Cornerstone Electronics Technology and Robotics I Week 17
**Diodes and Transistor Switches**

- **Administration:**
  - o Prayer
  - o Turn in quiz
- **Review:**
  - o Using fixed resistors design and build a voltage divider divides 5 volts in half. The maximum current permitted through the divider is 10 mA. Measure both the current and voltage in your design.
  - o Now use a potentiometer to do the same task.
- **Semiconductor Diodes:**
 - o Semiconductor Diode Symbol:

  - o Diode Markings: The cathode is always identified by a ring, dot or some other mark.

  - o Two properties of diodes:
    - ▪ First, a diode is a device designed to permit current flow in one direction (from left to right in the symbol above) and to block flow in the other direction.
      - Forward Biased: In this orientation, once a small potential is applied to the diode, current will flow through the diode.
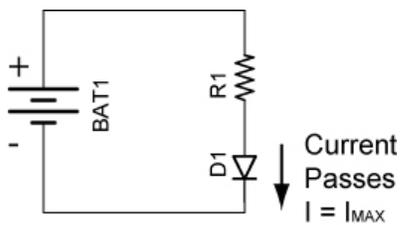

**Forward Biased Diode**   **Switch Analogy**
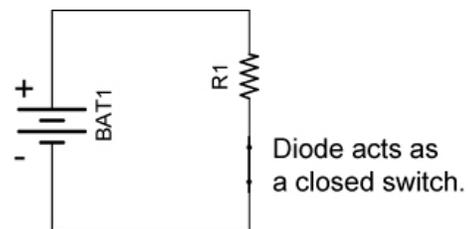
      - Reversed Biased: Now reverse the polarity of the diode. A very small current (called leakage current) flows through the diode which can be measured in microamperes (μA). The current is practically blocked by the diode (I = 0) until the voltage is raised to the breakdown voltage.
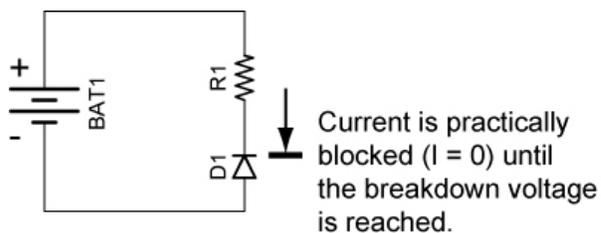

**Reversed Biased Diode**   **Switch Analogy**
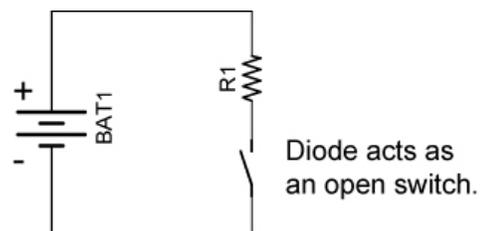
- The second property of diodes is that they have a voltage drop. Typical voltage drops for different types of diodes are as follows:
 - Normal silicon diodes: 0.6 – 0.7 volts

  Symbol:

  Anode   Cathode
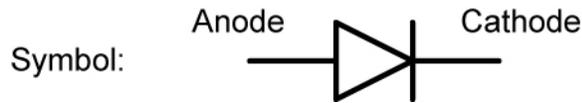
  - Schottky diodes: 0.1 – 0.2 volts

  Symbol:

  Anode   Cathode
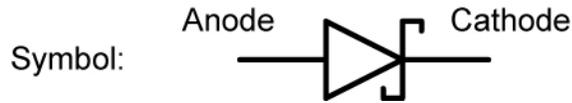
  - LEDs: 2 – 3 volts (depends upon the color)

  Symbol:

  Anode   Cathode
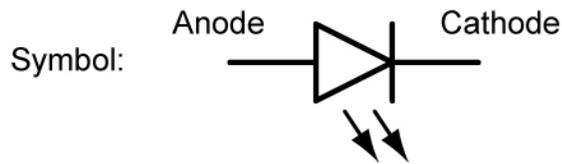
  - Zener diodes: In the "forward" direction (right to left), no current will flow until the voltage across the diode is about 0.7 volts (as with a normal diode). Zener diodes will also allow current to flow from the left to right if the voltage approaches the "zener" voltage. Zener diodes are available in many different voltages, commonly from 1.2 to 200 volts.

  Symbol:

  Anode   Cathode
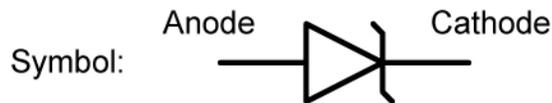
- Structure: A semiconductor diode is made of P-type and N-type semiconductors that are fused together. The P-type material is deficient in electrons (thus the positive charge) and the N-type material has a surplus of electrons (negative charge). In the illustration below, if the diode is forward biased it will permit current to flow from right to left; if it is reversed biased; it will practically stop the current.
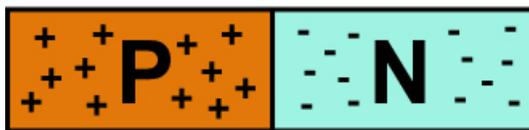
  Web site that details the behavior of the PN junction:
 http://www.electronics-tutorials.ws/diode/diode_3.html

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- o 1N400X Diode Family:
  - The 1N400X diodes are a popular 1.0 amp general purpose rectifier family.
  - Rather than writing 1N4001 – 1N4007 to specify the 1N400X family, we simply write 1N400X where X = 1, 2, 3, 4, 5, 6 or 7.
  - Similarly, X is used in other component families such as the Microchip 16F87X family, where X = 3, 4, 6, or 7.
  - The table below shows the blocking voltages of each of the members of the 1N400X family:

Model Number	Peak Reverse Voltage
1N4001	50
1N4002	100
1N4003	200
1N4004	400
1N4005	600
1N4006	800
1N4007	1000

  - See a 1N400X family datasheet at: http://www.fairchildsemi.com/ds/1N%2F1N4001.pdf

- **Transistor Switches:**
  - o A transistor is an example of an "active" electronic component. An active component injects power into a circuit. A transistor produces an output signal that has more power than the input signal. It is able to increase the power of a signal because it injects power from an electrical power source that is separate from the signal. A passive component has no power gain, in fact, they often cause power to be lost (example: resistor).
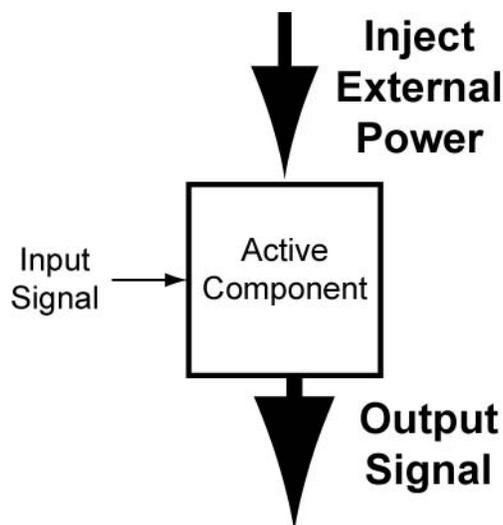
An Active Electronic Component Injects Power into a Circuit

- o Perform Diodes and Transistor Switches Lab 1- LM393N Current Limitations.
- o Lab 1 revealed the current capability limitations of the LM393 comparator. Because most chips use their output pins only to send signals to other circuit devices, this problem has been solved. This lesson will employ a bipolar transistor as the solution to this problem.
- o PNP and NPN Bipolar Transistors:
  - ▪ Bipolar transistors are made of N-type and P-type semiconductor materials similar to diodes, but they have three layers and two junctions. Bipolar transistors are current amplifying or current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing current applied to their base terminal.
  - ▪ Basic construction of PNP and NPN transistor (three layers, two junctions):

Collector	Base	Emitter
P	**N**	**P**
C	B	E

Collector	Base	Emitter
N	**P**	**N**
C	B	E
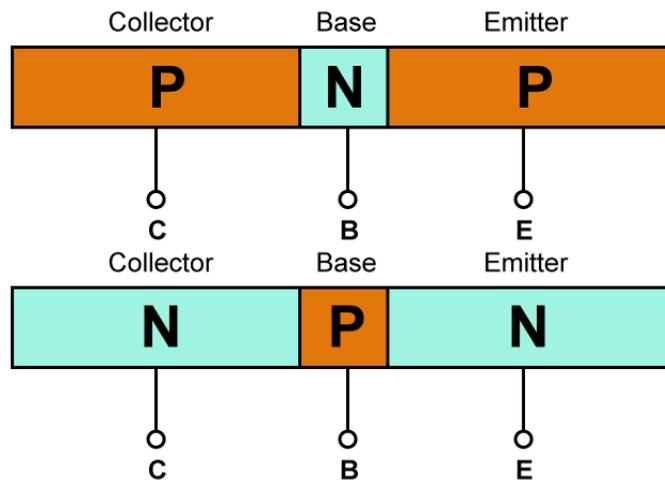
Where C = Collector
B = Base
E = Emitter

  - ▪ The principle of operation of the two transistor types (NPN and PNP) is exactly the same, the only difference being in the biasing (base current) and the polarity of the power supply for each type.
  - ▪ PNP and NPN Transistor Equivalent Diode Models: Two discrete diodes connected back to back will not function as a transistor. The models serve only to help visualize the structure of a transistor. The two PN junctions must be formed on a single wafer of silicon.

PNP Equivalent Circuit

NPN Equivalent Circuit

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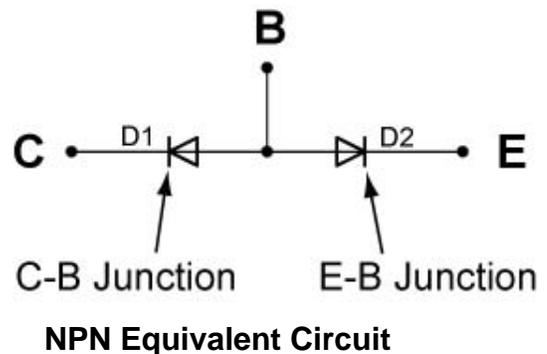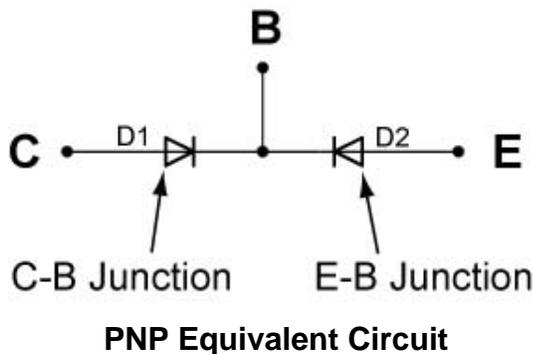
- Schematic Symbols:
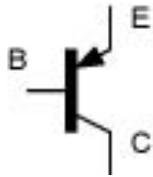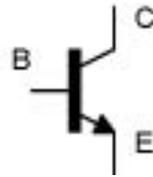
PNP Transistor   **NPN Transistor**

- For a PNP transistor, the arrow points toward the base; for the NPN transistor, the arrow points away from the base (NPN – "**N**ot be **P**ointing i**N**"). The arrow points toward the direction of conventional current flow - toward ground.
- Transistors are current controlling devices. A very small current flowing through the base (say 1 mA) can control a larger current flowing through the collector/emitter junction (may be 100 mA). See the figures below.

PNP   **NPN**
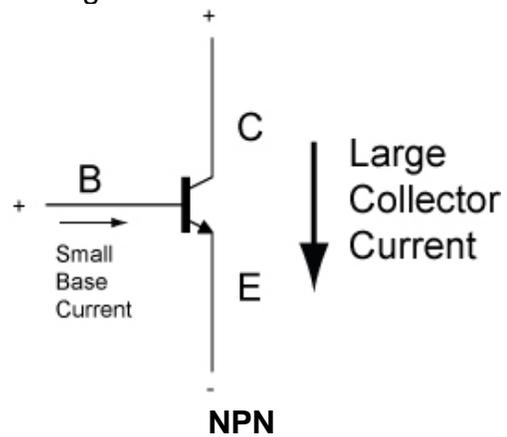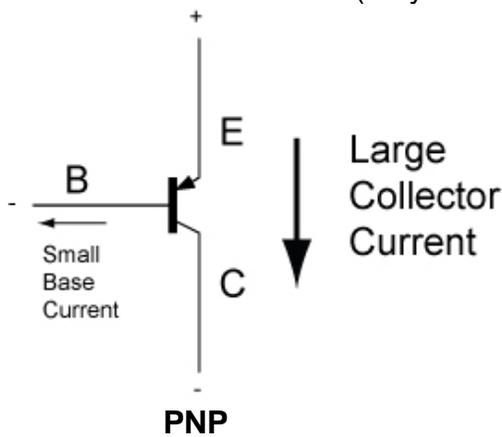
Note that in the NPN transistor, the base current flows into the base while in the PNP transistor, the base current flows out of the base.

- Pinouts for PNP and NPN Transistors (TO-92 package) that We Use:
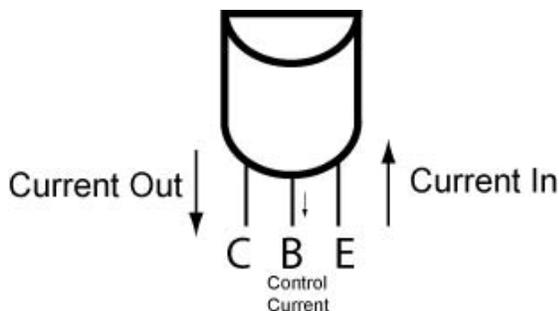
PNP Transistor Lead Configuration   **NPN Transistor Lead Configuration**
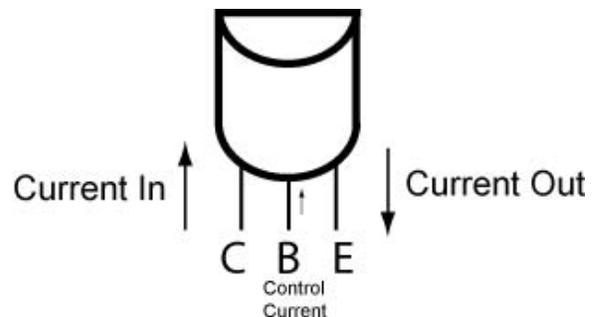
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- Current in Bipolar Transistors (NPN and PNP):

$$I_E = I_C + I_B$$

  Where: I_E = Emitter current
        I_C = Collector current
        I_B = Base current

- Amplification or Gain (β):

$$\beta = I_C/I_B, \quad I_C = \beta\, I_B$$

  Where: β = Amplification
        I_C = Collector current
        I_B = Base current

- The gain won't be identical even in transistors with the same part number. The gain also varies with collector current and temperature.
- See: http://www.learnabout-electronics.org/bipolar_junction_transistors_05.php
- Perform Diodes and Transistor Switches Lab 2 – Testing a 2N2222A NPN Transistor.
- Show samples.

o Transistors as Switches: Both the NPN & PNP type bipolar transistors can be made to operate as an "ON/OFF" type solid state switch for controlling high power devices such as motors, solenoids, or lamps.
- On/Off switching in a transistor is controlled by the biasing of the transistor's base-to-emitter junction.
  - If the base-to-emitter junction is forward biased, the transistor turns on. The low resistance between the collector and emitter permits current to flow similar to a closed switch (see the illustrations below).
  - When a transistor is on, it is driven into saturation, i.e., the base bias voltage is increased to such a point that any further increase in bias voltage will not cause any further increase in current through the collector and emitter. The base current is high enough to give a collector-emitter voltage of near 0 volts resulting in maximum collector current flowing; the device is switched fully on.
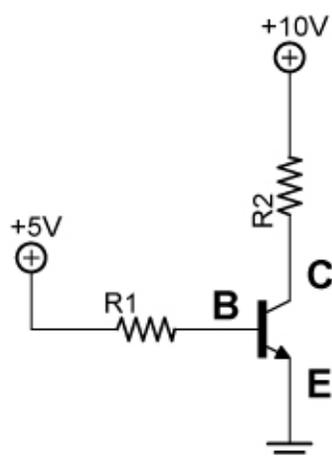
NPN B-E Junction Forward Biased   **Analogous Closed Switch Circuit**

- A transistor is not a perfect switch. Even in saturation there will be a voltage across the transistor between the collector and the emitter. This voltage is known as Vce(sat). This will usually range between .3V and 1V, depending on the voltage and currents. In many circuits Vce(sat) can be ignored.
- If the base-to-emitter junction is reversed biased, the transistor turns off. The high resistance between the collector and emitter stops current flow similar to an open switch. See the illustration below.
- When a transistor is off, it is driven into cutoff, i.e., the base bias voltage is decreased to such a point that it stops current through the collector and emitter.
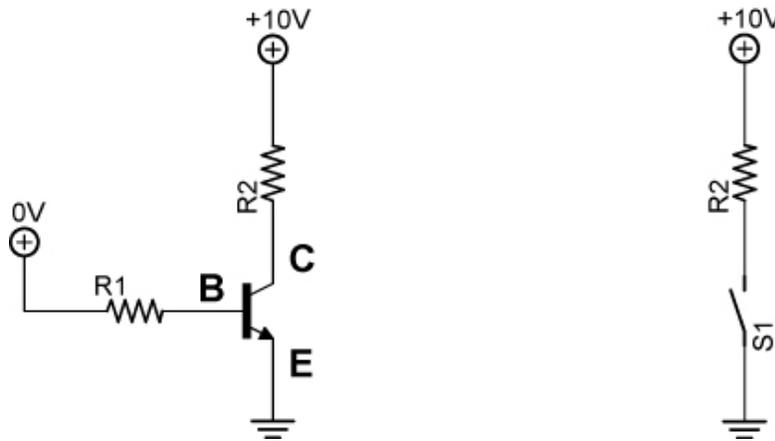
NPN B-E Junction Not Forward Biased   Analogous Open Switch Circuit

See applets: http://www.falstad.com/circuit/e-pnp.html
http://www.falstad.com/circuit/e-npn.html

- The transistor isn't a perfect switch. When in the off state, there is a small current that flows (measured in μA) and when on it has a small voltage drop.

- Calculating the base resistor value for a transistor switch circuit:
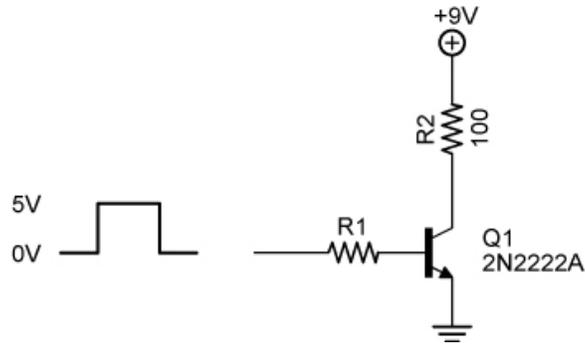
1. Using the circuit above, calculate the collector current assuming the transistor switch is on.

$$I_C = I_{R2} = V_{R2}/R_2$$

Where: I_C = Collector current
V_{R2} = Voltage drop across R_2
R_2 = Resistance of R_2

From the 2N2222A datasheet, the collector-emitter voltage at saturation ($V_{CE(SAT)}$) equals 0.3V.

$$I_C = V_{R2}/R_2$$
$$I_C = (9V - 0.3V) / 100\ \Omega$$
$$I_C = 8.7V / 100\ \Omega$$
$$I_C = 87\ mA.$$

2. Now calculate the needed base current required to turn on the transistor. Looking at the datasheet, β (or h_{fe}) could be as low as 35. Assume the worst case value.

Remember, $\beta = I_C / I_B$, so $I_B = I_C / \beta$

$$I_B = I_C / \beta$$
$$I_B = 87\ mA / 35$$
$$I_B = 2.5\ mA$$

3. Add a factor of two to make sure the transistor turns on fully; $I_B = 5.0$ mA.
4. Now calculate the value of R1. Take into account the 0.7 volt drop across the base-emitter junction.

$$R_1 = V_{R1} / I_{R1}$$
Since $I_{R1} = I_B$,
$$R_1 = (5V - 0.7V) / 0.005\ A$$
$$R_1 = 4.3V / 0.005\ A$$
$$R_1 = 860\ \Omega$$

Use an 820 Ω resistor.

From:
http://www.physics.unlv.edu/~bill/PHYS483/transbas.pdf

- Summary of steps for calculating the base resistor value for a transistor switch circuit:

+9V

② $I_B = I_C / \beta$

① $I_C = I_{R2} = V_{R2} / R2$

Remember to subtract $V_{CE(SAT)}$ when calculating V_{R2}.

③ Double I_B

$I_C = I_{R2}$

$I_B = I_{R1}$

R1

R2

$V_{CE(SAT)} = 0.3V$

$V_{BE} = 0.7V$

④ $R1 = V_{R1} / I_{R1}$

$R1 = V_{R1} / I_B$

Remember to subtract V_{BE} when calculating V_{R1}.
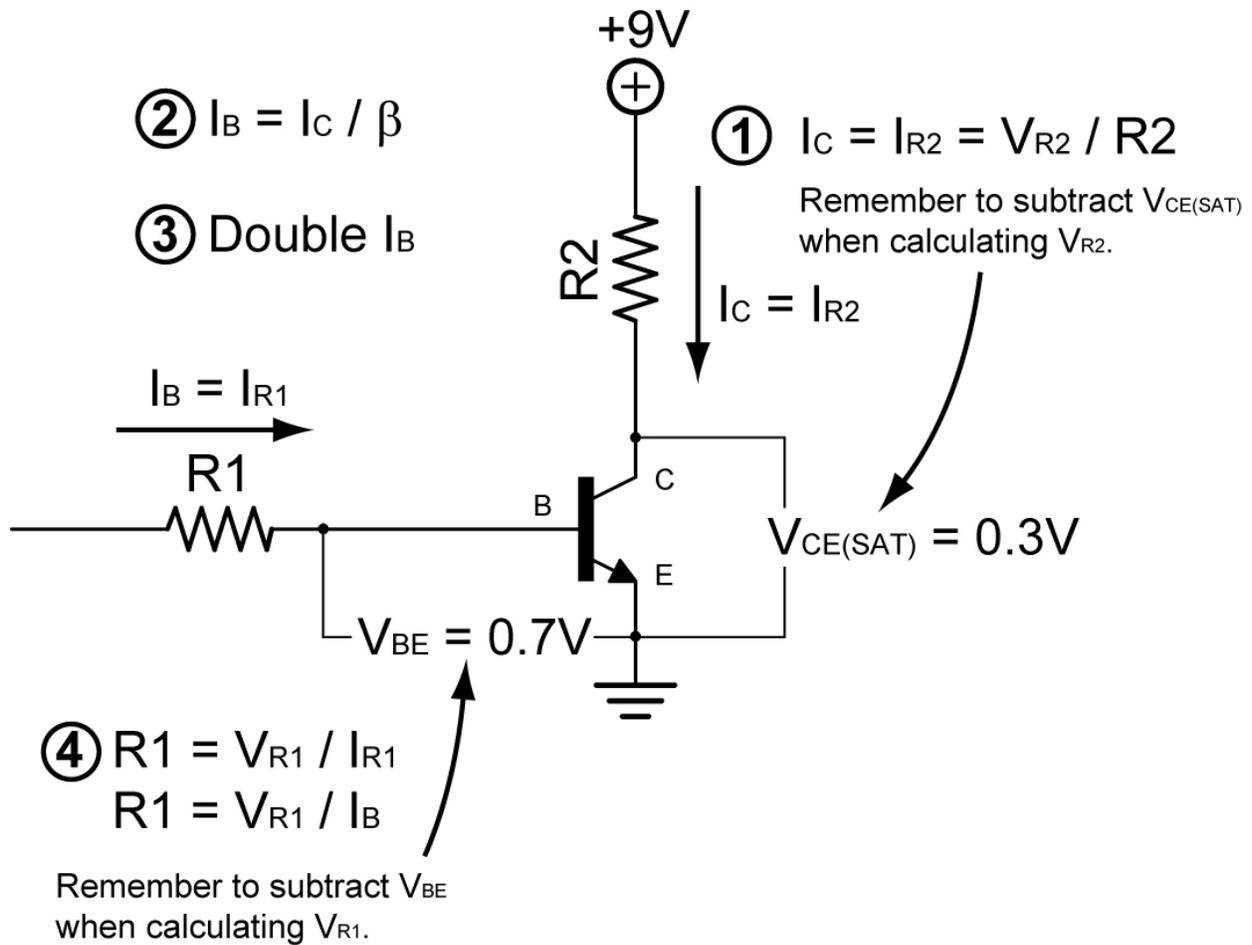
- Load placement for NPN and PNP transistor switches:
  - If the transistor is simply acting as a switch in our application, is it critical how the load R2 and the transistor switch are arranged? Can the load be placed between the emitter and ground rather than between the power supply and collector? After all in the analogous circuit to the right, the switch could be placed on either side of the load since the load and the switch are in series.
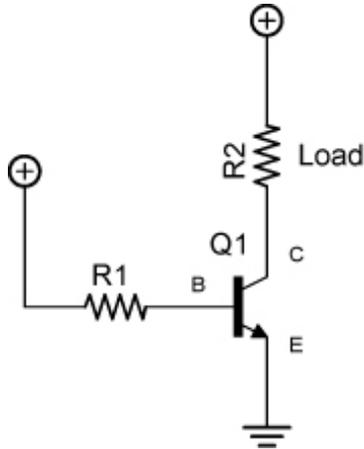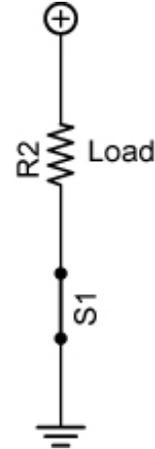
Proper Load Placement for NPN Transistor   **Analogous Switch Circuit**

In other words, are the two circuits below electrically equivalent? The answer is no.
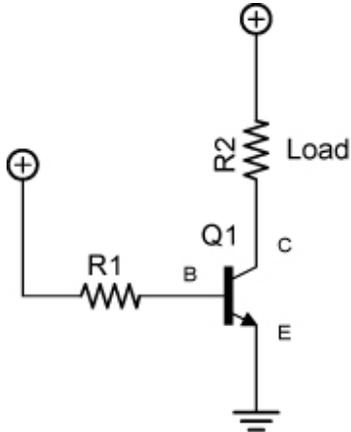
Load between the Power Supply and Collector   **Load between the Emitter and Ground**
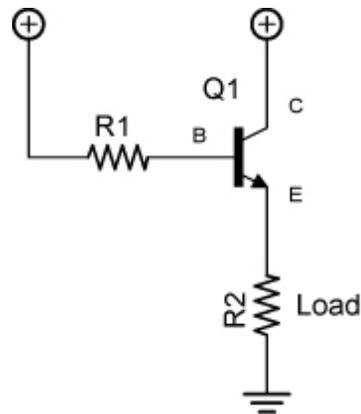
  - The problem with the load being placed between the emitter and ground is that current flows through load R2 which creates a voltage drop across the load. This raises the voltage at the emitter which causes the base current to decrease which reduces the current through the transistor. The collector-emitter voltage then rises, diminishing the performance of the transistor switch. The load should be placed between the power supply and collector in a NPN transistor switch circuit.

- Likewise, the load should be placed between the collector and ground for a PNP transistor switch. See the circuit on the right below:
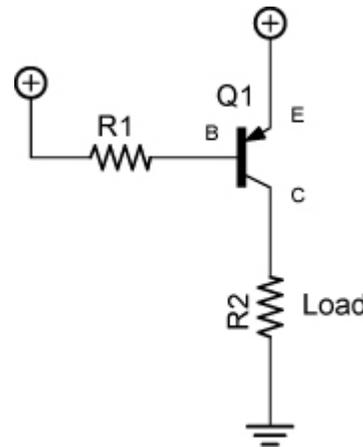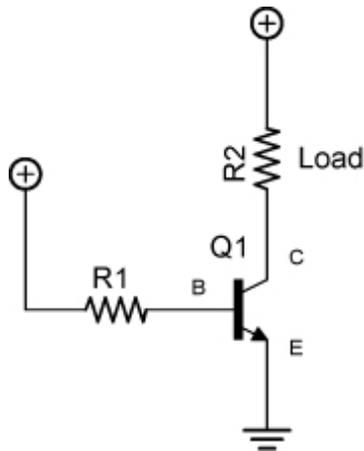
Proper Load Placement for NPN Transistor   **Proper Load Placement for PNP Transistor**

- Perform Diodes and Transistor Switches Lab 3 – NPN and PNP Transistor Load Placement
- Perform Diodes and Transistor Switches Lab 4 – NPN and PNP Transistor Switches.
  - 2N2907A Transistor:
    - Bipolar PNP general purpose amplifier transistor
    - Data Sheets:
      - http://www.eletrica.ufsj.edu.br/ensino/eletronica1/pasta/2n2907.pdf
      - http://www.fairchildsemi.com/ds/PN/PN2907A.pdf
    - The 2N2907A can source 800 mA continuously which is greater than our needs for the two motors and six LEDs.
  - See applet: http://www.falstad.com/circuit/e-transswitch.html
  - Perform Diodes and Transistor Switches Lab 4 – NPN Switch Circuit Application
  - Block diagram of Sandwich circuits:

| Sensors (Photoresistors) | → | Controller (LM393 Comparator) | → | Current Amplifier (2N2907A Transistor) | → | Output Devices LEDs and dc Motor |
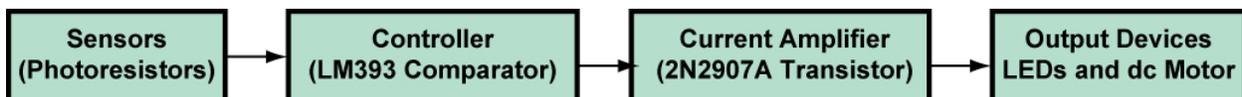
  - Perform Diodes and Transistor Switches Lab 5 – Brightness Comparator
  - References:
    - http://www.w9xt.com/page_microdesign_pt7_transistor_switching.html

- **Purpose:** The purpose of this lab is to acquaint the student with the current limitations of the LM393 voltage comparator.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – Gearhead Motor, HNGH12-1324Y-R
  - 1 – 150 Ohm Resistor
  - 3 – Yellow LEDs
  - 3 – Green LEDs

- **Procedure:**
  - Sandwich current requirements:
    - Measure and record the maximum current used by the gearhead motor in Sandwich. Use a DMM that saves the maximum current value. See schematic below.
    - Measure and record the current to power three series yellow and then three green LED's.
    - Total the maximum currents of the components.

  - Review the attached data sheet for the LM393 comparator. Note the typical Output Sink Current value. Record and determine the difference.

- **Results:**

Part	Maximum Current (mA)
2 Gearhead Motors	
3 Yellow LEDs	
3 Green LEDs	+_____
Total Current Required by Sandwich	
Typical Output Sink Current of LM393	-_____
Difference	

- **Conclusions:**
    - Does the LM393 provide sufficient current output to handle the load requirements of Sandwich?

LM393, LM393A, LM293, LM2903, LM2903V

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 Vdc, $T_{low} \leq T_A \leq T_{high}$,* unless otherwise noted.)

Characteristic	Symbol	LM393A			Unit
		Min	Typ	Max	
Output Leakage Current	I_{OL}				μA
$\quad V_{in-}$ = 0 V, $V_{in+} \geq$ 1.0 Vdc, V_O = 5.0 Vdc, T_A= 25°C		–	0.1	–	
$\quad V_{in-}$ = 0 V, $V_{in+} \geq$ 1.0 Vdc, V_O = 30 Vdc, $T_{low} \leq T_A \leq T_{high}$		–	–	1.0	
Supply Current	I_{CC}				mA
$\quad R_L = \infty$ Both Comparators, T_A = 25°C		–	0.4	1.0	
$\quad R_L = \infty$ Both Comparators, V_{CC} = 30 V		–	1.0	2.5	

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 Vdc, $T_{low} \leq T_A \leq T_{high}$, unless otherwise noted.)

Characteristic	Symbol	LM392, LM393			LM2903, LM2903V			Unit
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage (Note 2)	V_{IO}							mV
$\quad T_A$ = 25°C		–	±1.0	±5.0	–	±2.0	±7.0	
$\quad T_{low} \leq T_A \leq T_{high}$		–	–	9.0	–	9.0	15	
Input Offset Current	I_{IO}							nA
$\quad T_A$ = 25°C		–	±5.0	±50	–	±5.0	±50	
$\quad T_{low} \leq T_A \leq T_{high}$		–	–	±150	–	±50	±200	
Input Bias Current (Note 3)	I_{IB}							nA
$\quad T_A$ = 25°C		–	25	250	–	25	250	
$\quad T_{low} \leq T_A \leq T_{high}$		–	–	400	–	200	500	
Input Common Mode Voltage Range (Note 3)	V_{ICR}							V
$\quad T_A$ = 25°C		0	–	$V_{CC}-1.5$	0	–	$V_{CC}-1.5$	
$\quad T_{low} \leq T_A \leq T_{high}$		0	–	$V_{CC}-2.0$	0	–	$V_{CC}-2.0$	
Voltage Gain	A_{VOL}	50	200	–	25	200	–	V/mV
$\quad R_L \geq$ 15 kΩ, V_{CC} = 15 Vdc, T_A = 25°C								
Large Signal Response Time	–	–	300	–	–	300	–	ns
$\quad V_{in}$ = TTL Logic Swing, V_{ref} = 1.4 Vdc								
$\quad V_{RL}$ = 5.0 Vdc, R_L = 5.1 kΩ, T_A = 25°C								
Response Time (Note 5)	t_{TLH}	–	1.3	–	–	1.5	–	μs
$\quad V_{RL}$ = 5.0 Vdc, R_L = 5.1 kΩ, T_A = 25°C								
Input Differential Voltage (Note 6)	V_{ID}	–	–	V_{CC}	–	–	V_{CC}	V
$\quad$ All $V_{in} \geq$ Gnd or V– Supply (if used)								
Output Sink Current	I_{Sink}	**6.0**	**16**	–	6.0	16	–	**mA**
$\quad V_{in} \geq$ 1.0 Vdc, V_{in+} = 0 Vdc, $V_O \leq$ 1.5 Vdc T_A = 25°C								
Output Saturation Voltage	V_{OL}							mV
$\quad V_{in} \geq$ 1.0 Vdc, V_{in+} = 0, $I_{Sink} \leq$ 4.0 mA, T_A = 25°C		–	150	400	–	–	400	
$\quad T_{low} \leq T_A \leq T_{high}$		–	–	700	–	200	700	
Output Leakage Current	I_{OL}							nA
$\quad V_{in-}$ = 0 V, $V_{in+} \geq$ 1.0 Vdc, V_O = 5.0 Vdc, T_A = 25°C		–	0.1	–	–	0.1	–	
$\quad V_{in-}$ = 0 V, $V_{in+} \geq$ 1.0 Vdc, V_O = 30 Vdc,								
$\quad\quad T_{low} \leq T_A \leq T_{high}$		–	–	1000	–	–	1000	
Supply Current	I_{CC}							mA
$\quad R_L = \infty$ Both Comparators, T_A = 25°C		–	0.4	1.0	–	0.4	1.0	
$\quad R_L = \infty$ Both Comparators, V_{CC} = 30 V		–	–	2.5	–	–	2.5	

* T_{low} = 0°C, T_{high} = +70°C for LM393/393A
LM293 T_{low} = –25°C, T_{high} = +85°C
LM2903 T_{low} = –40°C, T_{high} = +105°C
LM2903V T_{low} = –40°C, T_{high} = +125°C

NOTES: 2. At output switch point, $V_O \approx$ 1.4 Vdc, R_S = 0 Ω with V_{CC} from 5.0 Vdc to 30 Vdc, and over the full input common mode range (0 V to V_{CC} = –1.5 V).
$\quad\quad$ 3. Due to the PNP transistor inputs, bias current will flow out of the inputs. This current is essentially constant, independent of the output state, therefore, no loading changes will exist on the input lines.
$\quad\quad$ 5. Response time is specified with a 100 mV step and 5.0 mV of overdrive. With larger magnitudes of overdrive faster response times are obtainable.
$\quad\quad$ 6. The comparator will exhibit proper output state if one of the inputs becomes greater than V_{CC}, the other input must remain within the common mode range. The low input state must not be less than –0.3 V of ground or minus supply.

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- **Purpose:** The purpose of this lab is to measure important variables for the operation of a 2N2222A NPN and 2N2907A PNP transistors.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 3 – Digital Multimeters
  - 1 – 2N2222A NPN Transistor
  - 1 – 2N2907A PNP Transistor
  - 1 – 100 Ohm Resistor
  - 1 – 1K Resistor
  - 1 – Resistor Substitution Box

- **Procedure:**
  - In the NPN circuit below, first calculate the value of R1.
  - Build the 2N2222A NPN transistor test circuit below.
  - Insert the resistor substitution box for R1 (the base resistor).
  - Measure the base and collector currents and also measure the voltage at the collector with respect to ground. Record your results.
  - Substitute all of the other resistor values in the result table for R1 and repeat the current and voltage measurements. Record your results.
  - Calculate and record the β for each trial resistor.
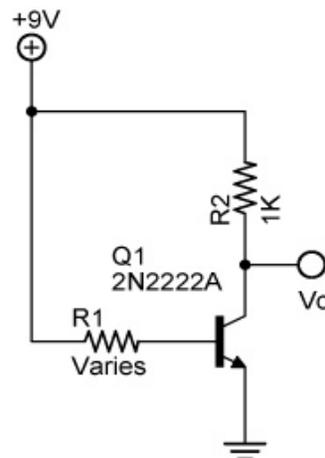
  - Repeat the above procedure for the 2N2907A PNP transistor.

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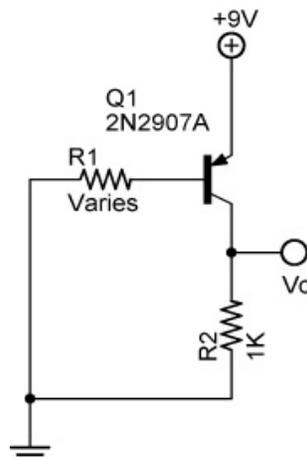
- **Results:**
  - 2N2222A NPN Transistor (R2 = 1K):

R_1	I_B	I_C	V_C	β
(Ω)	(mA)	(mA)	(V)	
10M				
1M				
820K				
680K				
560K				
470K				
390K				
330K				
270K				
220K				
180K				
150K				
120K				
100K				
47K				
33K				
10K				
3.3K				
1.0K				

- 2N2907A PNP Transistor (R2 = 1K):

R_1 (Ω)	I_B (mA)	I_C (mA)	V_C (V)	β
10M				
1M				
820K				
680K				
560K				
470K				
390K				
330K				
270K				
220K				
180K				
150K				
120K				
100K				
47K				
33K				
10K				
3.3K				
1.0K				

- **Conclusion:**
  - Does a very small current to the base control a larger current that flows through the collector/emitter leads?

  - What range of values does the amplification β remain relatively constant?

  - At what value of resistor do you think the transistor acts as a switch?

- **Sample Results:**
  - 2N2222A NPN Transistor Sample Results:

R2 (Load) = 1K Ohm:

R_1	I_B	I_C	V_C	β
(Ω)	(mA)	(mA)	(V)	
10M	0.0007	0.176	8.86	251
1M	0.0084	1.91	7.14	228
820K	0.0099	2.08	6.94	210
680K	0.0123	2.42	6.55	197
560K	0.0150	2.98	5.97	199
470K	0.0179	3.44	5.46	192
390K	0.0214	4.24	4.64	198
330K	0.0249	4.92	3.93	198
270K	0.0304	6.84	2.22	225
220K	0.0380	8.33	0.75	219
180K	0.0463	8.67	0.39	187
150K	0.0555	8.71	0.36	157
120K	0.0691	8.74	0.34	126
100K	0.0827	8.75	0.33	106
47K	0.174	8.78	0.30	50
33K	0.254	8.79	0.28	35
10K	0.827	8.86	0.23	11
3.3K	2.53	8.87	0.20	4
1.0K	8.30	8.85	0.20	1

R2 = 100 Ohm:

R_1	I_B	I_C	V_C	β
(Ω)	(mA)	(mA)	(V)	
				#DIV/0!
10M	0.0007	0.177	8.98	256
1M	0.0082	1.88	8.80	231
820K	0.0099	2.32	8.83	234
680K	0.0122	2.86	8.78	234
560K	0.0149	3.52	8.71	236
470K	0.0179	4.25	8.63	237
390K	0.0213	5.09	8.55	239
330K	0.0251	6.01	8.45	239
270K	0.0305	7.47	8.30	245
220K	0.0381	9.34	8.11	245
180K	0.0465	11.70	7.88	252
150K	0.0555	13.78	7.64	248
120K	0.0687	17.05	7.31	248
100K	0.0821	20.5	6.92	250
47K	0.171	42.4	4.69	248
33K	0.245	58.4	3.01	238
10K	0.784	79.9	0.90	102
3.3K	2.39	79.6	0.83	33
1.0K	7.93	80.7	0.70	10

Base and Collector Currents through a Random 2N2222A Transistor for a Varity of Base Resistors (5% Tolerance)
(Test setup according to the 2N2222A schematic in this lab.)

o   2N2907A PNP Transistor Sample Results:

R2 = 1K Ohm:

R$_1$	I$_B$	I$_C$	V$_C$	β
(Ω)	(mA)	(mA)	(V)	
				#DIV/0!
10M	0.0007	0.128	0.12	183
1M	0.0084	1.29	1.28	153
820K	0.0099	1.52	1.51	153
680K	0.0122	1.86	1.84	153
560K	0.015	2.25	2.25	150
470K	0.0179	2.66	2.66	149
390K	0.0214	3.15	3.15	147
330K	0.0252	3.69	3.69	146
270K	0.0305	4.48	4.47	147
220K	0.0382	5.57	5.55	146
180K	0.0465	6.64	6.62	143
150K	0.0558	7.73	7.71	139
120K	0.0692	8.58	8.55	124
100K	0.0829	8.76	8.73	94
47K	0.175	8.80	8.78	50
33K	0.254	8.83	8.79	35
10K	0.829	8.87	8.84	11
3.3K	2.51	8.88	8.85	4
1.0K	8.26	8.88	8.85	1

R2 = 100 Ohm:

R₁ (Ω)	I_B (mA)	I_C (mA)	V_C (V)	β
				#DIV/0!
10M	0.0008	0.130	0.01	163
1M	0.0084	1.32	0.13	157
820K	0.010	1.56	0.16	156
680K	0.0120	1.92	0.19	160
560K	0.0150	2.36	0.24	157
470K	0.0179	2.82	0.29	158
390K	0.0214	3.37	0.34	157
330K	0.0252	3.99	0.40	158
270K	0.0306	4.90	0.50	160
220K	0.0383	6.10	0.62	159
180K	0.0467	7.44	0.75	159
150K	0.0559	8.99	0.91	161
120K	0.0694	11.46	1.16	165
100K	0.0829	13.44	1.36	162
47K	0.175	29.7	2.99	170
33K	0.253	41.0	4.14	162
10K	0.810	79.2	8.00	98
3.3K	2.45	82.0	8.28	33
1.0K	8.09	82.3	8.32	10

Base and Collector Currents through a Random 2N2907A Transistor for a Varity of Base Resistors (5% Tolerance)
**(Test setup according to the 2N2907A schematic in this lab.)**

- **Purpose:** The purpose of this lab is to demonstrate that the placement of the load in a NPN transistor switch is critical.

- **Apparatus and Materials:**

    - 1 – Solderless Breadboard with 9 V Power Supply
    - 2 – Digital Multimeters
    - 1 – 2N2222A NPN Transistor
    - 1 – SPST Switch
    - 1 – 470K Resistor
    - 1 – 1K Resistor
    - 1 – LED

- **Procedure:**
    - Build the first NPN test circuit. Note the placement of the load (the resistor R2 and the LED). Measure and record the collector, emitter, and base currents. Also measure and record the collector-emitter voltage.
    - Now move the load to the emitter side of the transistor and measure and record all three currents again and the collector-emitter voltage.
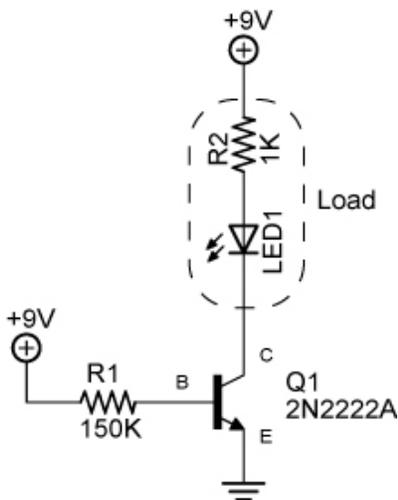
NPN Transistor as a "Low Side" Switch   **NPN Transistor as a "High Side" Switch**
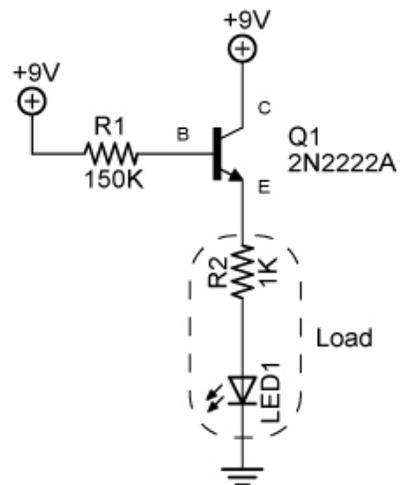
- **Results:**
  - Load connected to collector: Load connected to emitter:

	Current (mA)
Collector I_C	
Base I_B	
Emitter I_E	

V_{CE}	

|	Current (mA)
Collector I_C	
Base I_B	
Emitter I_E	

V_{CE}	

- **Conclusions:**
  - Insert your results in the circuits below:

Load connected to collector: Load connected to emitter:
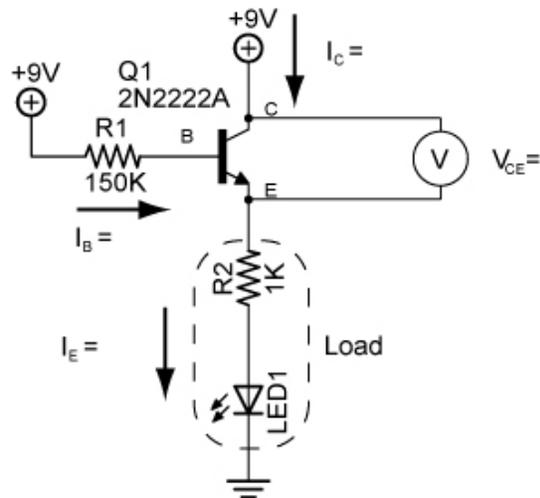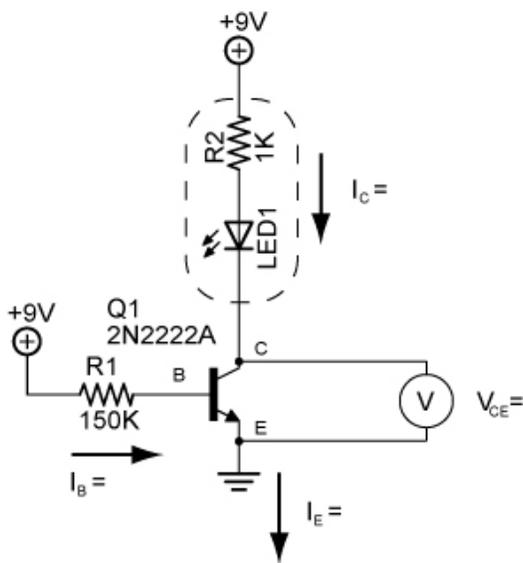
  - If the 2N2222A NPN transistor is serving as a switch, what problem does the collector-emitter voltage cause in the right circuit?

  - Which circuit functions better as a switch? Why?

  - Draw a PNP transistor circuit showing the proper position for the load.

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- **Sample Readings:**
  - Load connected to collector: Load connected to emitter:

	Current (mA)
Collector I_C	6.74
Base I_B	0.055
Emitter I_E	6.80

V_{CE}	0.21 V

	Current (mA)
Collector I_C	3.59
Base I_B	0.018
Emitter I_E	3.60

V_{CE}	3.40 V

- **Purpose:** The purpose of this lab is to demonstrate a practical use of a transistor switch.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – 2N2222A NPN Transistor
  - 1 – 10K Ω Resistor
  - 1 – Photoresistor
  - 2 – 470 Ω Resistor
  - 1 – LED

- **Procedure:**
  - Wire the following circuit on a breadboard.
  - Vary the amount of light entering the photoresistor using a flashlight.
  - Measure and record the highest and lowest voltage readings at Point A, V_A, with respect to ground.
 - Also measure and record the voltage at Point A when the LED just lights.
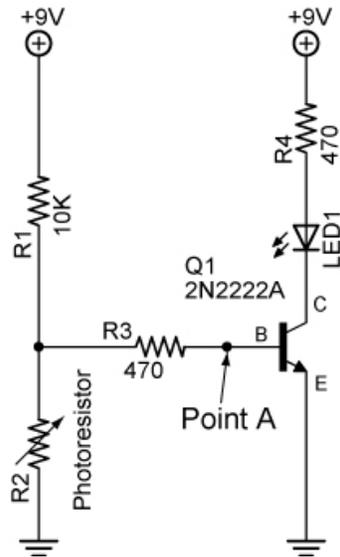
- **Results:**

Point A	Voltage (V)	State of LED
Lowest Reading		
Highest Reading		
LED Just Lights		

- **Purpose:** The purpose of this lab is to set up the switching circuit for the line following robot Sandwich.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – LM393N Voltage Comparator
  - 2 – 2N2907A PNP Transistors
  - 2 – 150 Ω Resistors
  - 2 – 1 K Ω Resistors
  - 3 – Green LEDs
  - 3 – Yellow LEDs

- **Procedure:**
 - Wire the brightness comparator transistor circuit:
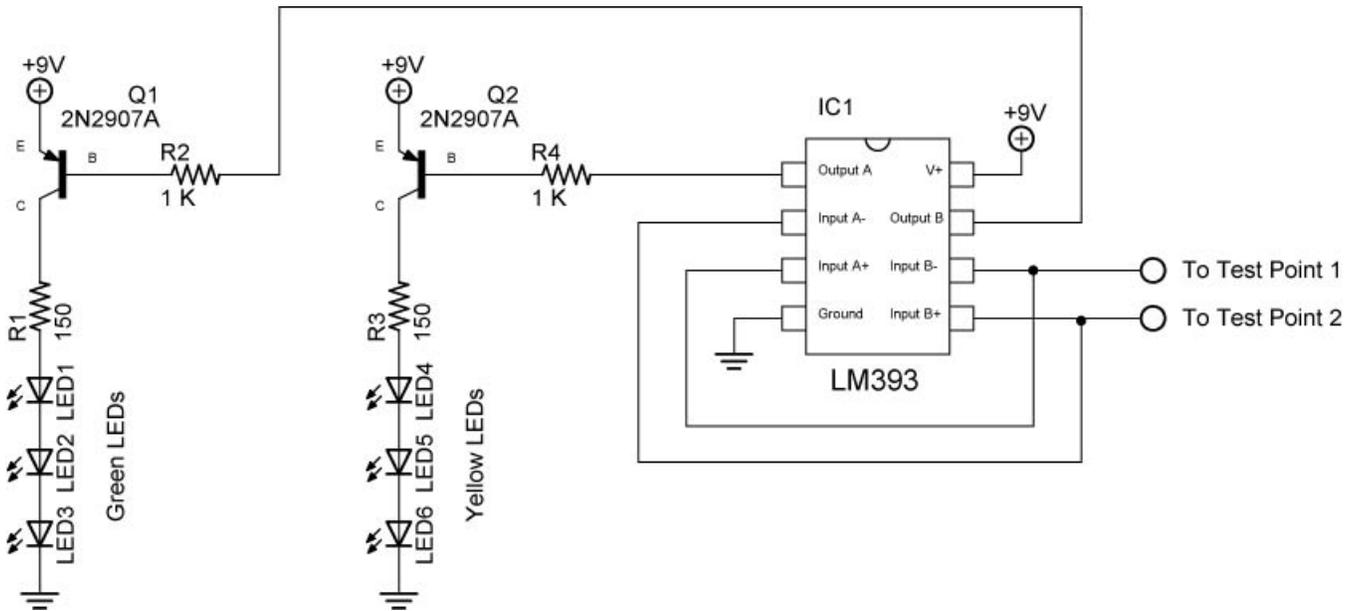
  - Test Points 1&2 are located in the Brightness Balancing circuit (Week 12):
    http://cornerstonerobotics.org/curriculum/lessons_year1/ER%20Week12,
    %20Other%20Sources,%20Photoresistor.pdf
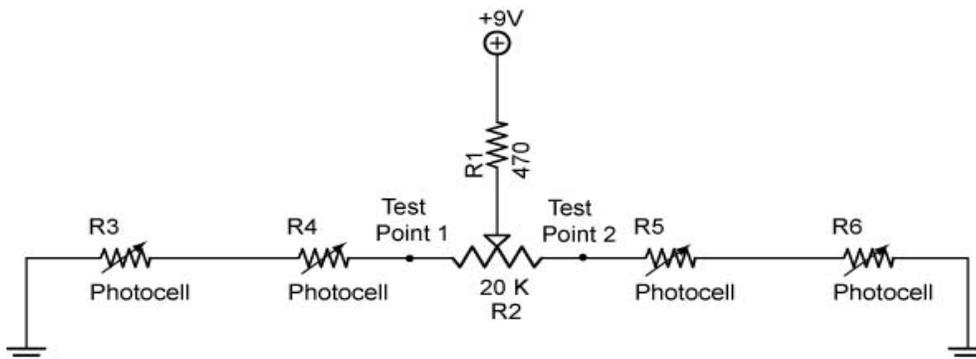
- **Purpose:** The purpose of this lab is to build a robotic car whose movement is controlled by two flashlights.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9V and 5V Power Supplies
  - 1 – LM393N Voltage Comparator
  - 2 – 2N2907A PNP Transistors
  - 2 – 1 K Ω Resistors
  - 4 – 1K Potentiometers (Tripots)
  - 2 – 12K Photoresistors (Jameco #120249)
  - 2 – 1N5817 Schottky Diodes
  - 2 – 12V DC Motors

- **Procedure:**
  - Fabricate a temporary robotic car platform to support the breadboard and dc motors using various materials at hand.
  - Control Circuit:
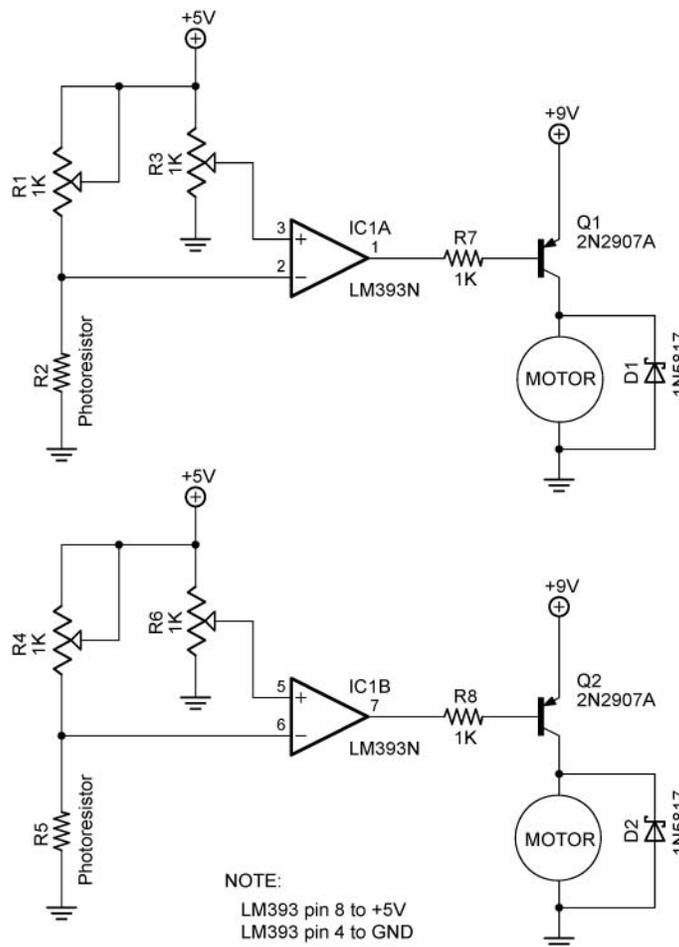
  - Adjust R1 and R3 so that the motor turns on when the flashlight is aimed at the photoresistor R2. Repeat for R4, R6 and R5.