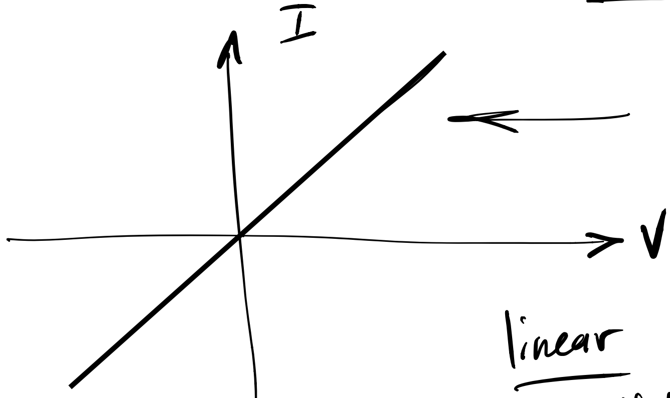
Non-Linear Devices

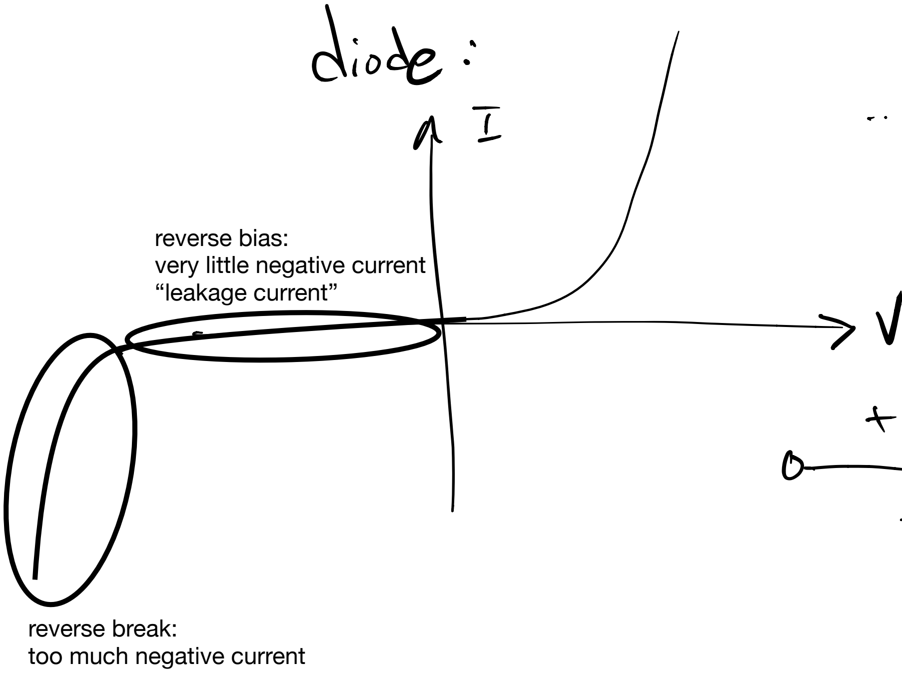
resistor:



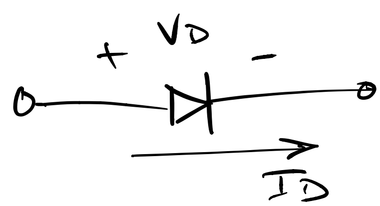
slope $= \dfrac{\Delta I}{\Delta V} = \dfrac{1}{R}$

linear relationship between voltage and current

diode:



∴ not just non-linear, not much (ideally zero) current at negative voltages!



conductors : easily pass current, low resistance

Ag Al Cu

insulators (a/k/a dielectrics) : high resistance

glass, plastic, rubber, etc..

Semiconductors : Unique place in between

elemental : Ge Si

$\hookrightarrow$ germanium

alloy : nichrome, brass

$\hookrightarrow$ used in resistance wire for wirewound resistors

-- atomic structure of material determines current flow properties!

.. Silicon is very abundant on planet Earth

$\longrightarrow$ most important semiconducting material

.. elemental Si has no free electrons and thus high resistance

.. "doping" is the addition of other chemicals to change electronic characteristics

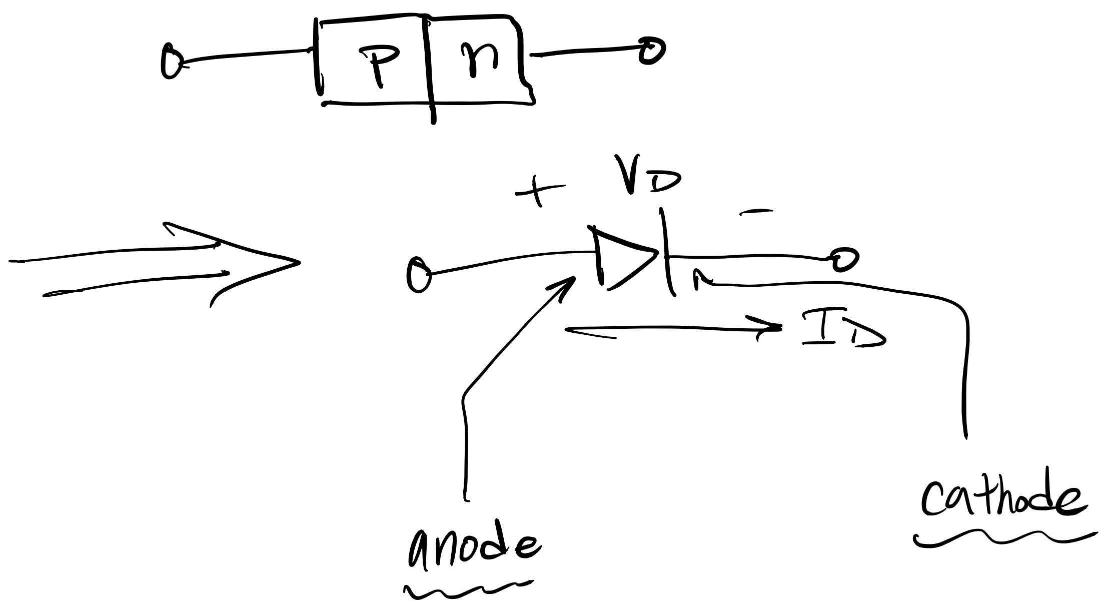
Si doped with boron → <u>p-type silicon</u>

Si doped with phosphorus → <u>n-type silicon</u>

<u>pn junction</u> : n-type and p-type sandwich

→ results in a <u>silicon diode</u>.

pn junction: p stands for positive,
n stands for negative



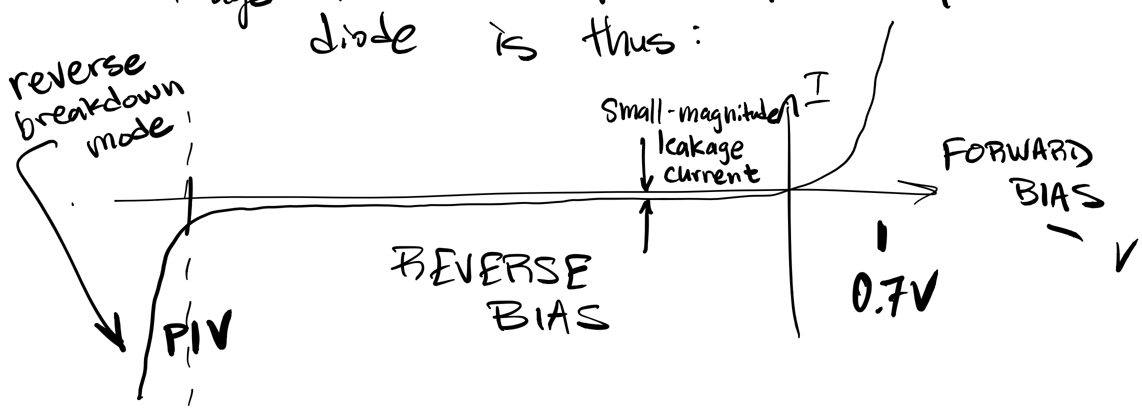
∴ if V_D is positive; i.e., the anode is more positive than the cathode, I_D will flow from anode to cathode and the diode is said to be

forward biased.

[electrons are flowing from cathode to anode]

∴ if V_D is negative, i.e. anode negative with respect to cathode, very little current will flow [unless V_D becomes very negative] and the diode is reverse biased.

∴ voltage-to-current relationship for p·n silicon diode is thus:

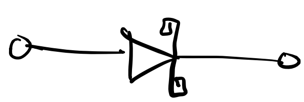


- note: for Si diode, current rapidly increases above ~ 0.7 V [@ room temperature; smaller voltage as T ↑]

∴ We often use a constant drop model for forward-biased Si diode of 0.7 V.

- germanium diodes have lower V_D of ~ 0.2V
  - much more leakage current in reverse-bias
  - worse temperature coefficient

- Schottky diodes have V_D ~ 0.15 to 0.4V



but much more sensitive to reverse breakdown

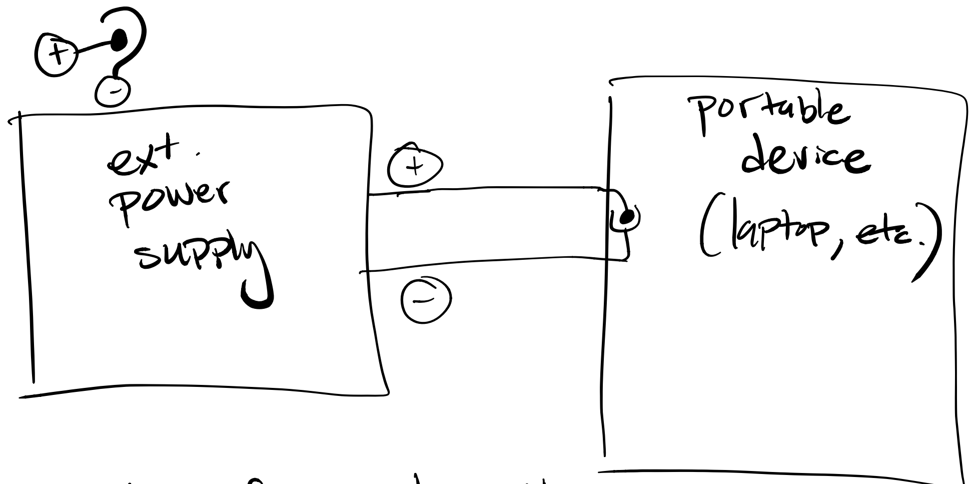
→ low PIV rating

peak inverse voltage

↳ essentially maximum negative V_D before breakdown

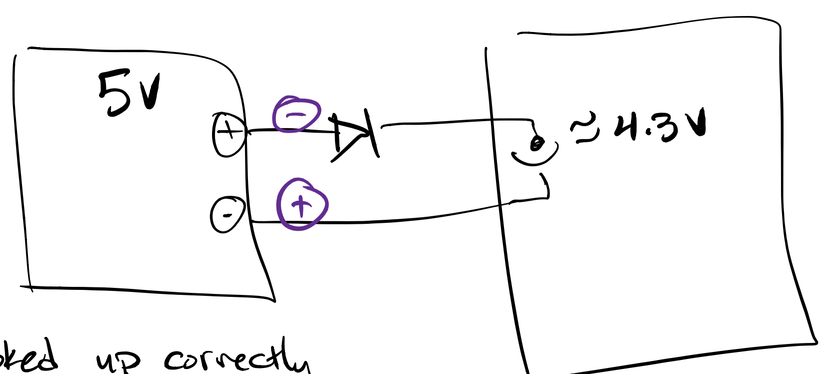
∴ what are diodes good for?

ex: reverse-polarity protection



∴ what if you have the <u>wrong</u> power supply and polarity is reversed? BAD things happen!

∴ use a diode to essentially prevent current flow if backwards



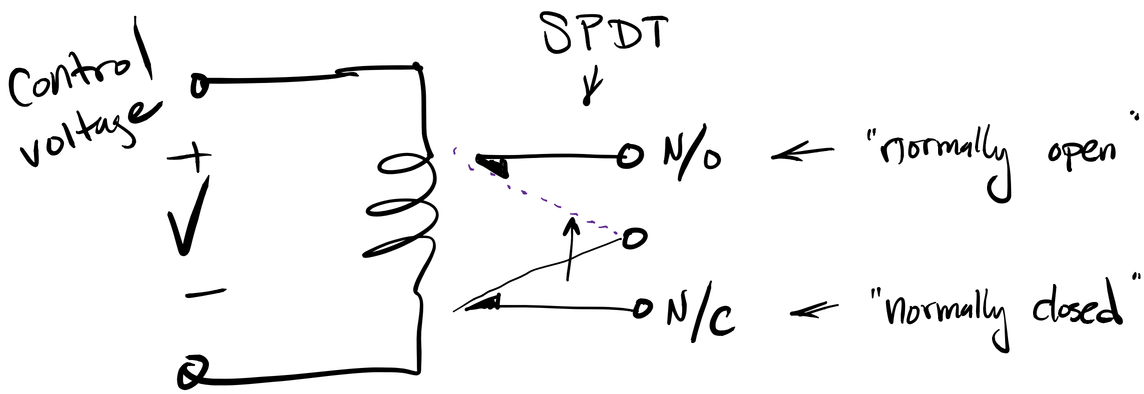
∴ hooked up correctly, forward-biased; <u>lose ~0.7V if Si</u>

∴ hooked up backwards, <u>reverse biased</u>; doesn't work

- transient supressor (a/k/a flyback diode)

  - introduce electromechanical relay

    - uses solenoid to open or close switch contacts w/ external voltage



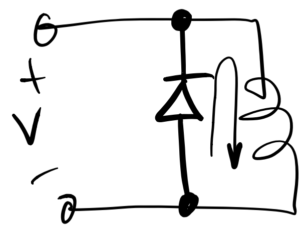
- solenoid is inductive

- switching voltage into coil → no big deal
- switching OFF : interrupts current in inductor

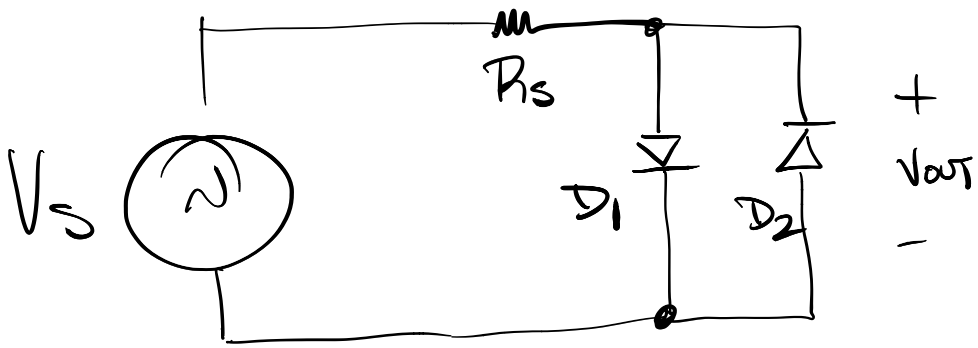
→ large back EMF spike

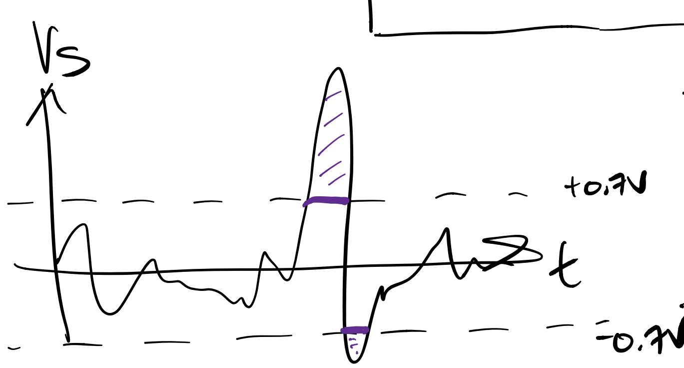
$$V_L(t) = L \frac{di_L(t)}{dt}$$

∴ solution: add a diode in parallel w/ relay coil → clamps voltage to ~0.7V when switching off



ex: clipping circuit: what if we need some time-varying signal to be limited to a certain magnitude?



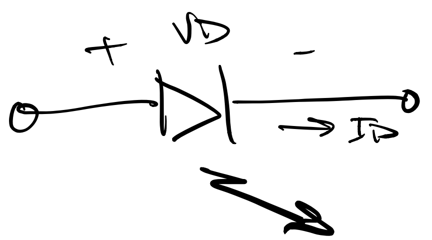


∴ large positive peaks forward-bias D_1 and limit V_{OUT} to ~0.7V

∴ large negative peaks forward bias D_2 and limit V_{OUT} to ~ 0.7V

LED "light emitting diode"

- forward-bias: 1.8 - 2.2 V, depending on color ↑ determined by doping!

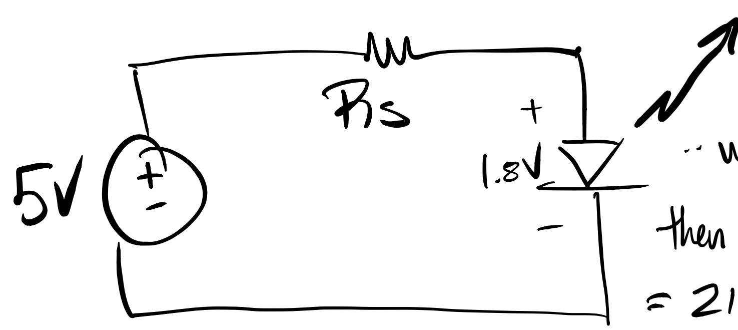


"cheap red LED" ~ 1.8V

- usually become visible @ ~ 1mA
  "good brightness" @ 10mA
  max. current: 30 mA or so

- LEDs do have relatively low PIV rating and are sensitive to reverse breakdown

ex:



- assume $V_D \sim 1.8V$
- want 15mA

then $R_S = \dfrac{5 - 1.8V}{0.015}$

$= 213.3 \rightarrow$ use 220 Ω ← E24

$\therefore$ check power in resistor:

$$P = I^2 R = 0.015^2 \cdot 220 = \underbrace{0.0495\,\mathbf{W}}$$

1/4-watt resistors in lab just fine!