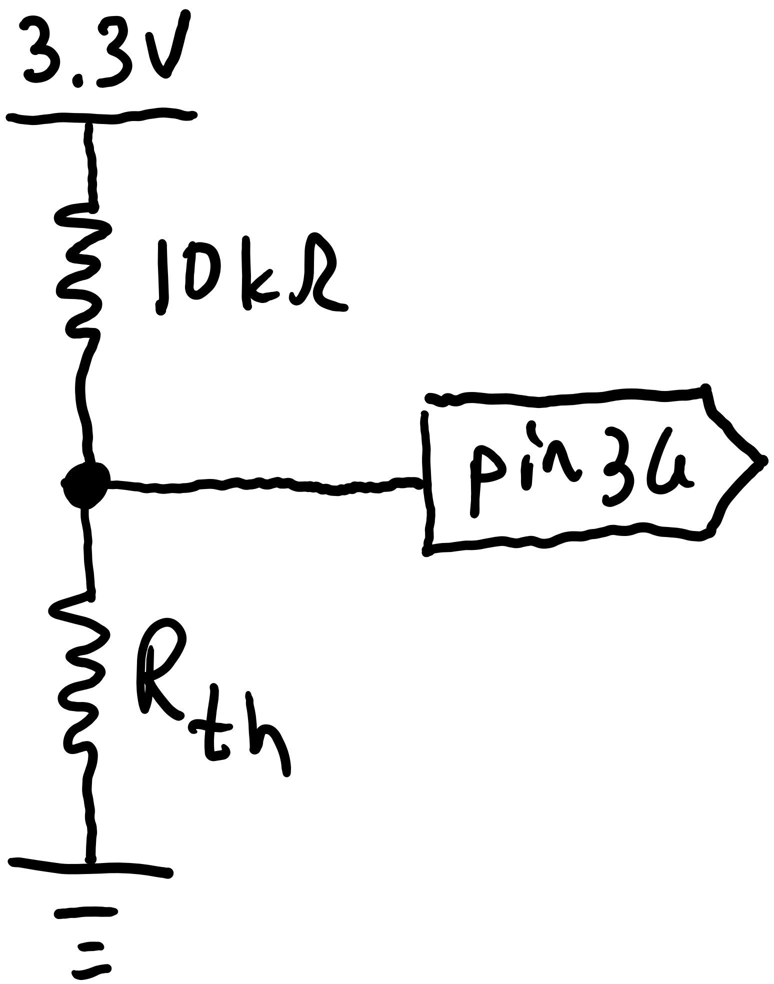
(Microcontrollers can’t read resistance directly.)

How is this useful?

(Microcontrollers can’t read resistance directly.)

They do, however, read voltages.

So let's put the thermistor in a voltage divider!



$$V_{out} = \frac{R_{th}}{R_{th}+10k\Omega} * 3.3V$$

So…

Let T = 25 C. <u>What is the voltage at the junction of the voltage divider</u>?

$$R = R_0 e^{-B\left(\frac{1}{T_0} - \frac{1}{T}\right)}$$

$$V_{out} = \frac{R_{th}}{R_{th} + 10k\Omega} * 3.3V$$

From the datasheet

- T_0 = 25 C; R_0 = 10 kOhms; B = 4300 K

Temperature (C)	Resistance (ohms)
17.5	14514
20	12792
22.5	11298
25	10000
27.5	8869
30	7881
32.5	7017

So…

Let T = 25 C. <u>What is the voltage at the junction of the voltage divider</u>?

$$R = R_0 e^{-B\left(\frac{1}{T_0} - \frac{1}{T}\right)} = 10k\Omega$$

$$V_{out} = \frac{\overset{=10k\Omega}{R_{th}}}{\underset{10k\Omega=}{R_{th}} + 10k\Omega} * 3.3V = \frac{1}{2} \cdot 3.3V$$

$$= \boxed{1.65V}$$

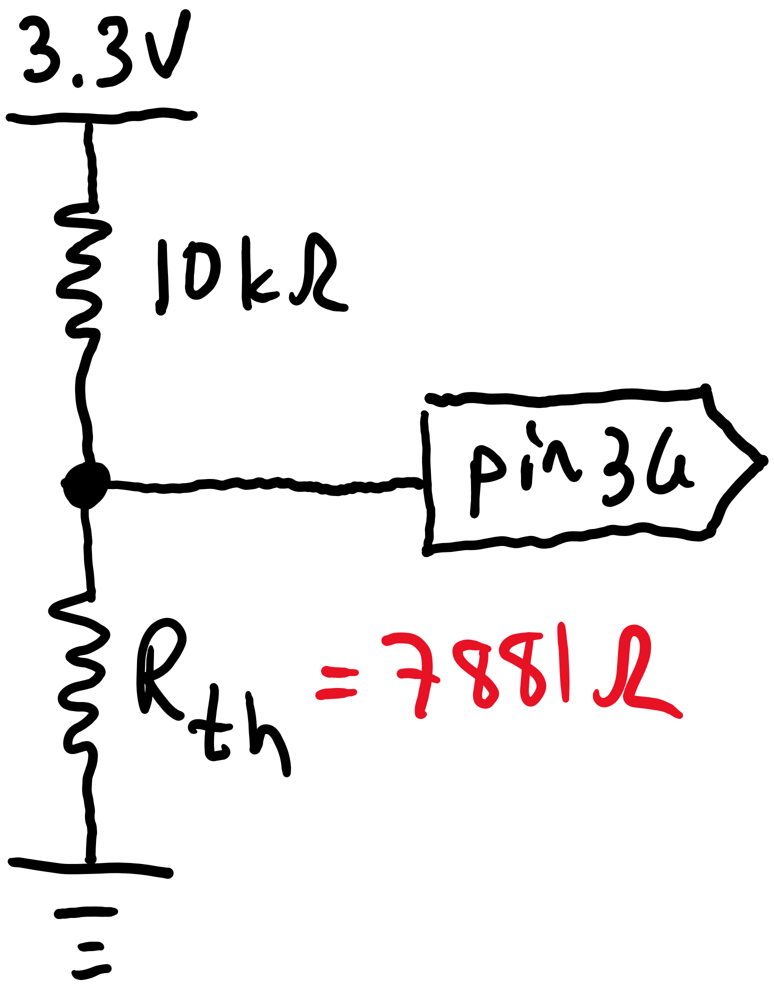
So…

Let T = 30 C. <u>What is the voltage at the junction of the voltage divider</u>?

$$R = R_0 e^{-B\left(\frac{1}{T_0} - \frac{1}{T}\right)} = 7881\,\Omega$$

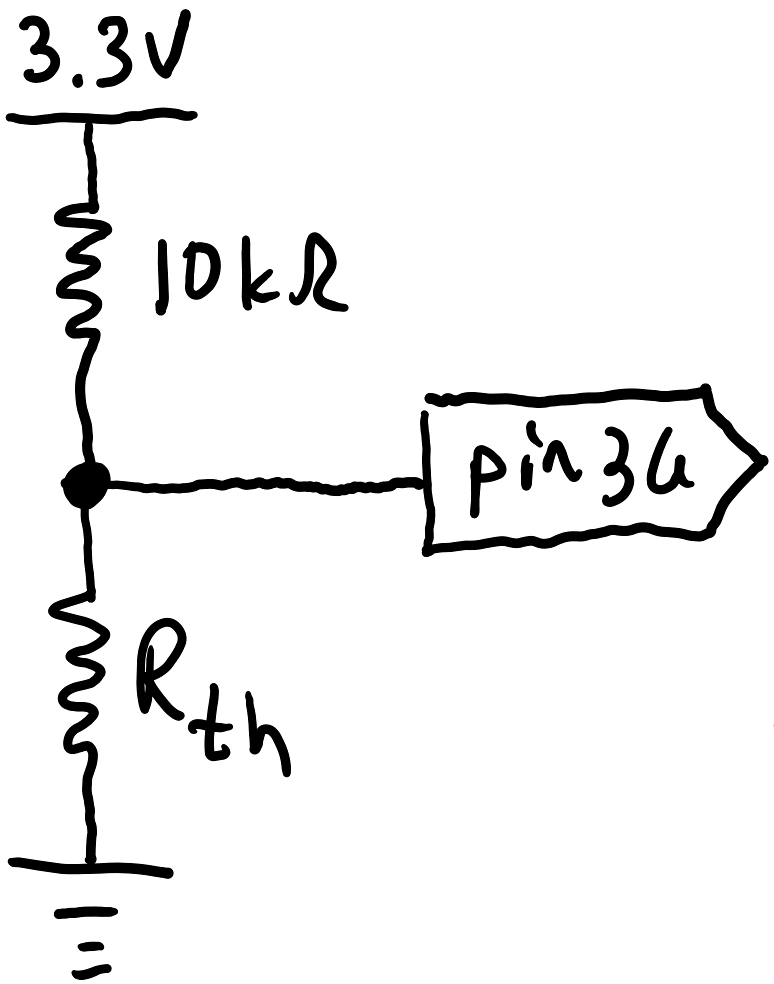
$$V_{out} = \frac{R_{th}}{R_{th} + 10k\Omega} * 3.3V$$

Will V_out be higher or lower than 1.65 V?



$$V_{out} = \frac{R_{th}}{R_{th} + 10k\Omega} * 3.3V$$

So let’s put the thermistor in a voltage divider!

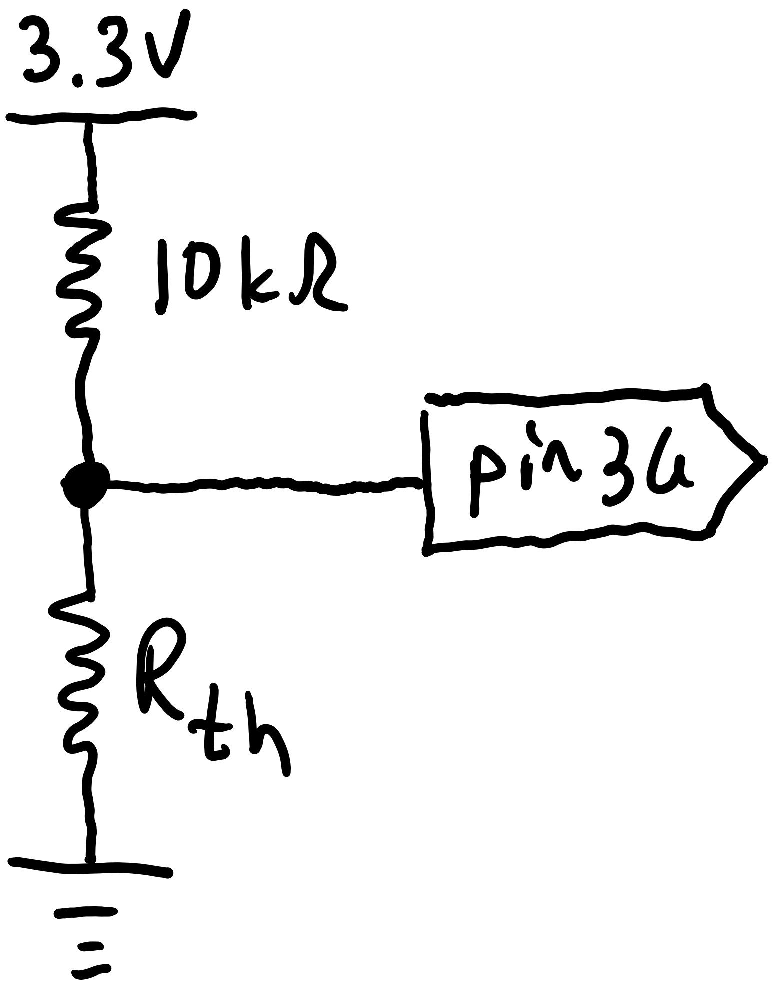


$$V_{out} = \frac{R_{th}}{R_{th} + 10k\Omega} * 3.3V$$

If $R_{th}\downarrow$, there is <u>less</u> voltage drop than across the 10kΩ resistor, so $V_{out}\downarrow$

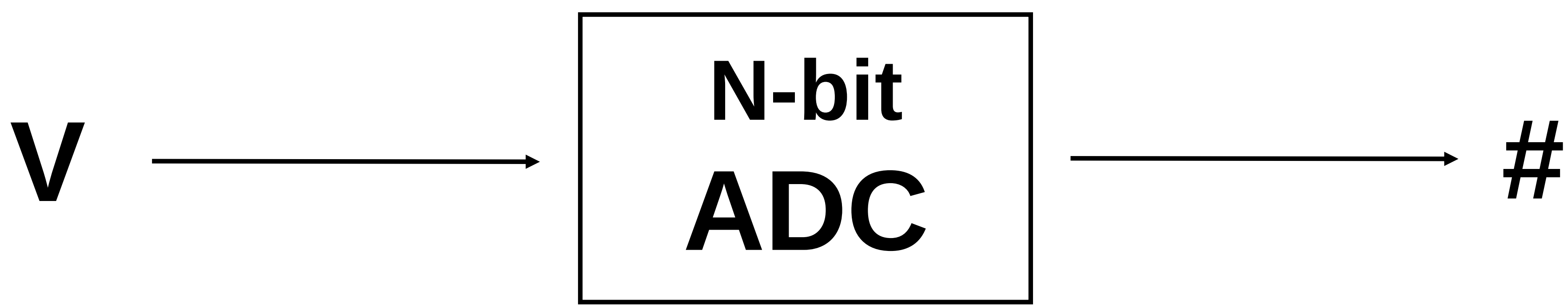
OK, so now what?

Microcontrollers use <u>numbers</u>, not voltage!



$$V_{out} = \frac{R_{th}}{R_{th}+10k\Omega} * 3.3V$$

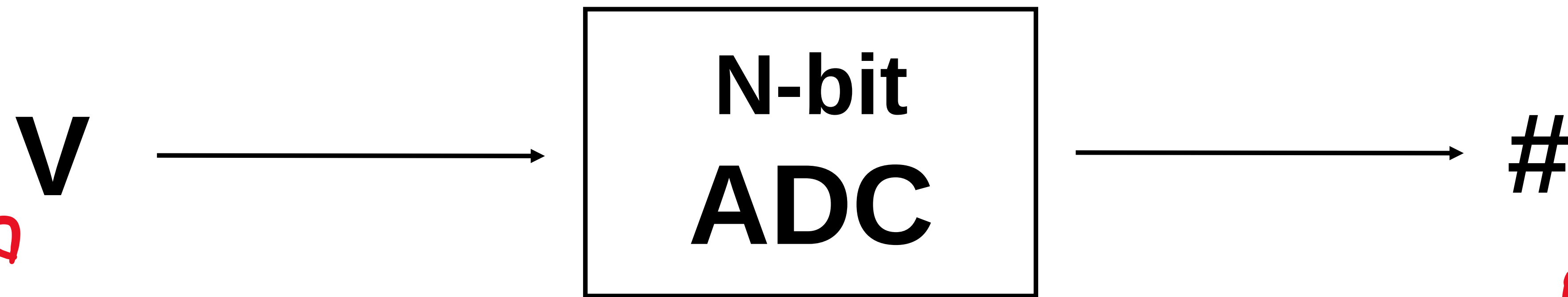
Analog-to-Digital Conversion (ADC)



$$\textbf{result} = \textbf{floor}\left[\frac{V}{V_{ref}} \times 2^{N}\right]$$

With one caveat: if V = V_{ref}, the result can't be 2^N. Why?

Analog-to-Digital Conversion (ADC)



"sample" voltage

result

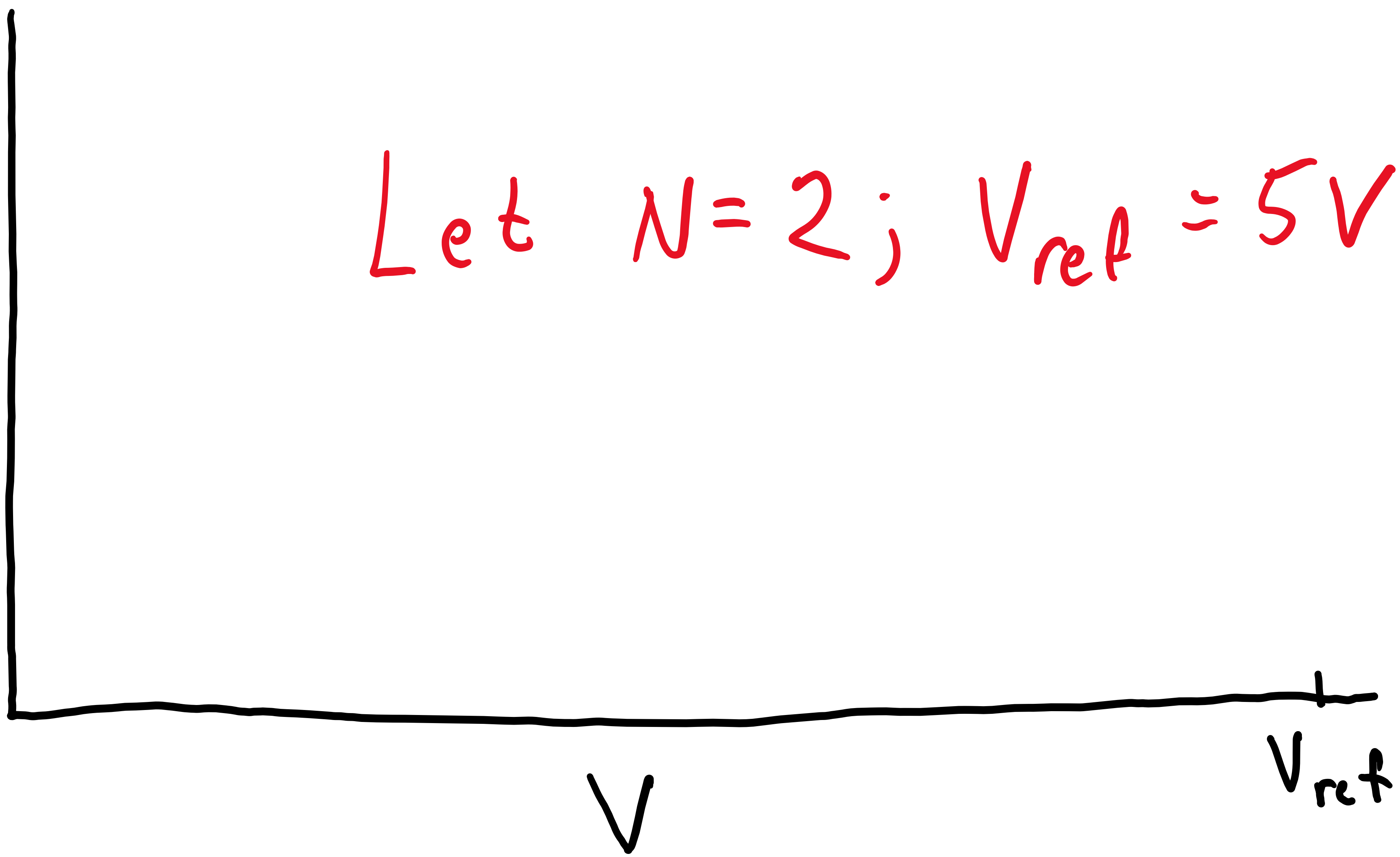
$$\textbf{result} = \textbf{floor}\left[\frac{V}{V_{ref}} \times 2^N\right]$$

reference voltage

With one caveat: if V = V_{ref}, the result can't be 2^N. Why?

ADC: What magic is this?

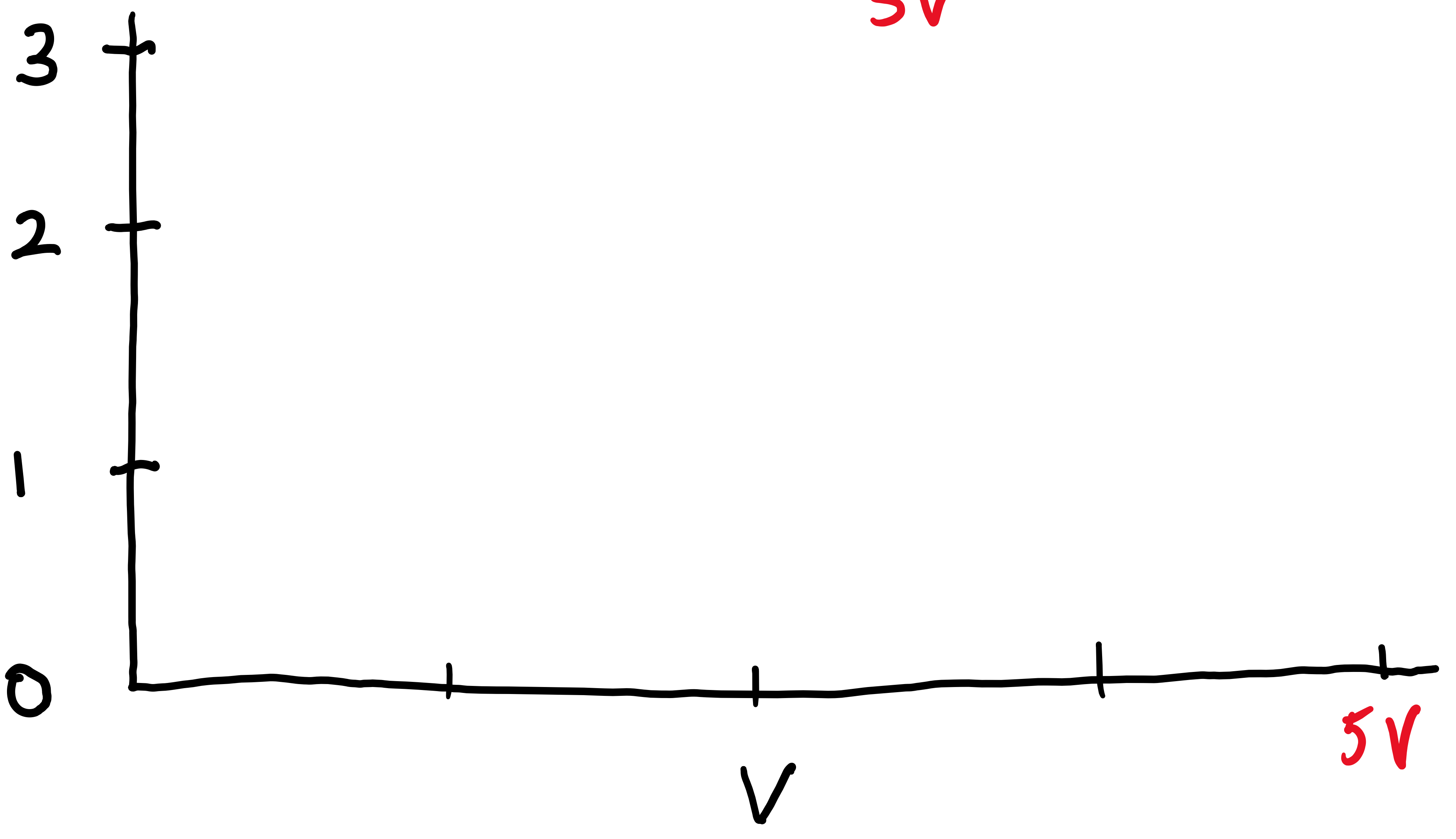
$$\textbf{result} = \textbf{floor}\left[\frac{V}{V_{ref}} \times 2^N\right]$$



ADC: What magic is this?

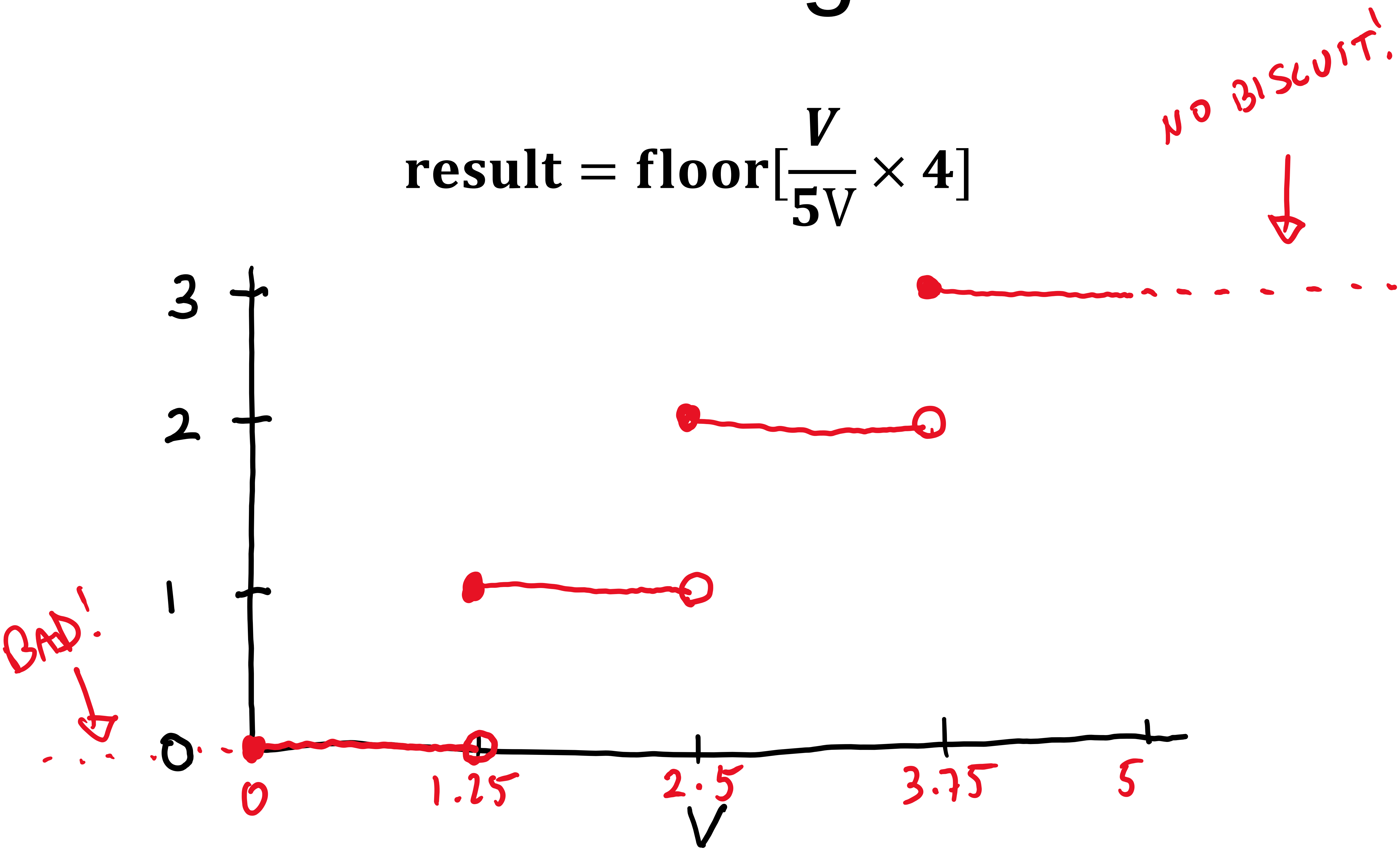
$$\mathbf{result} = \mathbf{floor}\left[\frac{V}{\cancel{V_{ref}}} \times \cancel{2^N}\right]$$

5V 4



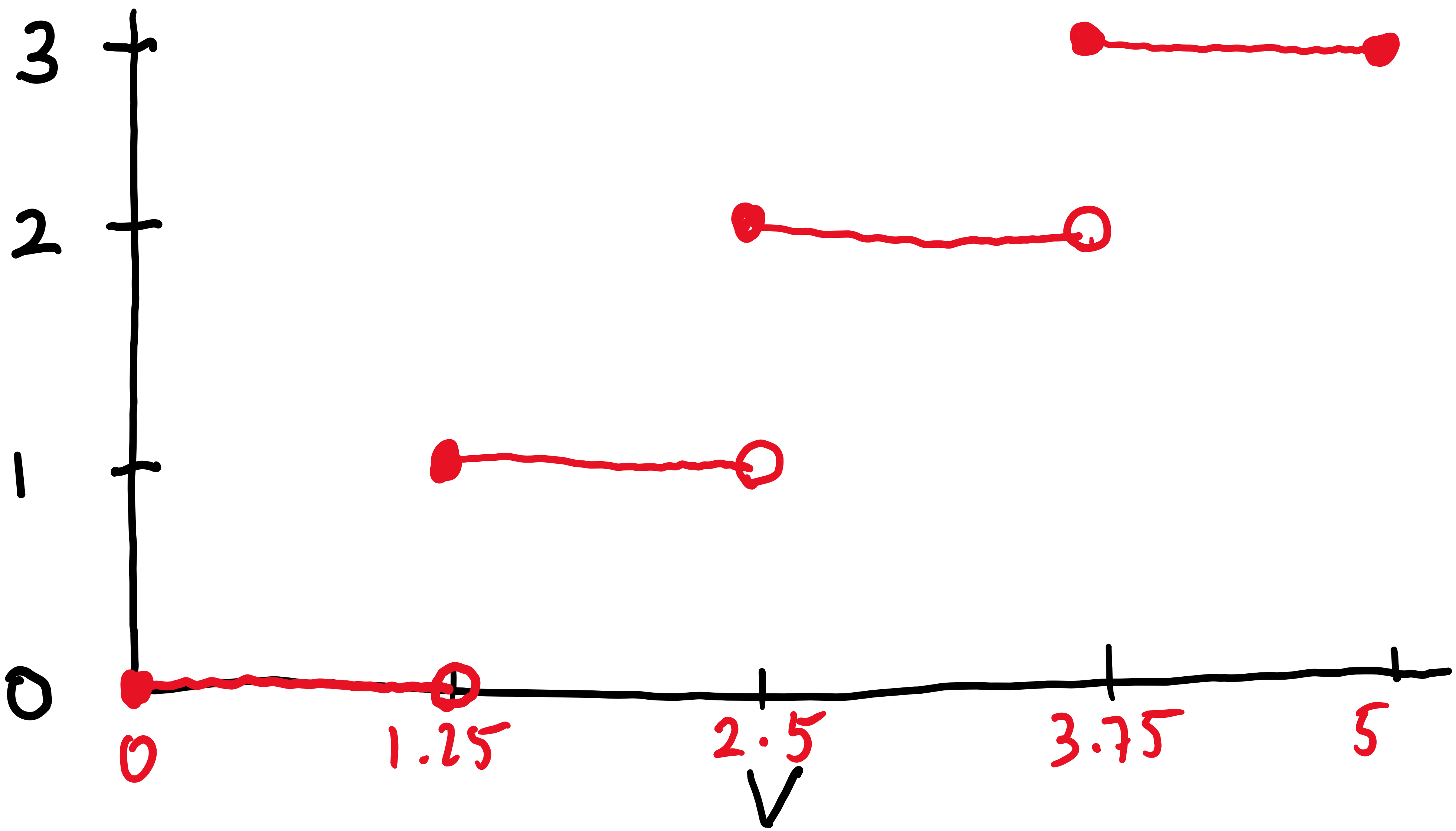
ADC: What magic is this?

$$\textbf{result} = \textbf{floor}[\frac{V}{5\text{V}} \times 4]$$

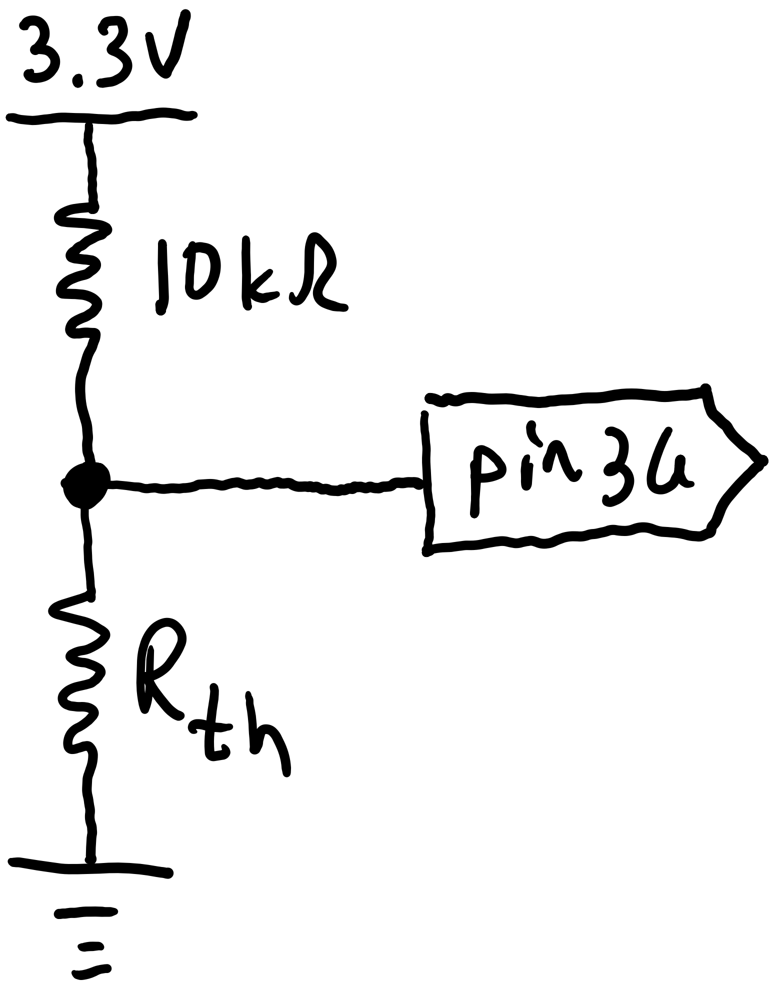


Working backwards

$$\mathbf{result} = \mathbf{floor}[\frac{V}{5\mathrm{V}} \times 4]$$



Now it's your turn: 2173



$$V_{out} = \frac{R_{th}}{R_{th}+10k\Omega} * 3.3V$$

Temperature (C)	Resistance (ohms)
17.5	14514
20	12792
22.5	11298
25	10000
27.5	8869
30	7881
32.5	7017

$$\mathbf{result} = \mathbf{floor}[\frac{\boldsymbol{V}}{\boldsymbol{V_{ref}}} \times \mathbf{2}^{\boldsymbol{N}}]$$