University of Alabama
Department of Physics and Astronomy
PH 102 LeClair / Mazumdar Summer 2011

Transistor circuits laboratory

1 Introduction

The transistor is our first example of an "active" component which can produce an output signal with more power than its input signal. This does not violate conservation of energy, the additional power simply comes from the transistor's power supply, the main point is that the transistor has a sort of *feedback* which will allow it to effectively add power to a given signal. It is in fact not really the power gain that we are most interested in, but this feedback property, the thing which makes a transistor an "active" component.

In this lab, you will construct two transistor circuits: a source of constant *current* (rather than the roughly constant *voltage* a battery provides), and an automatic "night light" that will light an LED when the ambient lighting is sufficiently low. Since at this point you have several dc circuits labs worth of experience to guide you, after outlining the basics we will simply give you the schematics and leave you to it!

2 You will need

- a lab box to provide supply voltages and measure currents
- $200\,\Omega$, $50\,\mathrm{k}\Omega$, and $100\,\mathrm{k}\Omega$ loose resistors (1 each)
- LED (1, loose)
- CdS photocell ('photoresistor'; 1, loose)
- 2N3904 npn transistor (1, loose)
- various lengths of wire (1, loose)
- prototyping ('proto') board
- (optional) a hand-held multimeter to verify component values and functionality

3 Basic transistor characteristics

We will not dwell on how one makes a transistor, or much of the theory behind their operation. We wish only to have basic operation knowledge of how to use them. With that in mind, we should first spell out the basic properties of a transistor. A transistor is essentially a valve in the simplest sense (not a pump). It does not *force* current to flow, it rather permits it to flow to a controllable degree while the rest of the circuit surrounding the transistor tries to force current through it.

A transistor has three terminals (rather than two like a resistor or capacitor), labeled the *emitter*, the *base*, and the *collector*. Roughly speaking, the collector "collects" power from the power source, delivering it to the emitter terminal which "emits" current. The base is the control terminal: applying a voltage to the base can either open or close the connection between the collector and emitter, modulating the current flow. In terms of a (rough) hydrodynamic analogy, the collector corresponds to a pressurized water source, the emitter the drain, and the base a valve to control the flow rate.

A crucial aspect is that this valve is *sensitive* - very small currents into the base can open and close the valve to allow much larger currents to flow between collector and emitter. In this way, amplification of power (normally called "gain") can be achieved - an input signal to the base can produce a much larger signal at the emitter.

3.1 Notation

In the sort of circuits we will discuss, all potential differences are measured relative to the circuit's ground point, which defines $V = 0$. Thus, it is enough to refer to the potential V at any point in the circuit, knowing that V is specified relative to ground. Subscripts on voltages refer to the transistor terminals:

$$V_e = \text{emitter voltage relative to ground} \tag{1}$$
$$V_b = \text{base voltage relative to ground} \tag{2}$$
$$V_c = \text{collector voltage relative to ground} \tag{3}$$

The same is done for currents, where the convention is that positive currents flow toward lower potential (i.e., closer to ground). Thus, I_b is the current into the base, I_c is the current into the collector, and I_e is the current out of the emitter. Two non-identical subscripts are used to refer to potential differences in shorthand, for example:

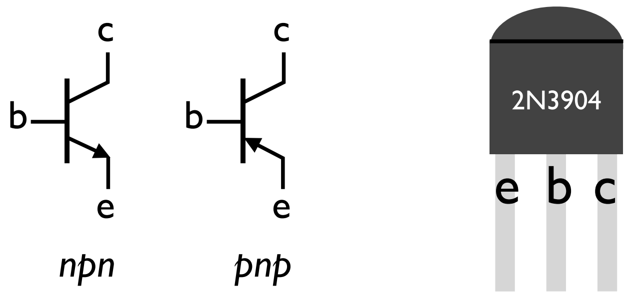
$$V_{be} \equiv V_b - V_e = \text{base-emitter potential difference} \tag{4}$$

Two identical subscripts are shorthand for a power supply voltage being fed in (usually to the collector):

$$V_{cc} = \text{collector supply voltage} \tag{5}$$

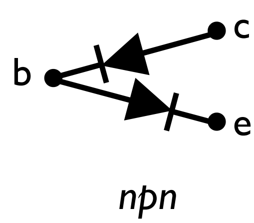
3.2 Modeling transistor behavior

Transistor comes in two flavors, *npn* and *pnp*. We will focus on the *npn* variety, but in most cases *pnp* transistors behave the same way, but with opposite polarity. Their circuit symbols are shown below, along with an illustration of the pinout and packaging of the *npn* transistor (2N3904) you will encounter today.



From this point on, we will worry only about *npn* transistors. For the purposes of this lab, transistors of the *npn* type have three simple rules:

1. The collector potential is higher than the emitter potential, $V_c > V_e$, and the base potential is $\sim 0.6\,\text{V}$ higher than the emitter: $V_b = V_e + 0.6$.
2. The base-emitter and base-collector circuits look like diodes. Normally, the base-emitter diode is conducting, but the base-collector diode is reverse-biased.



3. If the preceding rules are obeyed, the collector current I_c is roughly proportional to the base current I_b, or $I_c \approx \beta I_b$, where β, the current gain, is typically around 100. The collector and emitter currents are approximately equal, $I_e \approx I_c$.

4 Your components

You will receive a number of tiny components for this lab. Below is a picture to help you identify them, and some helpful schematics.The photoresistor is easily identified by the squiggly line on its flat surface. Resistors you have seen many times, and the transistor will be the only one with three legs. Looking at the flat face of the transistor, the terminals are, from left to right, E-B-C. The LED you are familiar with, but be aware that the longer leg is the positive terminal, and current flows from positive (long) to negative (short) terminals.

5 The prototyping board

The prototyping board (“protoboard") is a device for quickly connecting electric circuits without needing any soldering or complicated mounting. Here is a picture of a typical small protoboard,

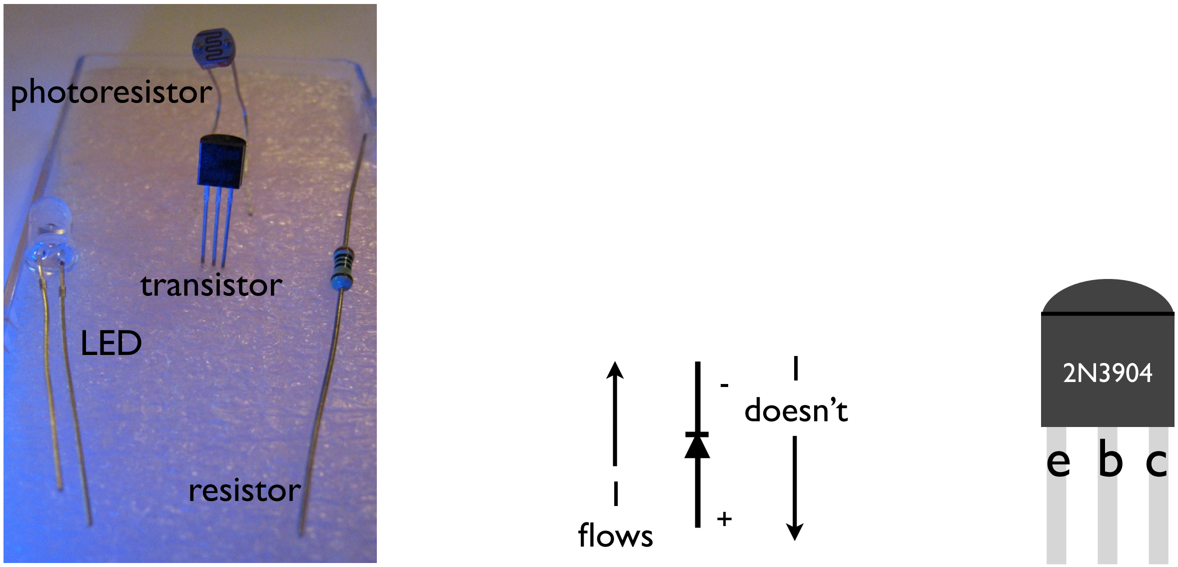
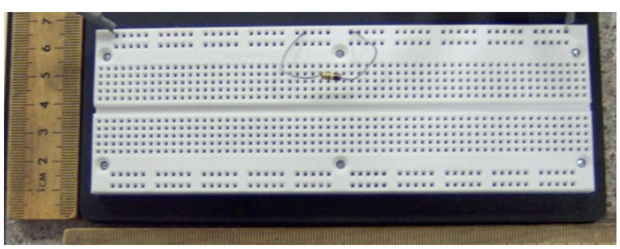
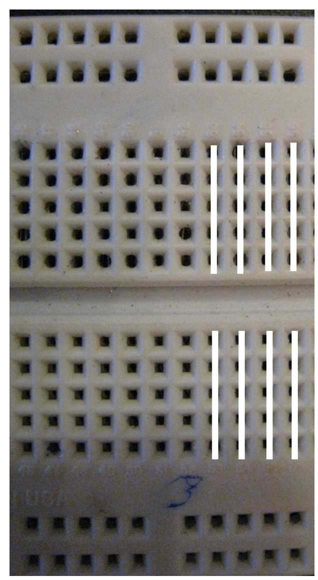


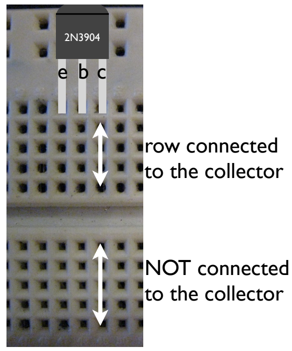
Figure 1: *Left: picture of the components. Center: diode schematic. Right:* npn *transistor schematic.*

along with a close-up of the central region.

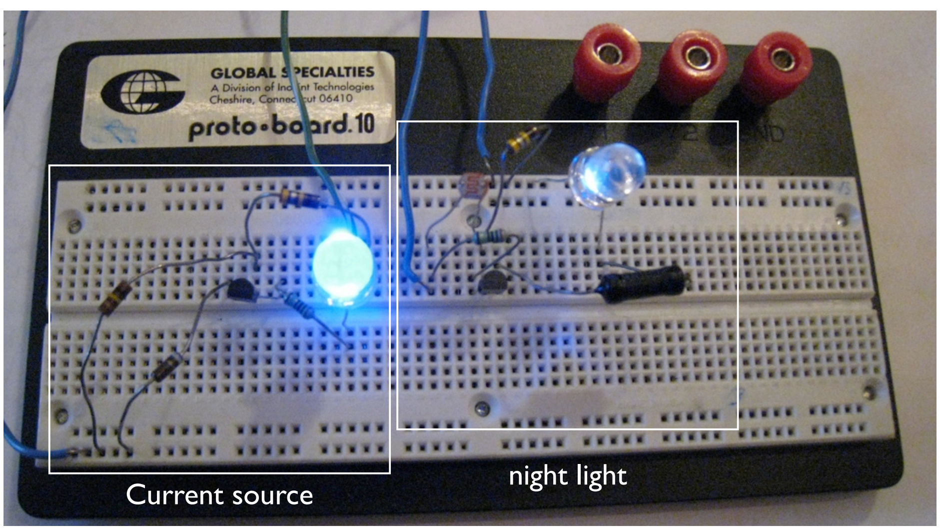




The protoboard has sets of holes arranged in lines, and these lines are electrically connected under the board itself. In the close-up picture of the center of the protoboard, you see two sets of vertical holes: one set of five holes, a gap, and then another set of five holes. The upper five holes are connected, and so are the lower five *but not to each other.* Take one of the upper sets of holes connected by the white line. Any component wires plugged into the holes along a given line are connected to each other across the protoboard, but not to horizontally-adjacent lines *or* to the set of vertical holes below it. For example, if we want to connect our transistor to the board, we could do this:



This connects the emitter, base, and collector to separate columns of holes. All four holes directly below the emitter are connected, and connected to the emitter plugged into the uppermost hole, so **any wire plugged into a hole directly below the emitter will be electrically connected to the emitter.** That's it! The horizontal sets of holes at the top and bottom of the protoboard are also wired together in sets of five, but grouped *horizontally* instead of vertically. You can choose to ignore the horizontal lines and just use the vertical lines in the center to make things easier. Here are your two circuits wired up on a single protoboard:

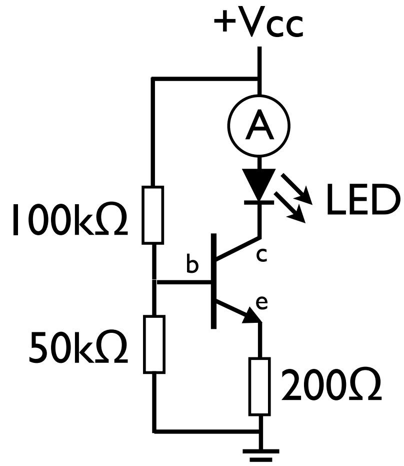


You can see in the lower left two resistors are plugged into a horizontal row, along with a blue wire. The blue wire is the ground connection (V_{out}^{-} on the lab box). The left-most resistor connects with its other end to the base terminal of the transistor, and the right-most resistor to the emitter. At the right of the current source circuit, you can see a resistor connected to the collector terminal, which then goes to a different column where it connects to an LED. The LED connects its other leg to the supply voltage (V_{out}^{+}). This means the resistor and LED are in series, and connected between collector and supply.

A couple of important points. First, **the supply voltage should be the last thing you connect**, after ensuring that the wiring is correct to the best of your knowledge. Second, we will have example circuits correctly wired up for you to inspect to be sure you understand the protoboard. Ask if you are not sure, we are here to help!

6 Circuit 1: constant current source

Here is your first circuit to construct.



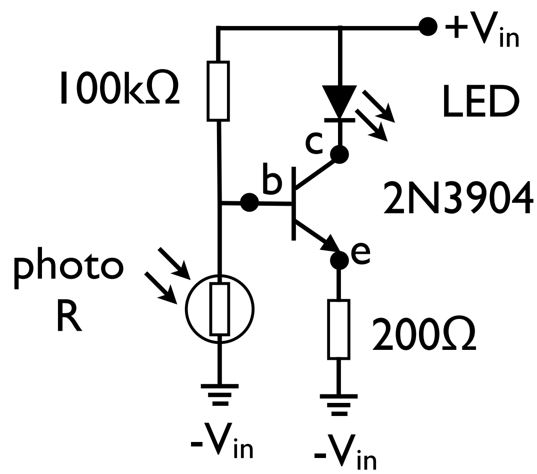
Some things to note: the ground connection at the bottom of the 200 Ω resistor is the "V_{out}^{-}" connection on the lab box, and $+V_{cc}$ is the 'V_{out}^{+}" connection on the lab box. The ammeter between the LED and $+V_{cc}$ is the I_{in} connections on the lab box – connect I_{in}^{+} to the supply voltage, and I_{in}^{-} to the *positive* leg of the LED.

Once you are confident the components are connected correctly, long wires from the proper points on the protoboard to the lab box terminals. You can unscrew the outer portion of the lab box connectors to insert the wire, and then tighten it up again to hold it fast. Then open the "Current vs. Voltage" panel in the lab box software, and measure the current for voltages swept from 0 to 4 V. You should find no current up to a threshold voltage, and a linear characteristic beyond. This means that a fixed supply voltage will result in a known and fixed current through the load device (an LED in this case).

Print the plot of I_c versus V_{cc} you just produced, and report the slope of the *linear region* in mA/V.

7 Circuit 2: automatic night light.

Here is your second circuit to construct; it is almost identical to the first circuit. In fact, if you look carefully, one need only replace the 50 kΩ resistor with the photoresistor (you can leave the ammeter in series with the LED, it will be handy to verify the current through the LED).



Once you think the circuit is ready, use the "multimeter" panel to source voltage to supply the circuit. Start with 3.5 V. For this circuit, the LED should light up when the photoresistor sees too little ambient light, or turn off when the light level is above a threshold value. Try covering the photoresistor with your finger! Watch the current (in the "multimeter" panel choose "Measure: current") change as you do so.

The threshold light level is set by two things. First, the value of the upper right resistor; 100 kΩ was chosen to give a reasonable threshold for CdS photocells. Second, the value of the supply voltage. The lower the supply voltage, the lower the threshold light level. Try varying the supply voltage and see if this is true. Try putting a 50 kΩ or 100 kΩ resistor in parallel or series with the existing 100 kΩ to lower raise the total resistance there to see what that does to the light threshold.

All you need to report in this case is a brief description of how your circuit worked, and approximate values of the collector current when the photoresistor is fully-dark and under full ambient illumination.

8 For your report

- A plot of the collector current I_c versus supply voltage V_{cc} for your current source.
- A brief description of how the night light circuit works, and both the dark and illuminated collector currents (note the supply voltage used).