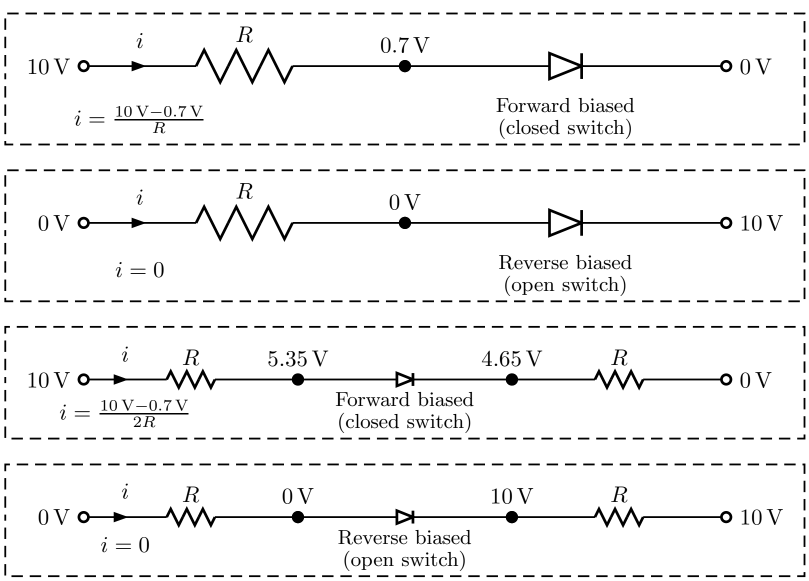
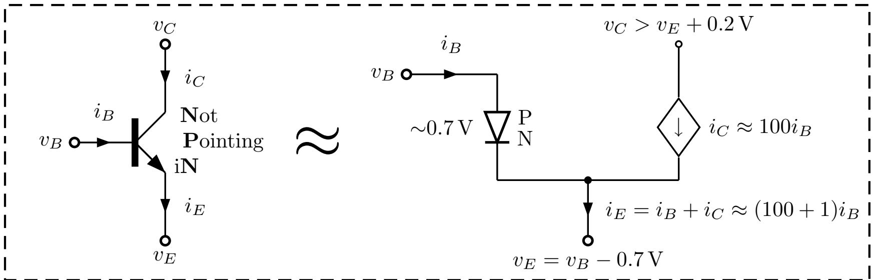
ECE 209: *Circuits and Electronics Laboratory*

Notes for Lab 6 (Nonlinear Circuits: Diode and Transistor Switch)

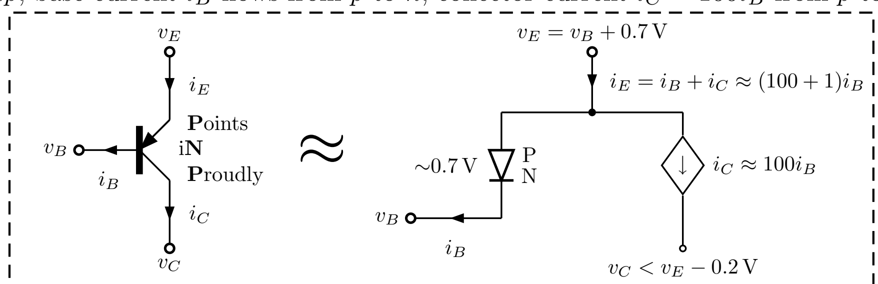
1. This lab strays a little from signals and systems into circuits.
   - Controls, signals, and communications engineers use abstract blocks. ***Gross*** oversimplification:
     - Signals and systems: analyze mathematical descriptions to determine impact on waveforms (input **and** output) (ECE 351/352/600).
     - Communications: How to change **input** to communicate over given channel (ECE 501/508).
     - Controls: How to adjust system for desired **output** (ECE 551/557).
   - Circuits people implement blocks with *physical devices* (ECE 323/327/628).
   - Materials people use *physical properties* to make devices (ECE 331/432/637).
   - Physicists do experiments (i.e., **science**) to describe behavior of physical world.
2. Nonlinear circuits (v not linearly related to i, i', or $\int i$)
   - A ***diode*** is a pn-**junction;** it joins a "p-type material" with an "n-type material."
     - The p-type material is **neutral,** but its covalent lattice is incomplete; it *lacks* electrons in spots. Those spots where it is lacking are called "holes" and they act like positive charges.
     - The n-type material is **neutral,** but there are **more** electrons than needed for covalent lattice.
     - When the two materials are joined, p-type "holes" diffuse into the n-type material and n-type electrons diffuse into the p-type material (like different colored gasses mixing).
     - Diffusion causes the n-type material to become positively charged and the p-type material to become negatively charged. This **dipole** creates a force that **stops** further diffusion.
     - By applying a voltage to cancel the dipole, diffusion can continue and current will easily flow through the diode like a closed switch.
     - For **silicon diodes** at **room temperature,** $\sim$0.7 V of "forward bias" turns off dipole.
       * Picture spring-loaded ball check valve — small forward "cracking pressure" opens valve.
       * We use 1N914/1N4148 diodes — $v_D \approx 0.7\,\text{V}$ @ $i_D \geq 10\,\text{mA}$; $v_D \approx 0.6\,\text{V}$ @ $i_D \approx 1\,\text{mA}$.
         - In today's lab, i_D will be slightly **less than** 1 mA, and so $v_D < 0.6\,\text{V}$ (e.g., 0.5 V).
     - Diode symbol indicates direction of forward bias (arrow pointing in direction of current flow) — current flows from p to n.



- A ***bipolar transistor*** is a sandwich of three alternating types of semiconductor (*npn* or *pnp*).
  - Current through device is amplified version of (forward-biased) *pn*-diode current.
    - Middle region is called **base.**
    - Complementary section of *pn* diode is called **emitter** (symbol arrow indicates emitter).
    - Other region is called **collector.**
  - For transistors in our lab, base current is amplified by ∼100:
    - For *npn*, base current i_B flows from *p* to *n*; collector current $i_C \approx 100 i_B$ from *n* to *n*.



    - For *pnp*, base current i_B flows from *p* to *n*; collector current $i_C \approx 100 i_B$ from *p* to *p*.



    - Collector-to-emitter region acts like **resistor** that *tries* to adjust to ensure $i_C \approx 100 i_B$.
      - A **transistor** is a **trans**fer (variable) re**istor.**
      - Also called a *transconductance* (variable) resistor, but the justification for that use is outside the scope of this class.
      - Transistor can only act like *positive resistance.* That is, when i_B gets too large, transistor acts like a *short circuit* between collector and emitter.
        - When $i_B \gg 0$, "saturation mode" puts "closed switch" between collector and emitter.
        - When $i_B = 0$, "cutoff mode" sets $i_C = 0$ (note that $i_B \geq 0$ always).
        - When i_B is small, "active mode" means $i_C \approx 100 i_B$ (not used today).
      - Just like diode, collector-to-emitter "switch" has a small voltage (∼0.2) across it.
  - Bipolar symbol has arrow showing position of diode.
    - *npn* symbol is **n**ot **p**ointing **in**; *pnp* symbol **p**oints **in** **p**roudly.
  - In this lab, we make i_B zero or so large that transistor is in its "switching" regions.
    - Collector-to-emitter is either "open" (cutoff: $i_B = 0$) or "closed" (saturation: $i_B \gg 0$).
    - "Active" mode *is* used in many *analog* applications (e.g., the 741 op. amp. — see schem.).

3. Introduce and complete the *Nonlinear Circuits: Diode and Transistor Switch* lab.

- Resistor color codes: Black, Brown, ROYGBV, Gray, White correspond to **digits** 0–9
  - Brown$_1$-Black$_0$-Red$_2$ = 1000 = 1 kΩ; Brown$_1$-Black$_0$-Orange$_3$ = 10000 = 10 kΩ
- Part pinouts handout has **top views;** book shows bottom views.
- **In your report,** try to explain different regions of curves in terms of switches turning on/off.
  - Remember that conducting **diode** (i.e., "closed switch") has 0.5∼0.7 V drop across it.
  - Remember that conducting **transistor** (i.e., "closed switch") has ∼0.2 V drop across it.
- For **part 3,** give **theoretical** and **actual** $V_{s1,s2}$ values for *both* designs (i.e., Figures 4 and 5).