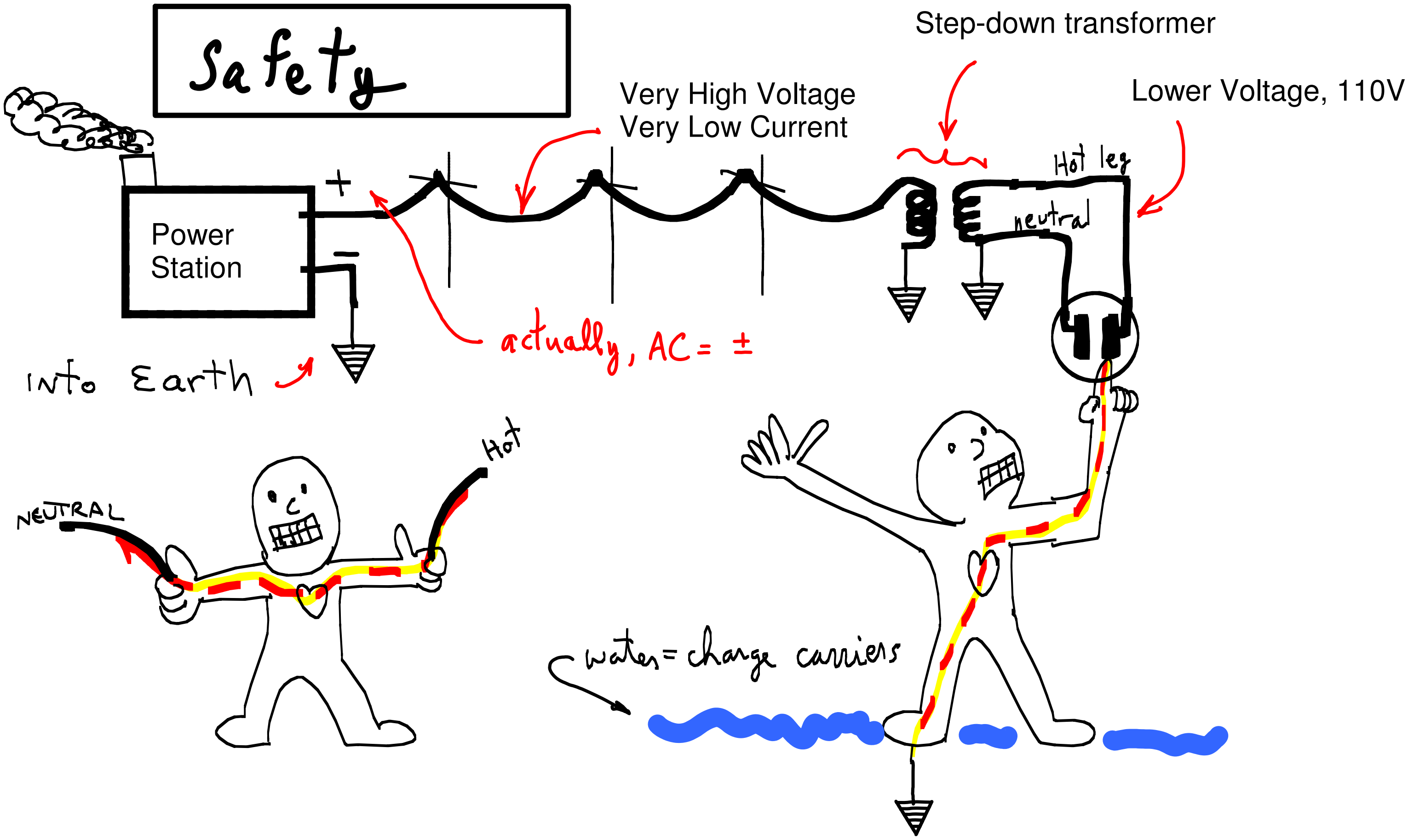
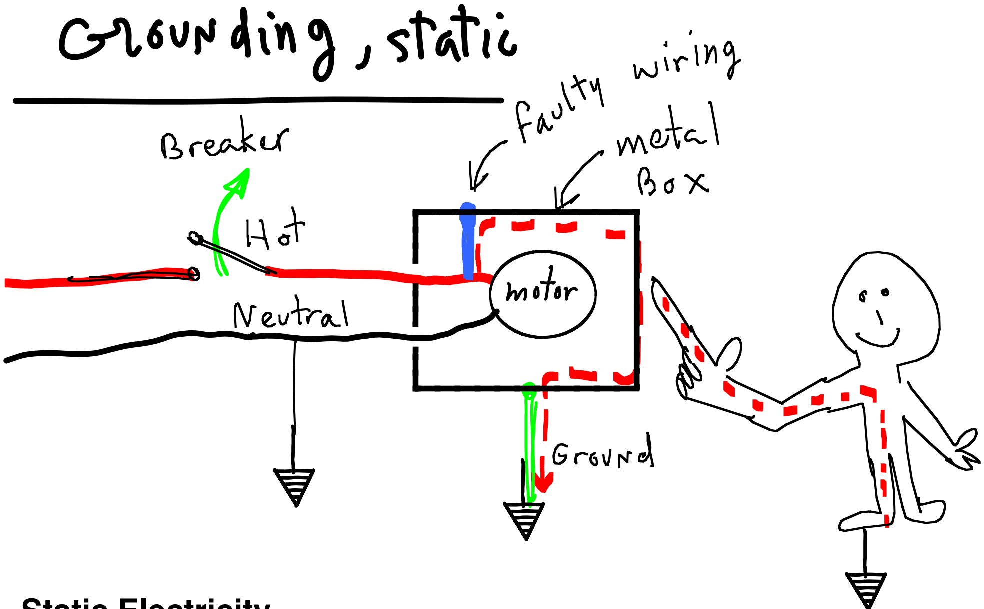
Safety



Grounding, static



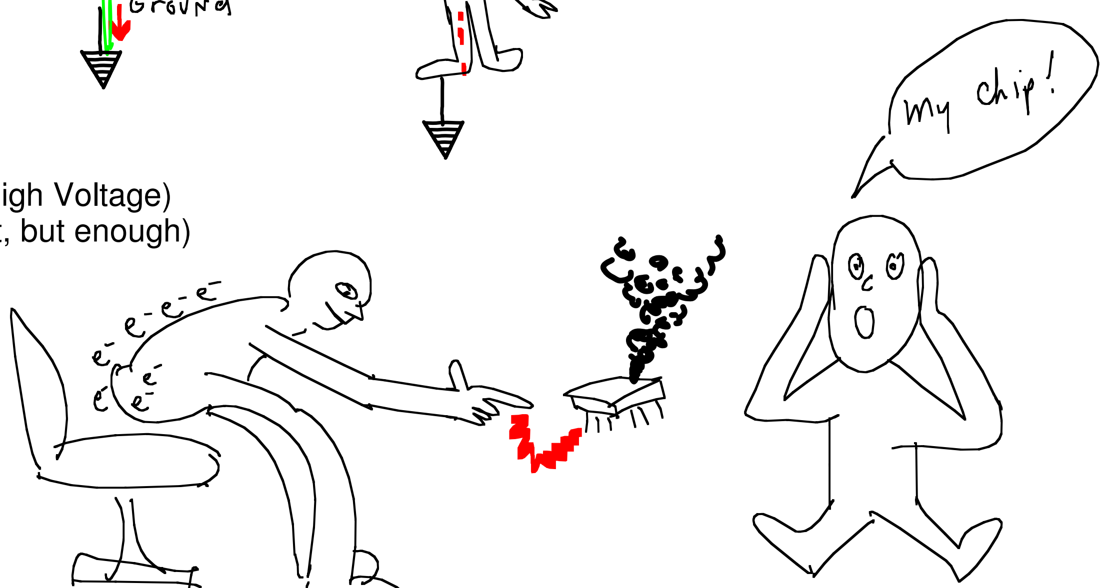
Grounding contact (3rd wire)

Faulty wiring makes box hot !!

Current path splits:
1) to ground (mostly)
2) through you (very little)

Excess current blows breaker.

Static Electricity
1. e- builds up by rubbing (High Voltage)
2. e- jumps (very low current, but enough)



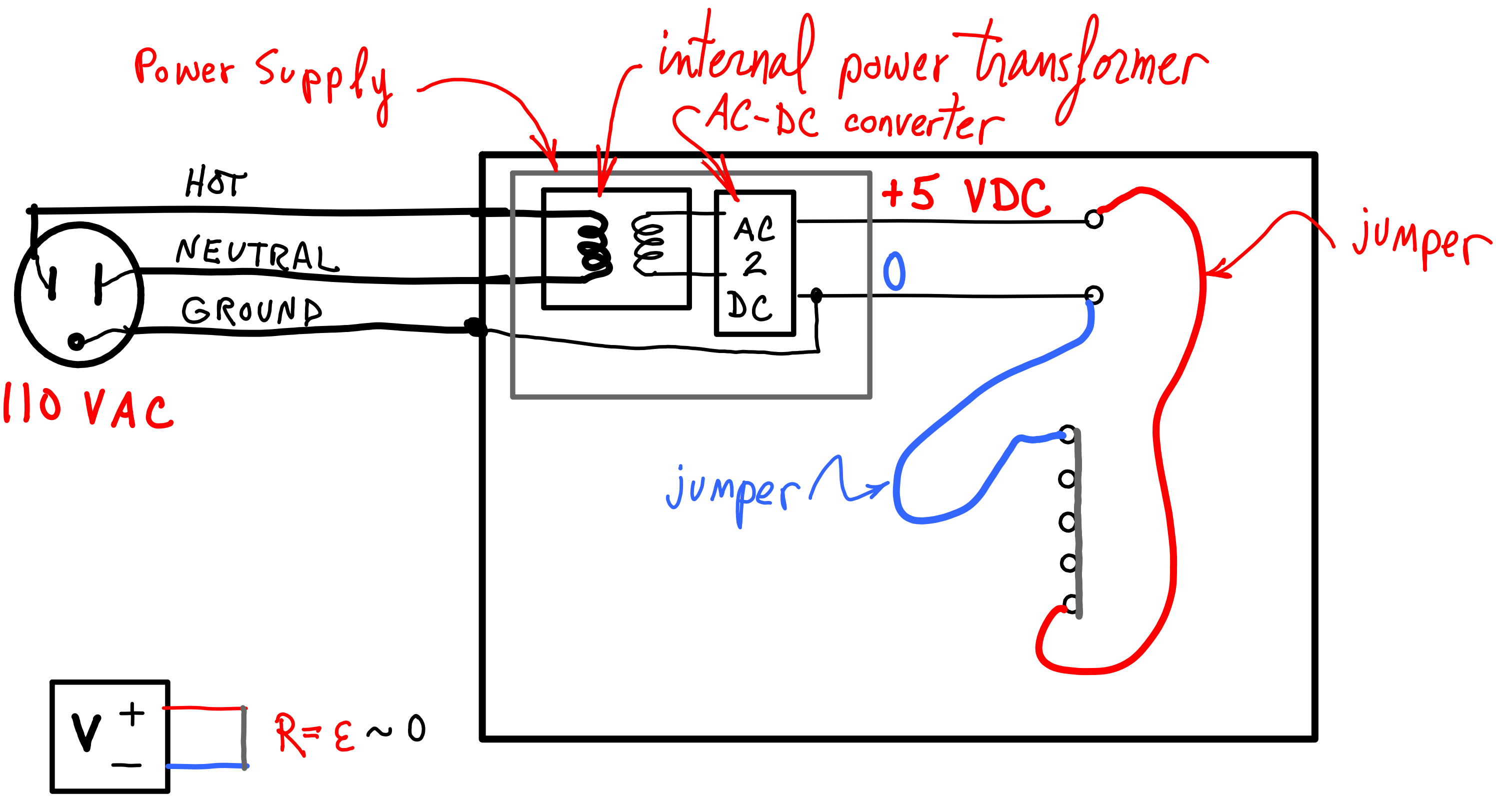
Discharge by touching: BNC coax shield, outlet metal cover plate, wire connected to GND

WARNING
NO short circuit power supply:

NO wire connection from voltage source to ground.
Destroys power transformer.

Wiring mistakes cause this.

TEST VOLTAGES AS YOU MAKE CONNECTIONS.

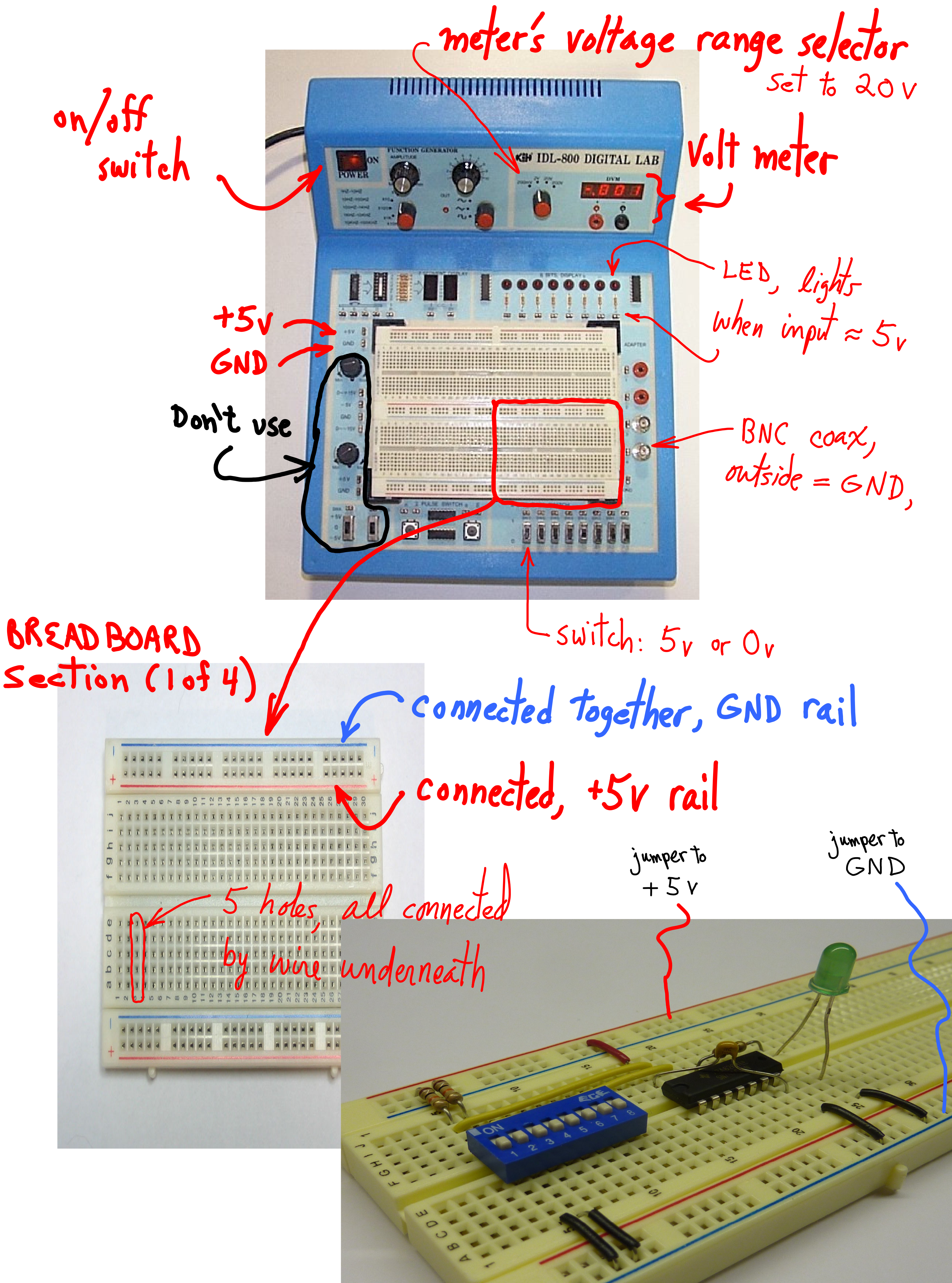


$5v = V = iR \quad i = 5/\varepsilon \qquad Power = iV = \left(\frac{5}{\varepsilon}\right)5 = 25/\varepsilon$

Plug the 0v and 5v power supply lines together:

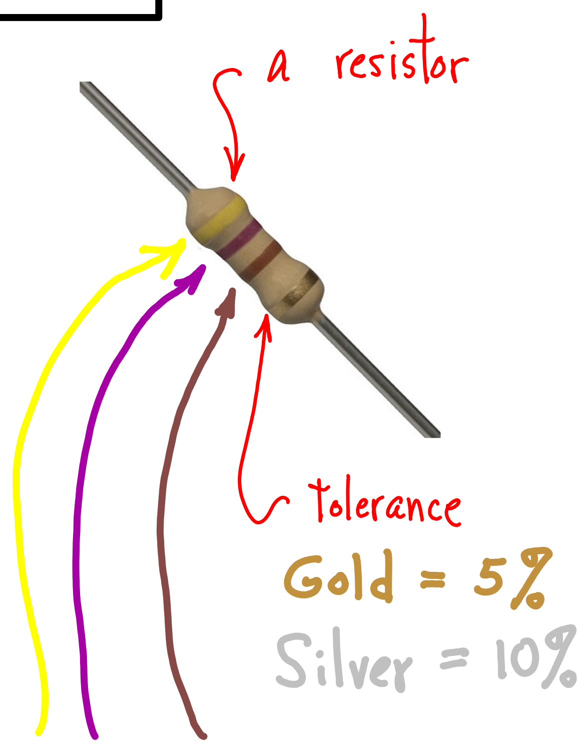
Short Circuit

Power Supply overheats and burns out.



meter's voltage range selector
set to 20v
on/off switch
IDL-800 DIGITAL LAB
POWER
FUNCTION GENERATOR
DVM
Volt meter
LED, lights when input ≈ 5v
+5v
GND
Don't use
BNC coax, outside = GND,
switch: 5v or 0v
BREADBOARD Section (1 of 4)
connected together, GND rail
connected, +5v rail
5 holes, all connected by wire underneath
jumper to +5v
jumper to GND

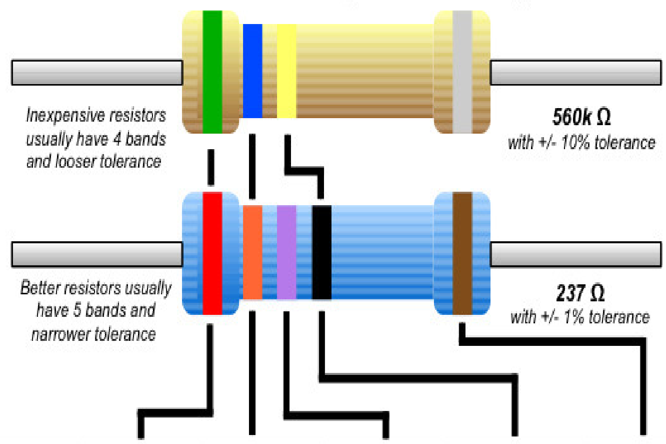
Resistors



$$47 \times 10^1 = 470\,\Omega$$

Resistor Identification

The end with more bands should point left when reading colors.



Color	1st Band	2nd Band	3rd Band	Multiplier	Tolerance
Black	0	0	0	x 1 Ω	
Brown	1	1	1	x 10 Ω	+/- 1%
Red	2	2	2	x 100 Ω	+/- 2%
Orange	3	3	3	x 1K Ω	
Yellow	4	4	4	x 10K Ω	
Green	5	5	5	x 100K Ω	+/- .5%
Blue	6	6	6	x 1M Ω	+/- .25%
Violet	7	7	7	x 10M Ω	+/- .1%
Grey	8	8	8		+/- .05%
White	9	9	9		
Gold				x .1 Ω	+/- 5%
Silver				x .01 Ω	+/- 10%

Surface-Mount

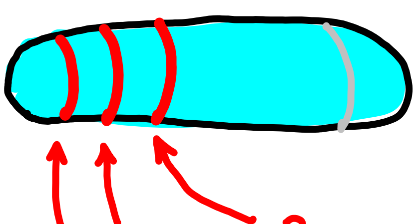
Surface-Mount (SMD) resistors use a similar system. Resistance is indicated by a 3-digit code like 104, sometimes followed by a letter. Rare, precision resistors have 4 digits (3+multiplier).

1st Digit	2nd Digit	3rd Digit (rare)	Multiplier
1	0		4

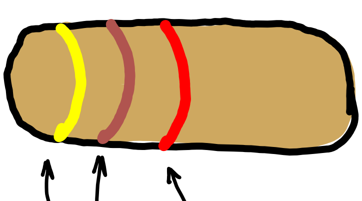
(10 with 4 zeros) = **100k Ω**

- 0 Ω resistors (marked “0”) are used instead of wire links to simplify robotic assembly.
- Resistors less than 100Ω use a 0 multiplier to mean “x 1” so “100” = 10Ω, “470” = 47Ω

This is a low-res version of the PDF available on www.zachpoff.com

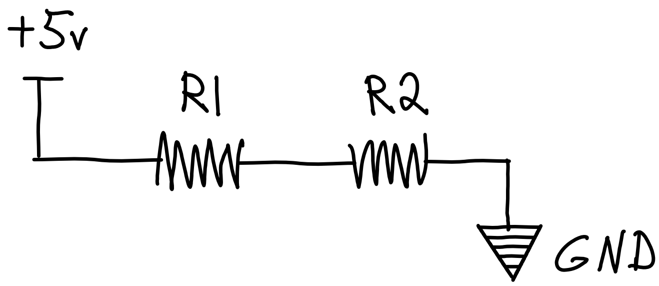


$$22 \times 10^2 = 22 \times 10^2\,\Omega$$
$$= 2.2\,k\,\Omega$$



$$41 \times 10^2 = 4.1\,k\,\Omega$$

our 1ST circuit



1. Measure voltage at +5v supply

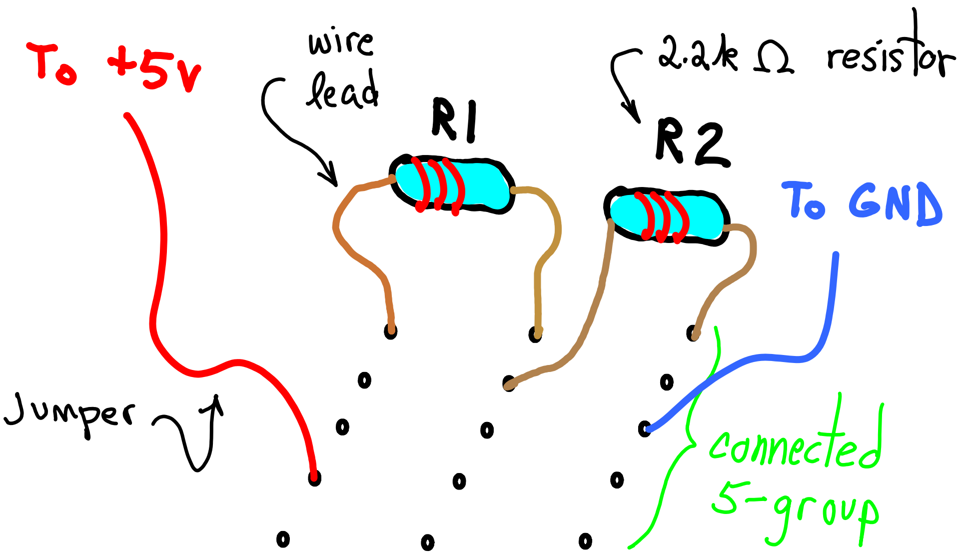
a. connect black probe to GND

b. touch red probe to +5v supply

Q. What voltage do you read ? _______________

2. Measure voltage at GND

Q. What voltage do you read ? _______________



Holes are connected together underneath board.

A. voltage is measured difference BETWEEN two physical contacts.

B. One contact can be GROUND, which is nominally 0 v.

C. Voltage ACROSS a device is difference between one side of device and other side.

D. To measure voltage across a device, touch meter's leads to wires from device, black to one side, red to the other.

3. Touch meter's leads to R1's leads.

Q. What is the voltage across R1 ? __________________

4. Touch meter's leads to R2's leads.

Q. What is the voltage across R2 ? __________________

5. Touch meter's leads input/output wires of the R1+R2 combination.

Q. What is the voltage across R1+R2 ? ________________

6. Which way is the current flowing through R1 ? _________________

7. Which way is the current flowing through R2 ? _________________

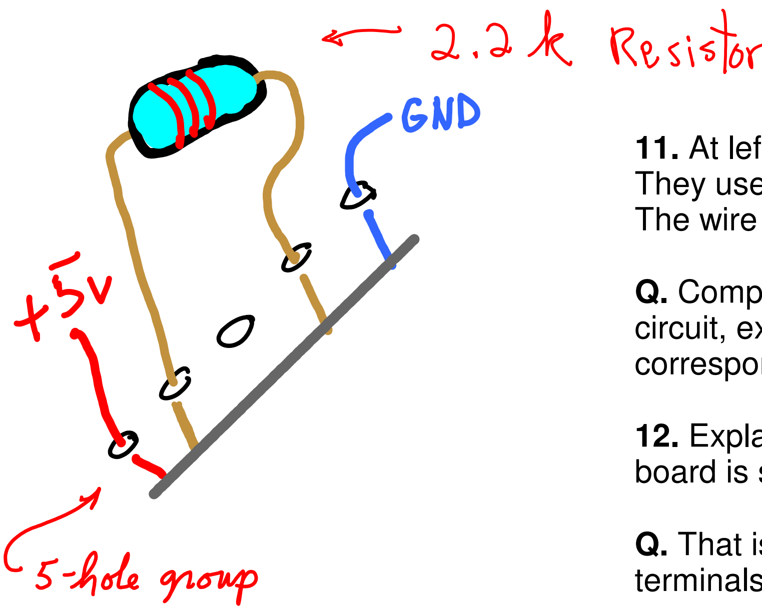
8. How much current is flowing?

____

NB--Ground contacts are labeled, but the BNC connector's external metal is also ground; you can push your ground probe into the BNC connector so that it rests between the plastic core and the metal case.

9. What is the voltage at the point between R1 and R2, relative to GND ? ____________________

10. What is the voltage between R1 and R2, relative to the +5v supply ? _____________________

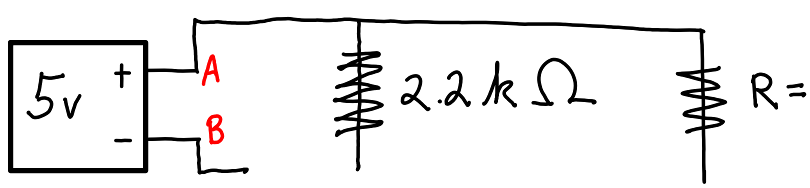


11. At left is a circuit someone wired on a breadboad. They used the holes in a single connected 5-group. The wire connecting the holes is shown in gray.

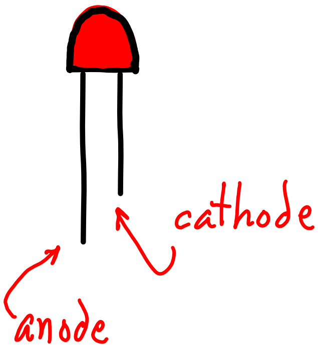
Q. Complete the circuit diagram shown below for this circuit, explaining which parts of the diagram correspond to which parts of the physical circuit.

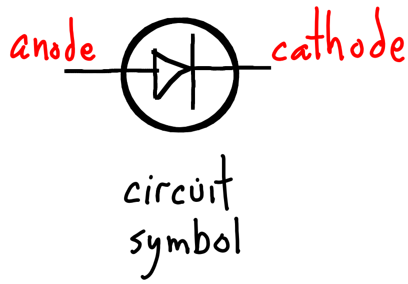
12. Explain what will happen to this set up when the board is supplied power.

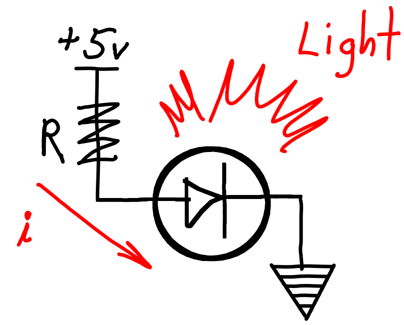
Q. That is, was is the power loss as heat between the terminals A and B?

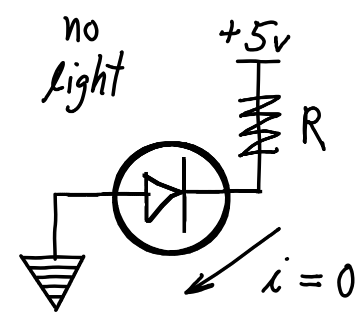


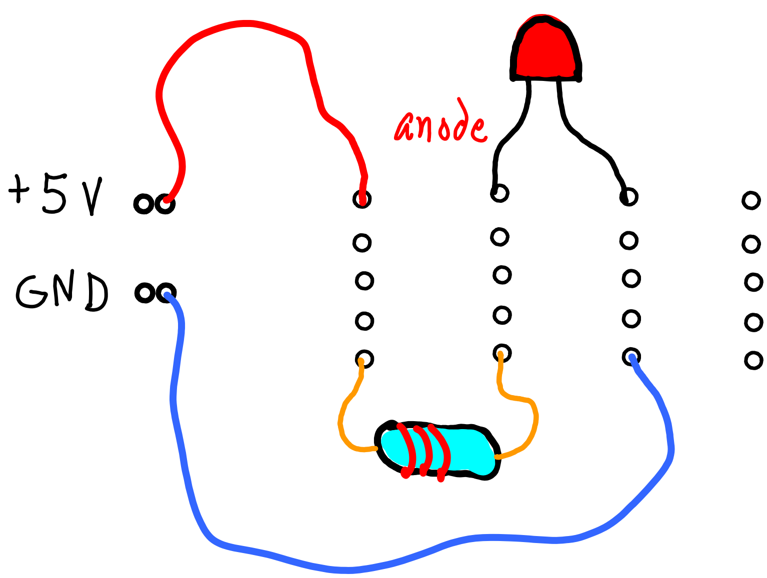
an LED (Light Emitting Diode) circuit

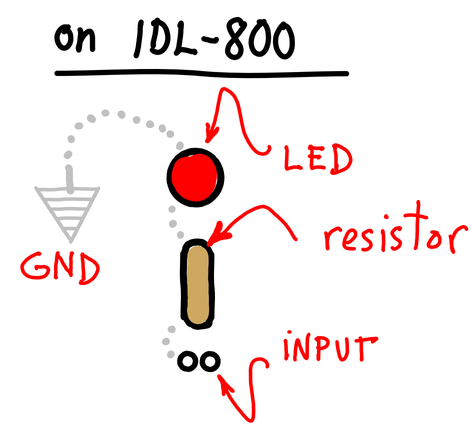












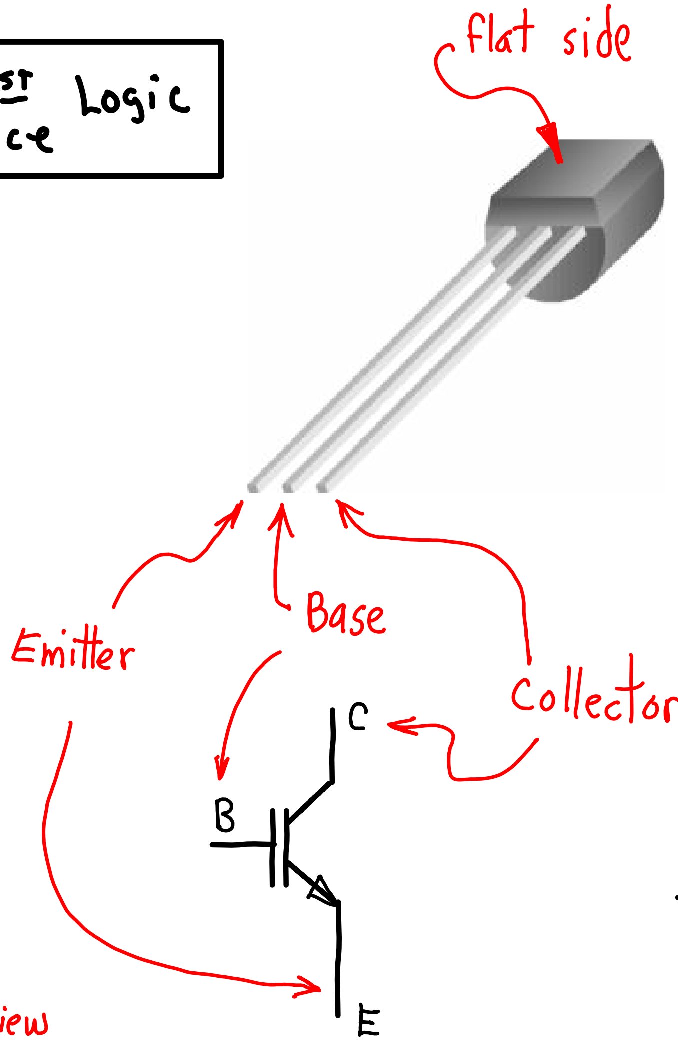
13. Depending on the LED, the resistance needs to more or less. Use a larger resistance, and if no light shows, change to a smaller resistance.

Q. Measure voltage drops across resistor and LED.

Our 1st Logic device

transistor

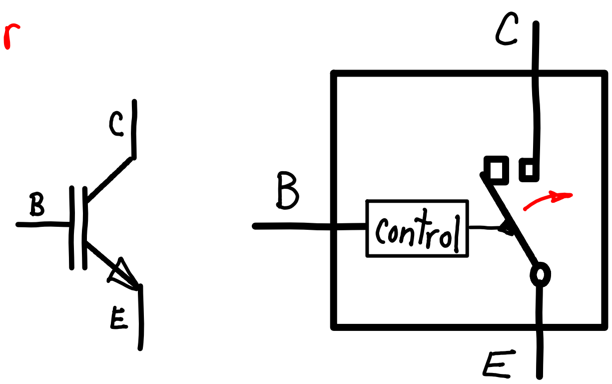
Voltage controlled switch

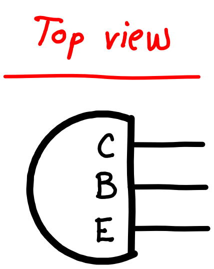


We have:

PN2222 or 2N4401 or BC337

npn Bipolar Transistors



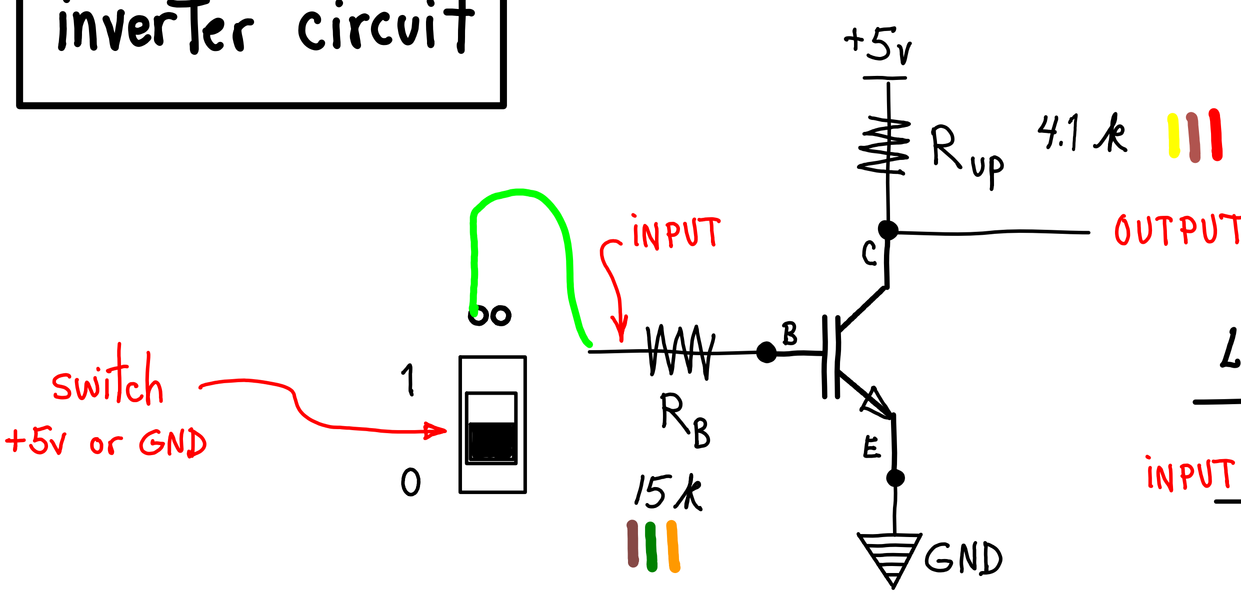


Warning

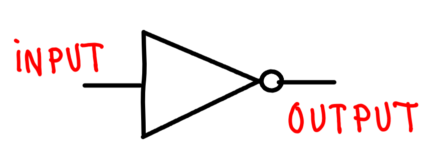
Base B must have a RESISTOR attached.

Else, transistor will BURN UP.

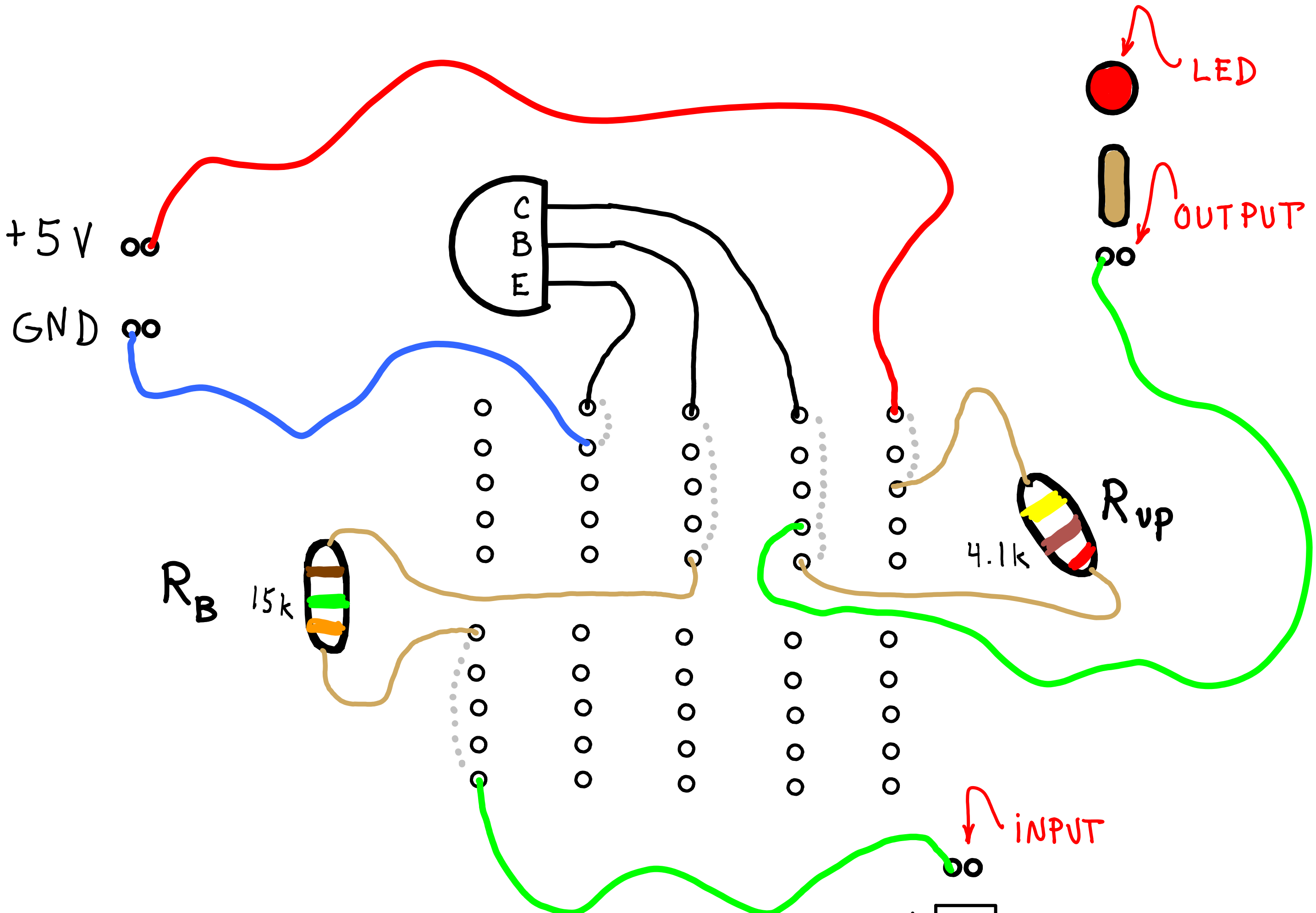
inverter circuit

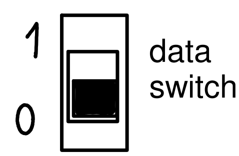


Logic symbol



Inverter BB ckt.





14. Setting the input switch to 0, measure voltage drops across resistors and transistor terminals:

V_{RB} ____, V_{Rup} ____, V_{CE} ____, V_{BE} ____, V_{CB} ____

15. Setting the input switch to 0, measure voltage drops across resistors and transistor terminals:

V_{RB} ____, V_{Rup} ____, V_{CE} ____, V_{BE} ____, V_{CB} ____

16. Set the data switch to 0. Measure the voltage at the input relative to ground. Disconnect the output from the LED and measure the output voltage relative to GND. Fill in the first row of the table at right.

17. Set the data switch to 1. Make the same measurements and fill in the second row of the table.

	INPUT	OUTPUT
switch 0		
switch 1		

TTL CHIPS

Here's how we use TTL chips on our breadboard.

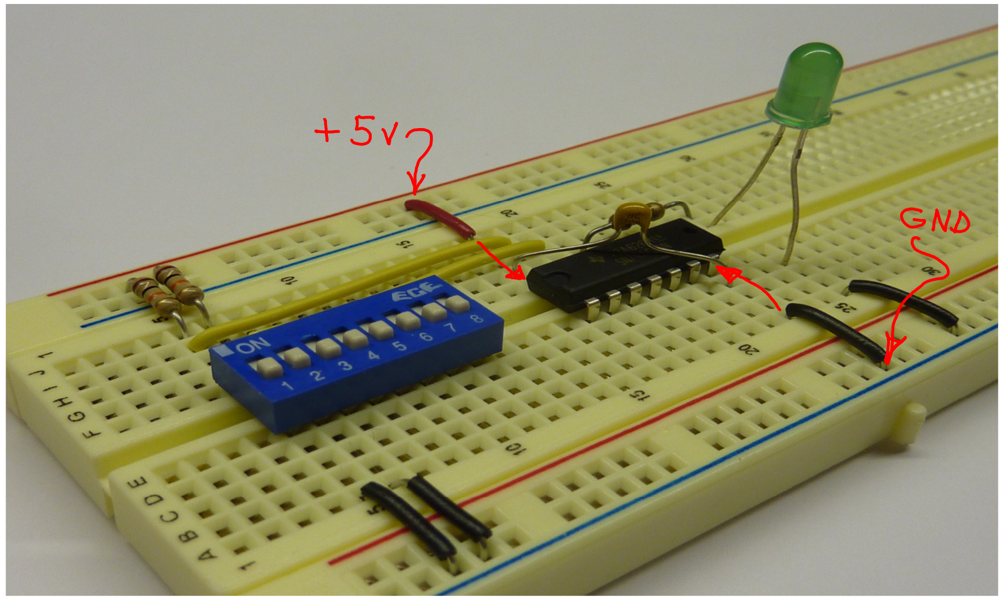
This circuit includes a set of switches and and LED output indicator.

The chip has its VCC pin connected to the +V rail, and its GND pin connect to to the GND rail.

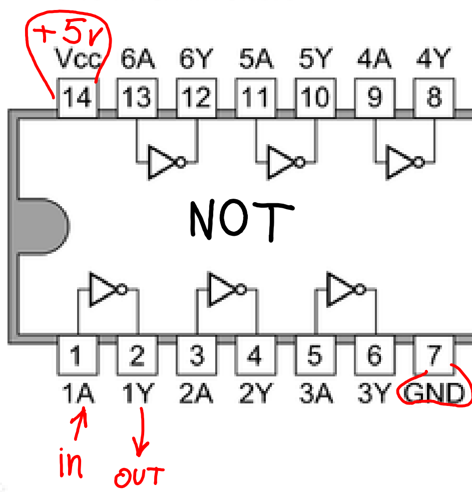
The input switches have pull-up resistors, and are wired as manual NOT gates.

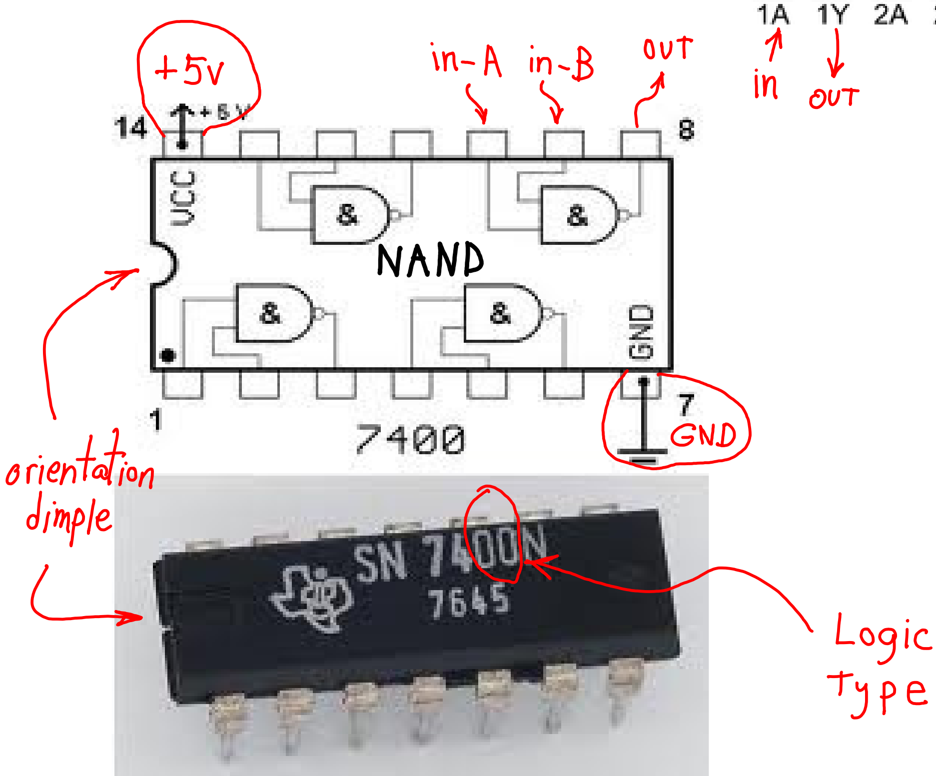
The LED has a resistor.

There is a capacitor across the power pins of the chip.

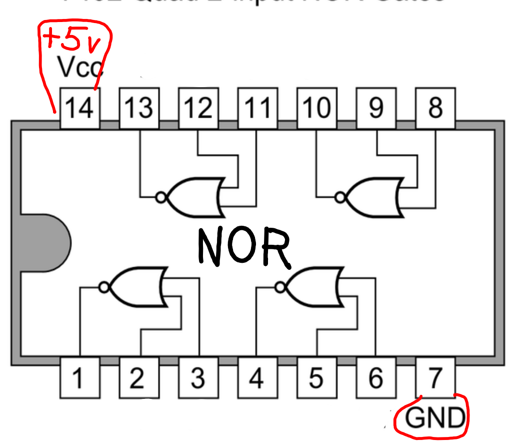


7404 Hex Inverters



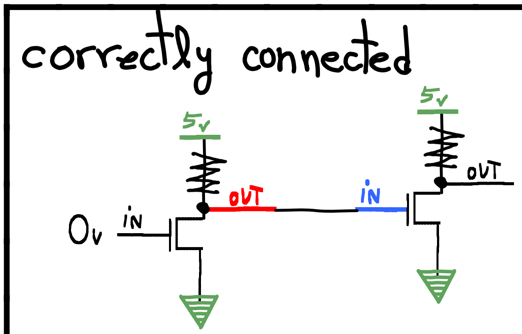


7402 Quad 2-input NOR Gates



NB--7402 has its inputs/outputs left-right flipped w.r.t. the 7400.
IF YOU **rotate by 180** degrees (swapping GND and +5v) they look the same.

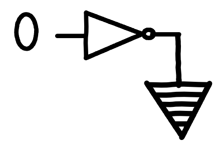
Do NOT tie gate outputs to Supply or Ground.

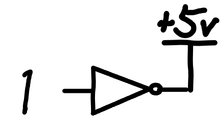


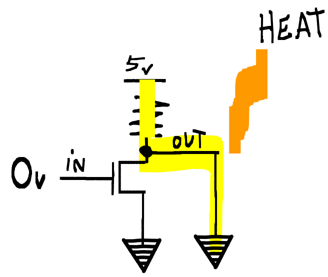
Each device has +5v and GND supplies.

Device **logic output** goes to
Device **logic input**

Device current is small

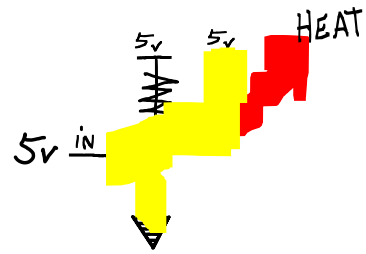






logic **output to GND**

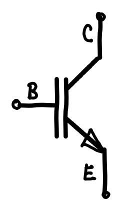
==> excess current.



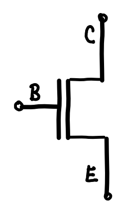
logic **output to +5v**

===> SHORT CIRCUIT

NB-- Different symbols for transistors of different types.
Both are switches controlled by the B input.

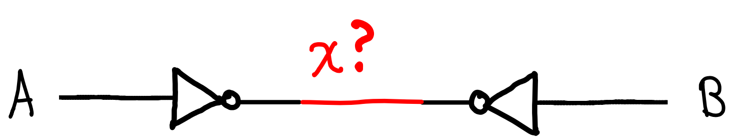


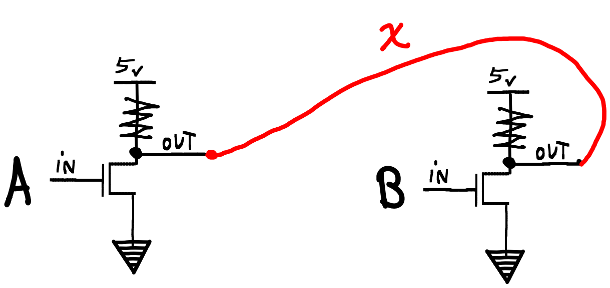
Bi-Polar



nMOS

Do NOT tie gate outputs together.



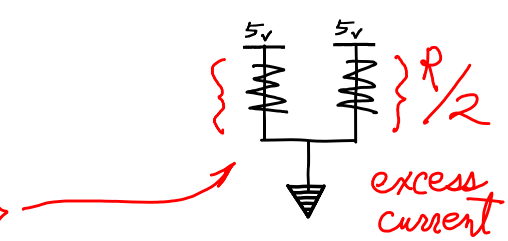


Which output determines the value of x?

A = 0, B = 1, x = ?

A = 1, B = 0, x = ?

input	X
A=0 B=0	1
A=0 B=1	0
A=1 B=0	0
A=1 B=1	0



Just so happens to be NOR(A, B)
Probably not what you were thinking.

Two types of logic circuits:

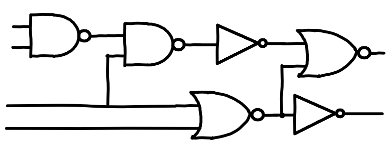
--- feedback (sequential circuits) ===> Sequential circuits hold state
--- no feedback (combinational circuits) ===> purely functional, cannot hold state

Basic logic gates:
NOT, NOR, NAND

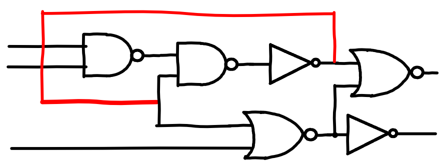
--- Combine to get any function or state machine

NOR(x, y) = NOT(OR(x, y))
NAND(x, y) = NOT(AND(x, y))

TTL chips:
7400 (four NANDs), 7402 (four NORs), and 7404 (six NOTs)

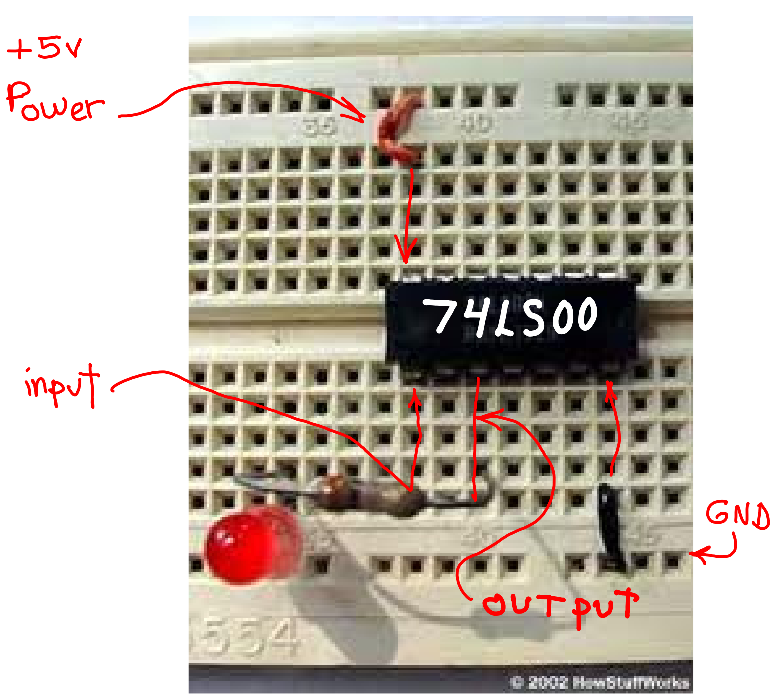


Combinatorial circuit
--- no feedback



Sequential circuit
--- feedback

TTL chips fit across breadboard channel. 7400 NAND has four NAND gates. Each gate has three pin connections: in-A, in-B, out-Y. NOTE: 7402 NOR has different pin pattern left-to-right: out-Y, in-A, in-B.



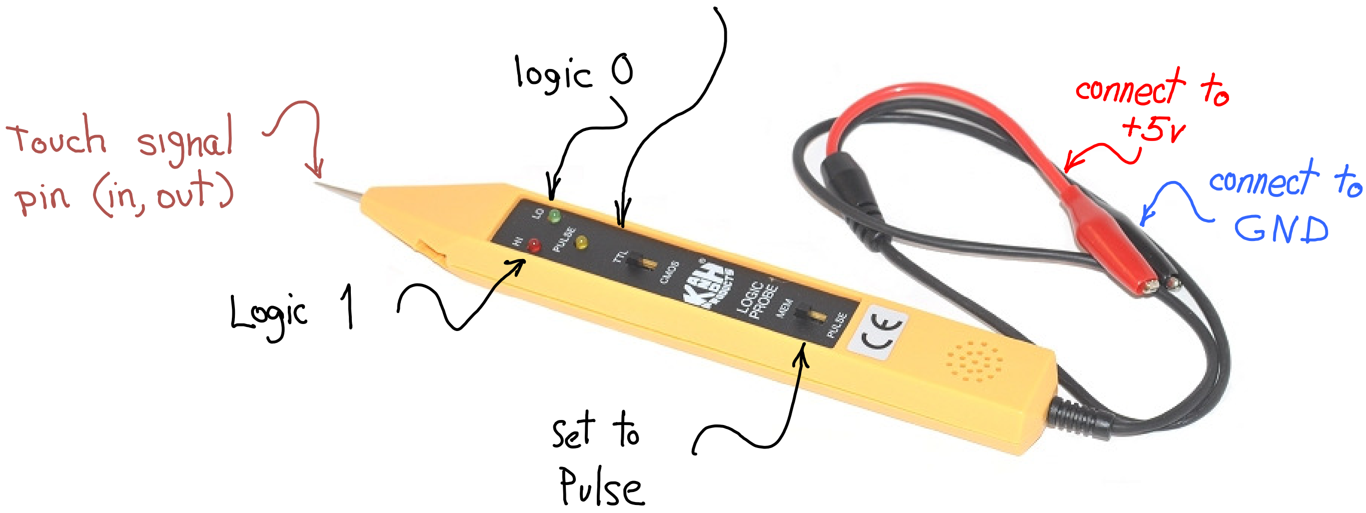
Use a chip puller to remove chips:

--- leads are easily bent
--- hard to straighten

Leave room between chips to get puller in

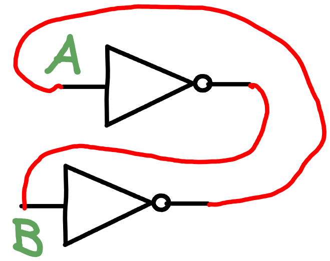
Logic Probe

May be inaccurate.
Check signal w/ volt meter
to be sure.



Exercises

1. Use a 7404 NOT to build this circuit:



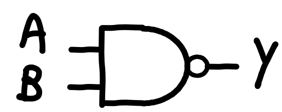
1.a What are the voltages at A and B? (Use the volt meter). ________________
1.b What are the logic values at A and B? (Use the logic probe). ________________

1.c Briefly connect, then immediately disconnect a wire from A to GND.
Now measure A and B (use both methods). ___________________________

1.d Now make the same connection at B instead, and measure A and B. ___________

1.e Is this a sequential or combinatorial circuit? _____________________
How many states does this circuit have? ____________________

2. Use a 7400 NAND, connect one gate's inputs to switches, and use your logic probe to see the output.



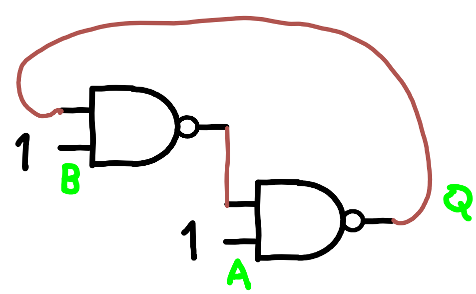
2.a Complete the following truth table for NAND:

in		out
A	B	Y
0	0	
0	1	
1	0	
1	1	

2.b Consider A to be a control signal, and set the A input to logic 1. Toggle the B input (switch from 0 to 1 to 0). Explain how Y is logically related to input B.

2.c Now set A to 0, and toggle B. Now how is Y related to B?

3. Build the circuit at right.



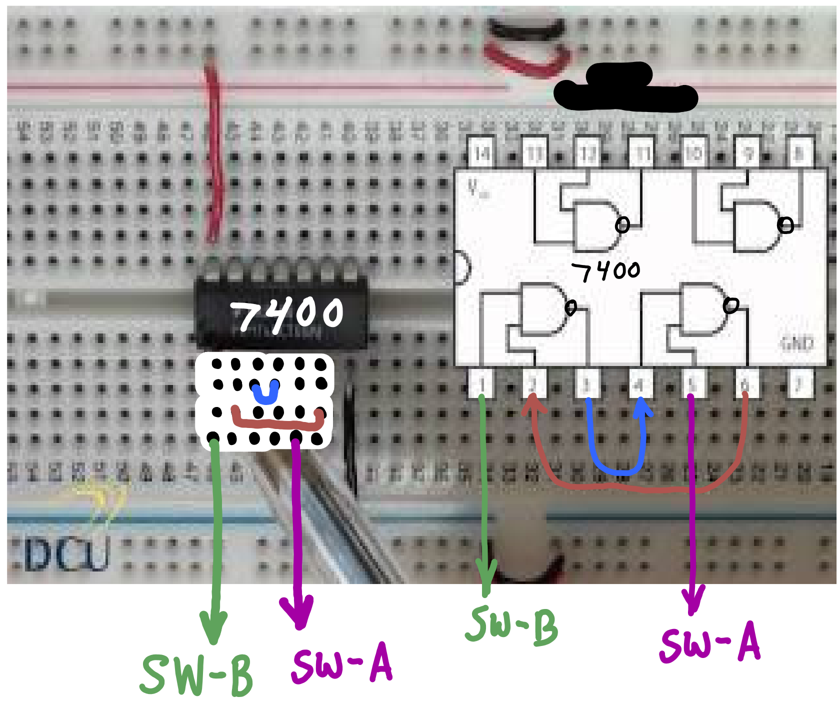
3a. How does this ckt compare with the NOT-NOT ckt above _____________________
(Use same testing procedure as you did for the NOT-NOT circuit.)

3b. Switch the input A to 0. What is the effect at Q? ____________________
3c. Switch A back to 1, then switch data B to 0. What is the effect at Q? ________

Breadboard Hints

Clean wiring

Although the larger, "bonded" flexible jumper wires are easy to plug in, they soon become a tangled mess. This makes it hard to debug a ciruit. Better to use small pieces of wire layed down neatly and flat. Do not cross wire over your chip as you may want to pull it off your board.



At right is a 7400 wired as in part 3 above w/ short, flat wires. The jumpers are away from chip's pins, making it easy to see and probe.

NB--By pulling out the 7400 and putting in a 180-degree rotated 7402 NOR chip instead, you will have wired the circuit shown below for part 4. Of course, you have to change upper-left pin to be connected to GND, and the lower-right pin to be connected +5v.

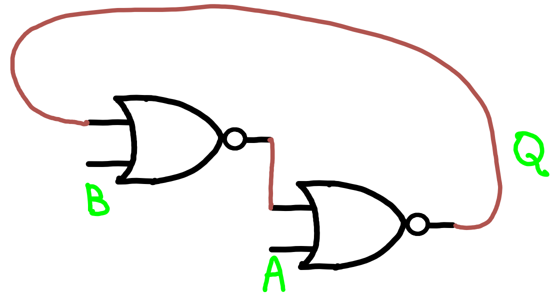
"SW-A" indicates one of the data switches.

Working w/ small wires and chip pins.

Pliers are needed to straighten small wires and firmly push them into the breadboard holes. Chip pins may need to be straightened and aligned. Use pliers to gently bend them. They break if bent too far. Gently align the pins to the holes so they all go in together.

DANGER

Do not leave a chip on the floor or out on a desktop: The pins are VERY SHARP.



4. Repeat (2) and (3) using a 7402 NOR.

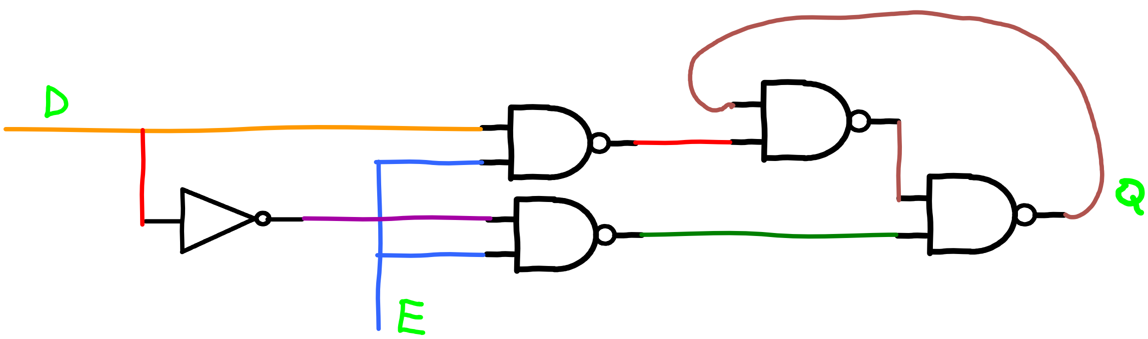
4.a How does the NOR-NOR ckt compare with the NAND-NAND ckt? ____________________

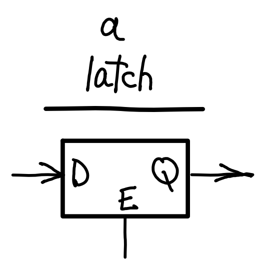
4.b What is the fundamental difference between them?

The latch

The circuits above are basic elements that remember a binary state, once it is set. But, we cannot control which state they are in. We need a control, Enable (E), and a Data (D) input.

5. Build the circuit below. This is a latch.





The circuit above is a "D-latch with enable".

5.a Set E = 1, D = 1. What is Q? ____________

5.b Set E = 0. What is Q? ________________

5.c Set D = 0. What is Q? ___________________

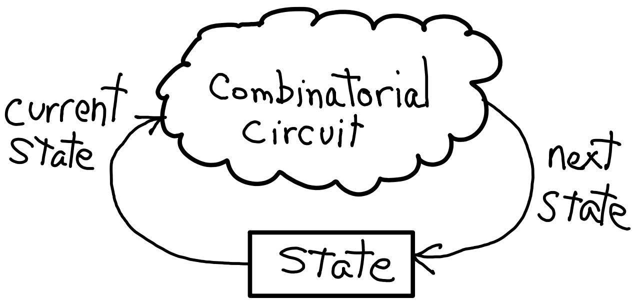
5.d Set E = 1, D = 1. What is Q? ______________

5.e Set D = 0. What is Q? ___________________

5.f Set E = 0. What is Q? ____________________

5.g Set D = 1. What is Q? _________________

The Flip Flop



Sequential Machine:

--- Has **state**
--- **Changes its state**
--- A **function** determines the **next state**
--- **Input** to the function is the **current state**

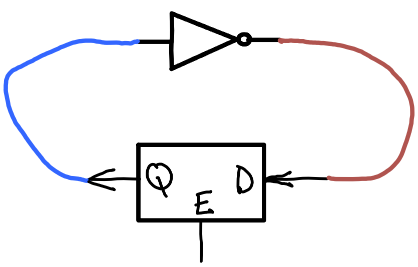
The **next-state function** is a **combinatorial circuit**

Machine's state is a **sequential ciruit**

--- We built a state-element circuit, the D-latch

The D-latch acts like a wire passing D to the Q whenever E = 1.

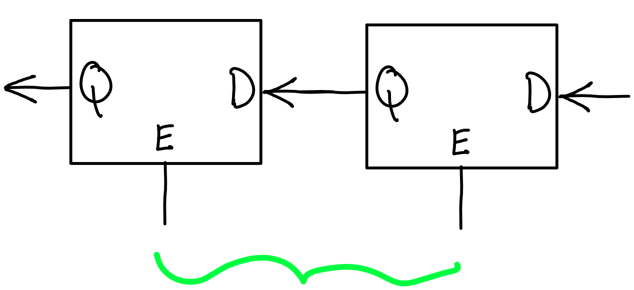
If we use a latch for our state element in our sequential machine, it will not change state when we want it to. Suppose the next-state function is NOT. What will happen?



6. Build the circuit at right.

6.a Set E = 1. Set E = 0. Repeat several times.
What state did it settle to each time E = 0?

The problem with the circuit above is that the next-state signal goes through the latch and changes the machine's state before we can set E = 0 again. We need a controlled way to do this. We use two latches, and only set one of the E's to 1 at a time, the other is 0.

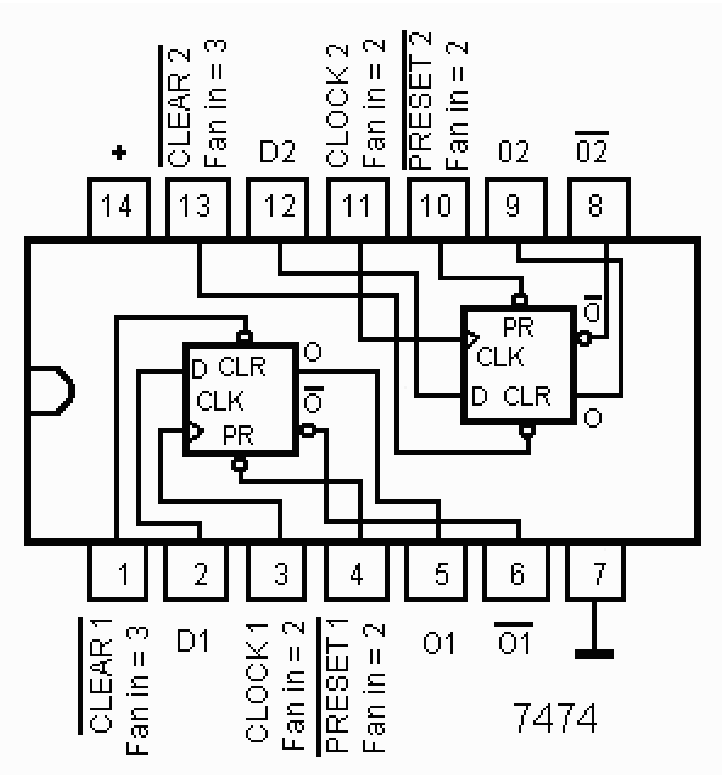


This state element is a **D-Flip-Flop**.

Only one of the enables is allowed to be logic 1.

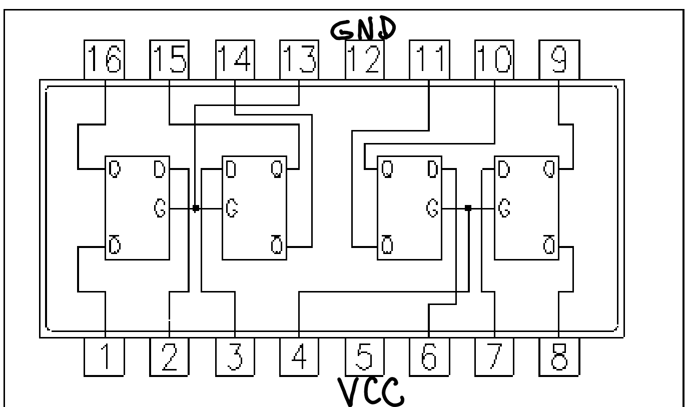
control separately so never both transparent at same time.

Other TTL chip diagrams



$\overline{PRE}$	$\overline{CLR}$	CLK	D	Q^+
0	1	X	X	1
1	0	X	X	0
1	1	↑	0	0
1	1	↑	1	1
1	1	0	X	Q

NB – this ↑ means a signal that changes from 0 to 1, called a "rising edge".



7475
4-Bit Bistable Latch
with Complementary Outputs

D	E	Q^+
0	1	0
1	1	1
X	0	Q