Mechatronics (ROB-GY 5103 Section A)

- **Today's lecture:**
  - Bit Operations
  - Optoelectronics
- (See Topics #2 and #6 from Main Text for details)

Variables

- Giving a name to a chunk of memory

```
myVariableName1 VAR Bit
myVariableName2 VAR Nib
myVariableName3 VAR Byte
myVariableName4 VAR Word
```

- Creating an **alias** for a variable
  - Given a byte size variable `BytVar`, create a variable to get lower nibble value of `BytVar`

    ```
    LowNib_BytVar VAR BytVar.LOWNIB
    ```

  - To determine if a number stored in a counter variable `Ctr` is odd/even, create an alias:

    ```
    Lowbit_Ctr VAR Ctr.LOWBIT
    ```

    Check if 0 or 1

Bit Operations

- How to add, subtract, multiply, and divide numbers using bits in BS2 (binary representation)

Subtraction

Two's Complement

- Not obvious how to represent negative numbers
- Binary representation of -1, -2, -3, etc.:

$$1 \xrightarrow{\text{D2B}} 00000001 \xrightarrow{\text{InvB}} 11111110 \xrightarrow{+1} 11111111$$
$$2 \xrightarrow{\text{D2B}} 00000010 \xrightarrow{\text{InvB}} 11111101 \xrightarrow{+1} 11111110$$
$$3 \xrightarrow{\text{D2B}} 00000011 \xrightarrow{\text{InvB}} 11111100 \xrightarrow{+1} 11111101$$

- To represent positive and negative values using a byte sized variable, by using the **most significant bit (MSB)** to encode sign of the number, we can represent values from -127 to +127.
- If MSB=0, then we have a positive number and no special treatment is needed.
- If MSB=1, then we have a negative number.

Two's Complement: PBasic

- Consider the following PBasic code snippet:

```
FixSizVar Var Byte

FixSizVar=0-1

Debug Bin FixSizVar
```

- The above code will produce 255, not -1. Recall, binary representation of 255 is %11111111. Similarly,
  - `FixSizVar=0-2` will produce 254 not -2.
    Recall, binary representation of 254 is %11111110.
  - `FixSizVar=0-3` will produce 253 not -3.
    Recall, binary representation of 253 is %11111101.

Two’s Complement: Example

- Let us restrict ourselves to working with NIB for now.
- For positive numbers: one NIB can give decimal numbers 0 to 15
- In order to use both positive and negative numbers:
  - we use the 3 low bits to encode the number
  - we use the MSB to encode the sign of number, 0 for positive and 1 for negative
- Now we can store decimal numbers 0 to 7.
- For positive numbers: we have

0000→0	0001→1	0010→2	0011→3
0100→4	0101→5	0110→6	0111→7

Multiplication and Division

Bit Shifting

- Multiplying by 2 → Shifting left
  - To multiply a binary number by 2^n, simply shift the bits of the original binary number n places to left!
- Dividing by 2 → Shifting left
  - Similarly, to divide a binary number by 2, simply shift the bits of the original binary number right by one position. (Integer division only, can't get fractional value out of this!)
- Distributive law of multiplication can help generalize these operations
- Actual implementation of division is more complicated but this gives you a taste

Other things

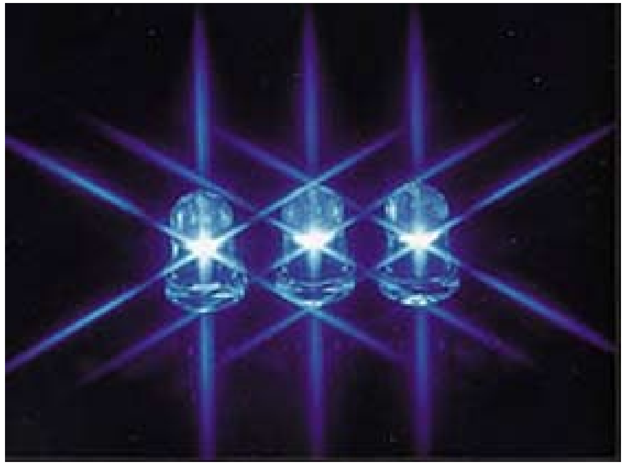
Bit Inversion

- The exclusive OR operator “^” works on a bit-wise basis.
- ^ compares corresponding bits in its two arguments:
  - set the result bit for current location to 1 if either of the two bits in argument are 1
  - set the result bit for current location to 0 if both bits in argument are 1
- Implementing bit inversion using ^:
  - given a = 1010, to invert all bits use: 1010^1111→0101

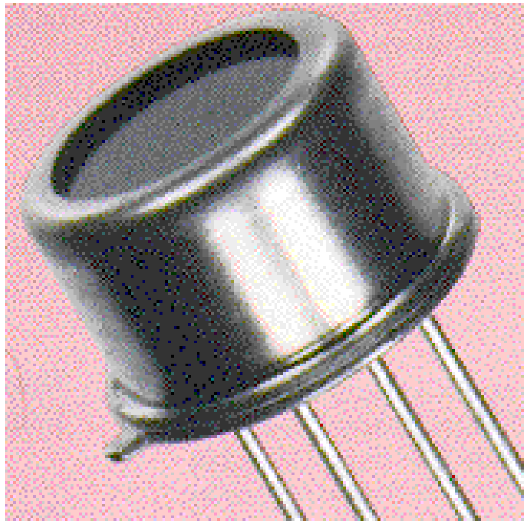
Let there be light

Optoelectronics

- Two types of devices:
  - **Light emitting:** generate electromagnetic energy under the action of electrical field.
    - Light emitting diodes (visible and infrared light).
  - **Light detecting:** transform electromagnetic energy input into electrical current/voltage.
    - Photoresistors, photodiodes, phototransistors, etc.



Light emitting diodes

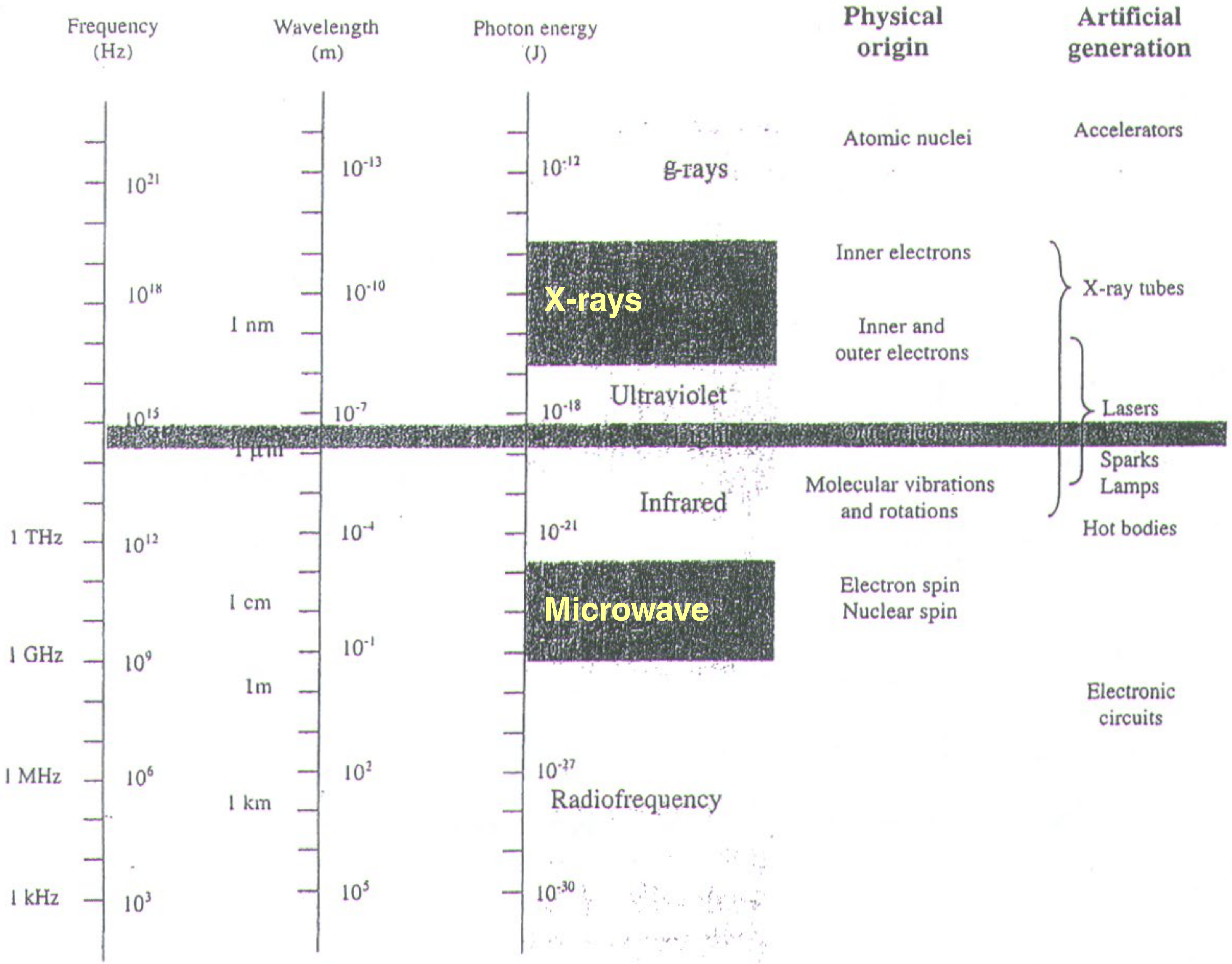


Infrared detector

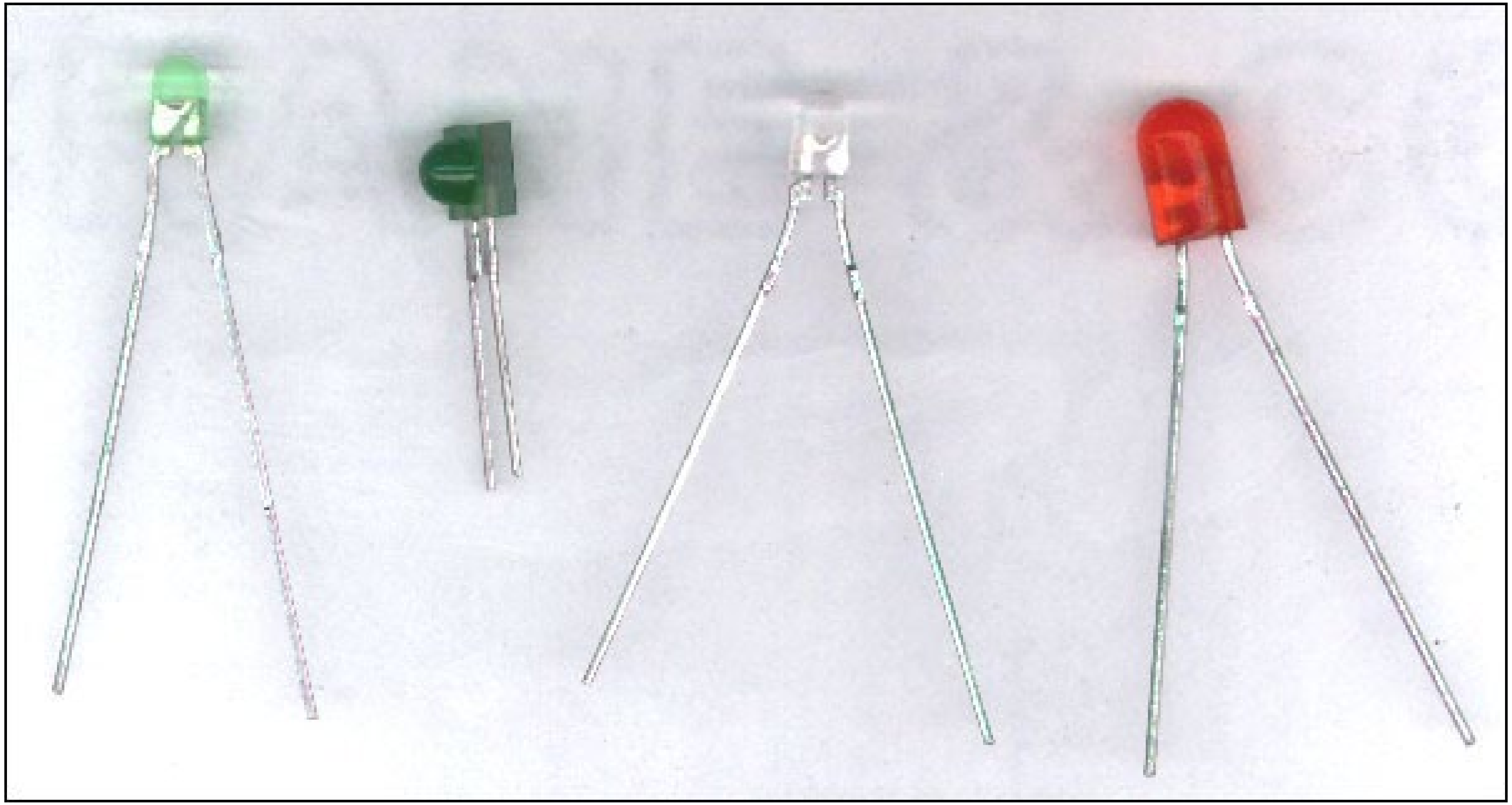
What is light?

- Photons are the fundamental particles of electromagnetic radiation.
- Photons of different wavelengths yield different portions of electromagnetic spectrum.
- Visible and infrared light are two narrow portions of the whole spectrum of electromagnetic radiation.

Electromagnetic Spectrum

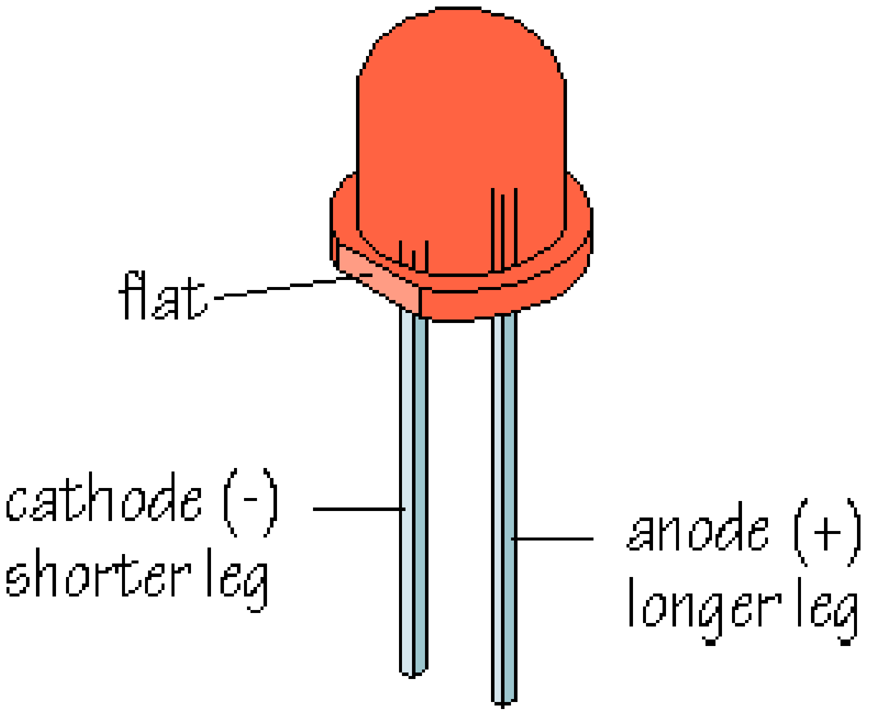


Light-Emitting Diodes (LEDs)



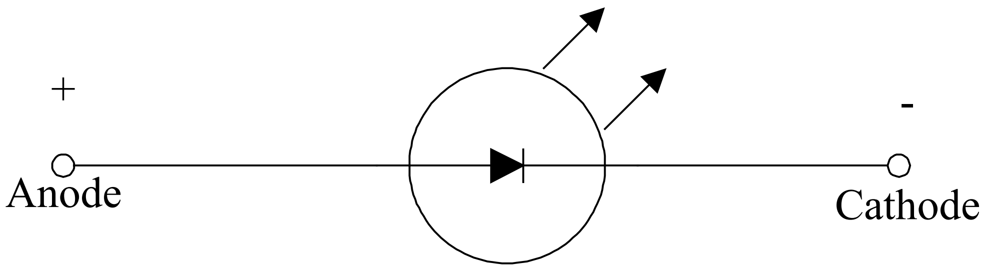
LED Review

- 2 lead semiconductor device.
- Light emitting PN-junction diode.
  - Visible or infrared light.
- Has polarity.
- Recall diodes act as a one way gate to current flow.
  - A forward-biased PN-junction diode allows current flow from anode to cathode.
- An LED conducts and emits light when its anode is made more positive (approx. 1.4V) than its cathode.
  - With reverse polarity, LED stops conducting and emitting light.



LED Review

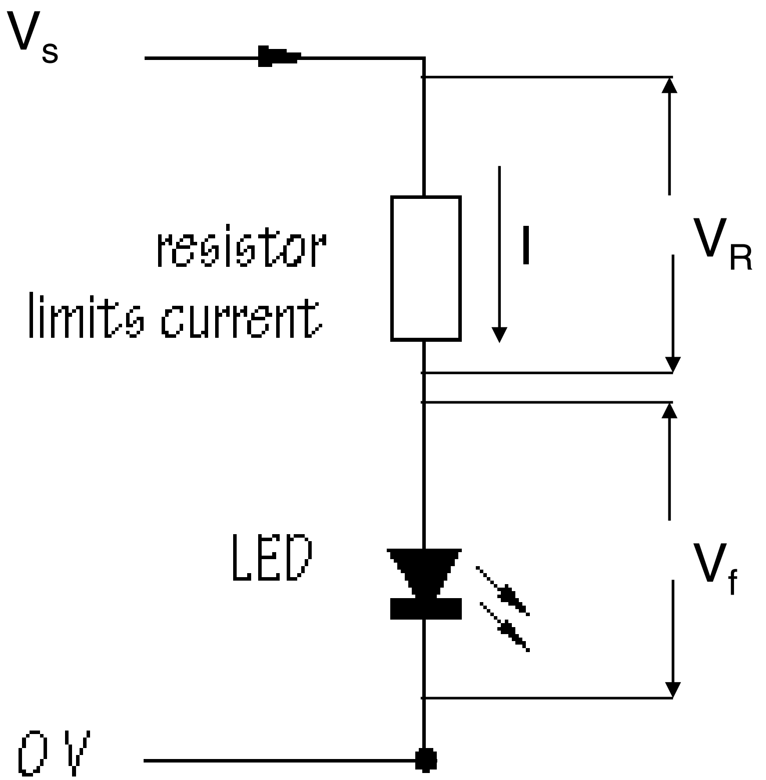
- Similar to diodes, LEDs are current-dependent devices.
  - LED brightness is controlled by controlling current through LED.
    - Too little current through LED $\rightarrow$ LED remains OFF.
    - Small current through LED $\rightarrow$ dimly lit LED.
    - Large current through LED $\rightarrow$ brightly lit LED.
    - Too much current through LED $\rightarrow$ LED is destroyed.
- A resistor placed in series with LED accomplishes current control



LED symbol

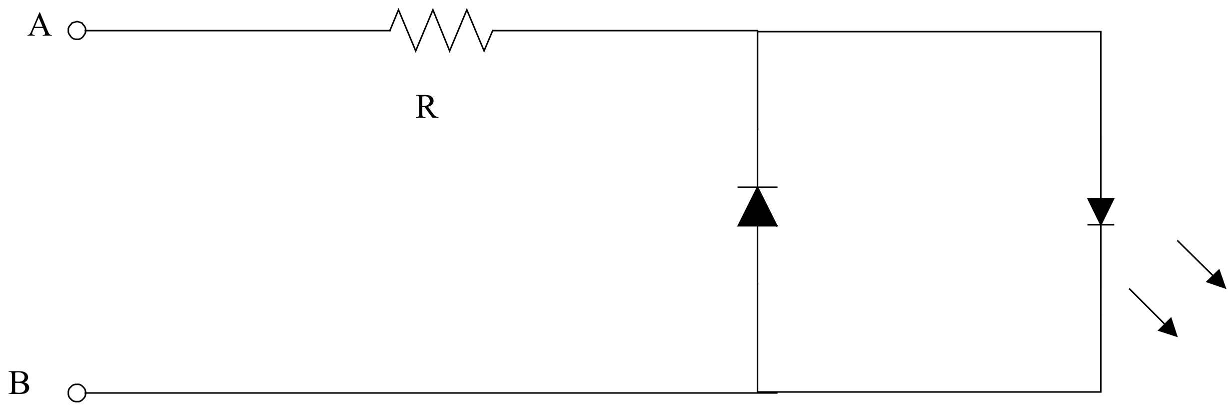
LED: Voltage Divider

- Let V_s be the supply voltage.
- Let V_f be the required forward bias voltage for the LED.
- Let I be the desired current flow through LED.
- If R is too small, a larger current will flow through the LED.
    - LEDs can handle only limited current (varies from 20mA to 100mA).
    - If current through LED is larger than the maximum allowed value, than the LED will be damaged.



LED: Forward Bias

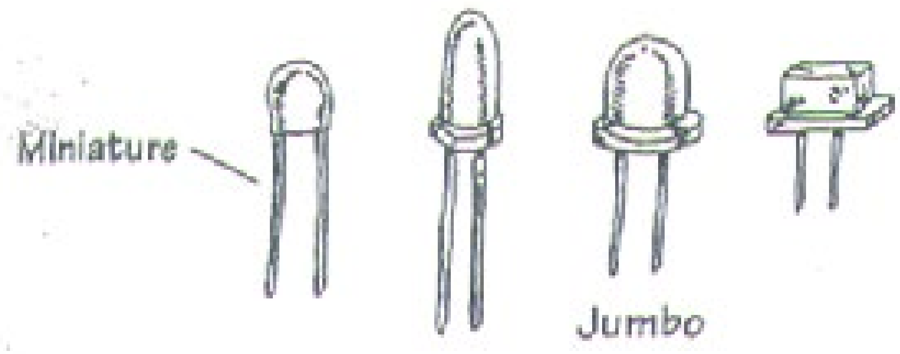
- LEDs conduct only in forward bias mode.
- If a reverse bias is applied across an LED with reverse bias voltage greater than the reverse breakdown voltage (usually 5V), then the LED can be damaged.
- To prevent LED damage in the presence of reverse bias, the following circuit can be used. **Provide an alternate path for the current.**



With $V_A > (V_B+1.6)$ volts LED conducts

With $(0.6+V_A)<V_B$ diode conducts

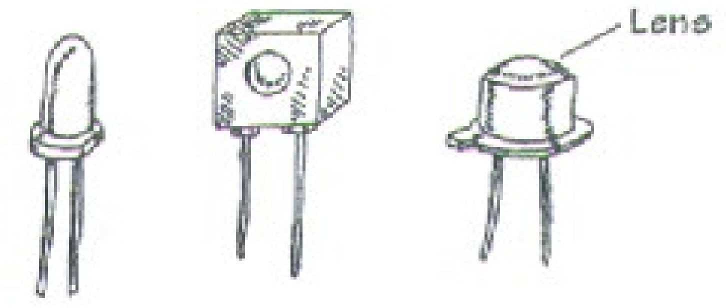
Visible-Light LED



- Inexpensive and durable.
- Typical usage: as indicator lights.
- Common colors: green (~565nm), yellow (~585nm), orange (~615nm), and red (~650nm).
- Maximum forward voltage: ≈ 1.8V.
- Typical operating currents: 1 to 3mA.
- Typical brightness levels: 1.0 to 3.0mcd/1mA to 3.0mcd /2mA.
- High-brightness LEDs exist.
  - Used in high-brightness flashers (e.g., bicycle flashers).

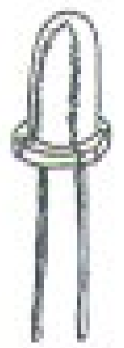
Infrared LED

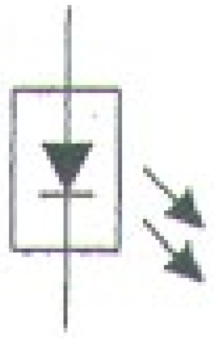
- Designed to emit infrared photons with wavelength ≈ 880 to 940 nm.
- IR LEDs are used in remote-control circuits in conjunction with photosensors.
- IR LEDs have a narrower viewing angle *vis-a-vis* visible-light LEDs.
  - Allows to efficiently direct information to be transmitted.
- Photon output is characterized in terms of output power per specific forward current.
  - Typical outputs range from around 0.50mW/20mA to 8.0mW/50mA.
- Maximum forward voltage at specific forward currents range from 1.6V@20mA to 2V@100mA.



Blinking/Flasher LED

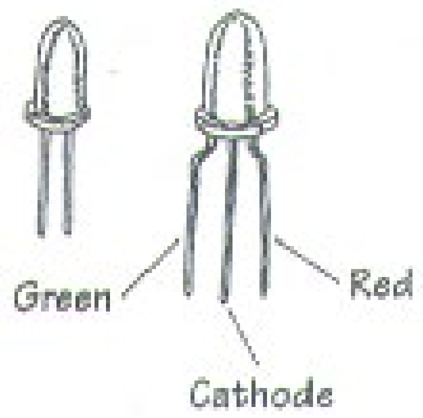
- Contain a miniature integrated circuit that causes LED to flash from 1 to 6 times/s econd.
- Typical usage: indicator flashers. May also be used as simple oscillators.

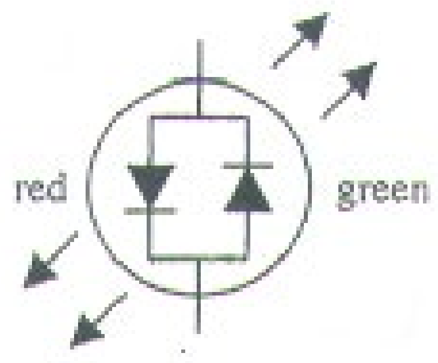




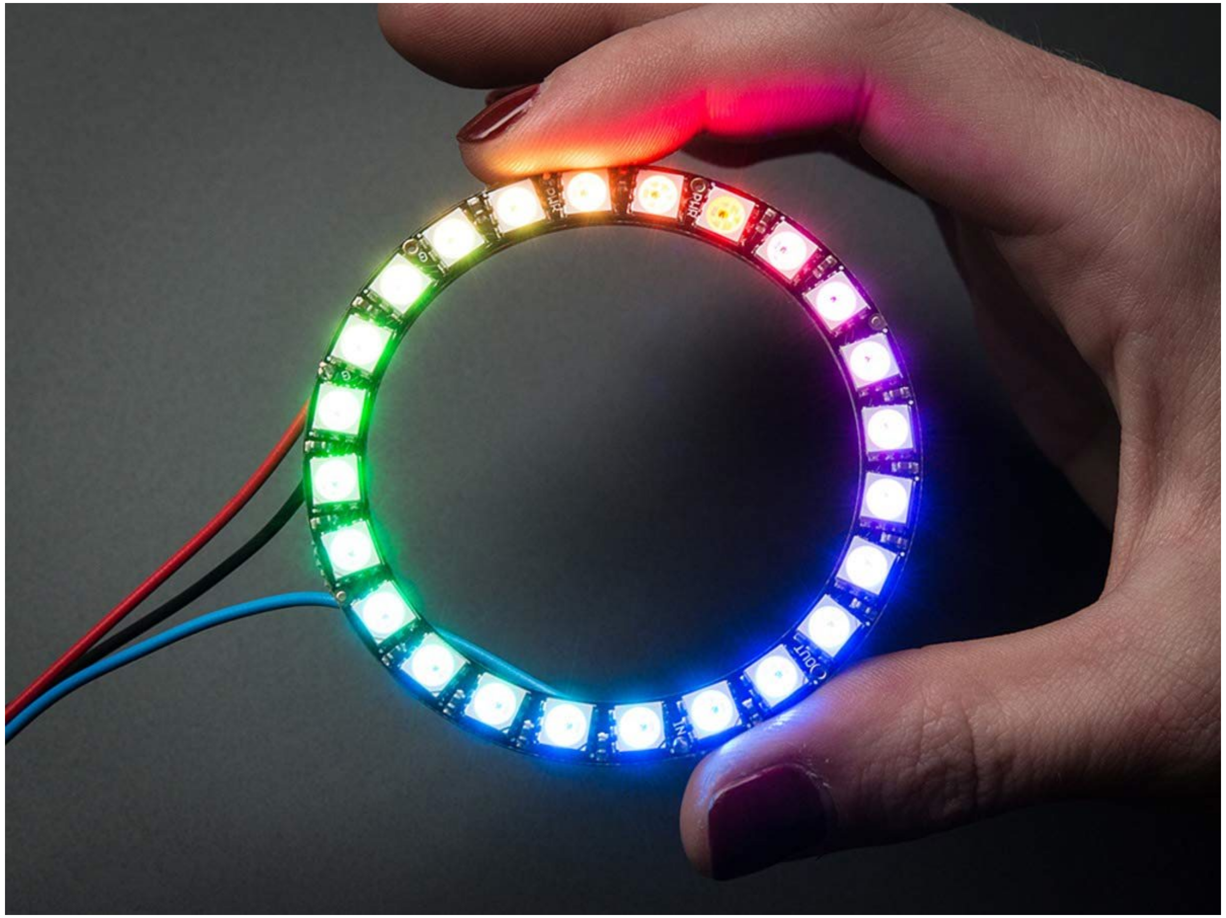
Tristate LED

- Two LEDs placed in parallel facing opposite directions.
- One LED is red or orange, the other is green.
- Current flow in one direction turns one LED ON while the other remains OFF due to reverse bias.
- Current flow in the other direction turns the first LED OFF and the second LED ON.
- Rapid switching of current flow direction will alternatively turn the two LEDs ON giving yellow light.
- Used as a polarity indicator.
- Maximum voltage rating: 3V
- Operating range: 10 to 20mA





RGB LED

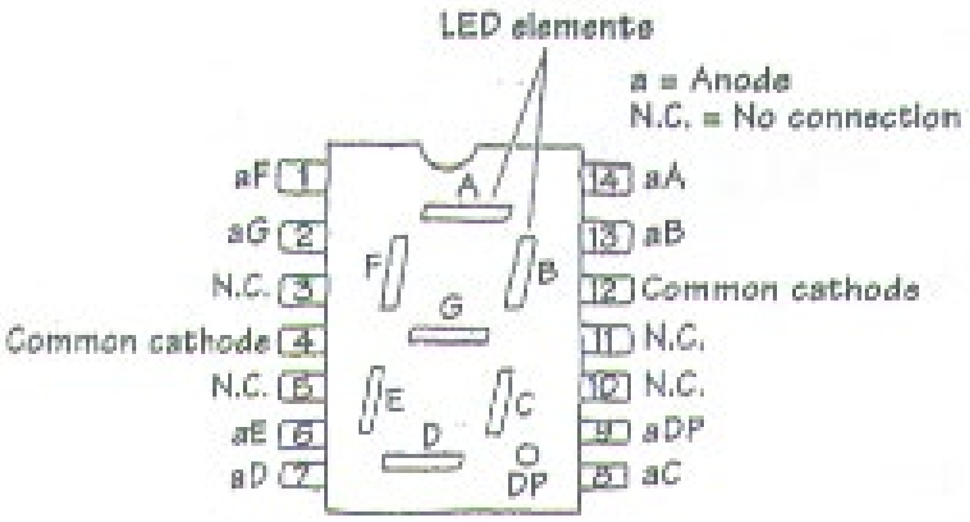


LED Specs

MNFR #	TYPE OF LED	COLOR	TYPICAL FORWARD VOLTAGE DROP (V) V_F	MAX. REVERSE BREAKDOWN VOLTAGE (V) V_R	MAX. DC FORWARD CURRENT (mA) I_F
NTE3000	Indicator	Clear red	1.65	5	40
NTE3010	Indicator	Green	2.2	5	35
NTE3026	Tristate	Red/green	1.65, red	—	70, red
			2.2, green	—	35, green
NTE3130	Blinker (3 Hz)	Yellow blink	5.25	0.4	20
NTE3017	Infrared	900 nm	1.28	6	100

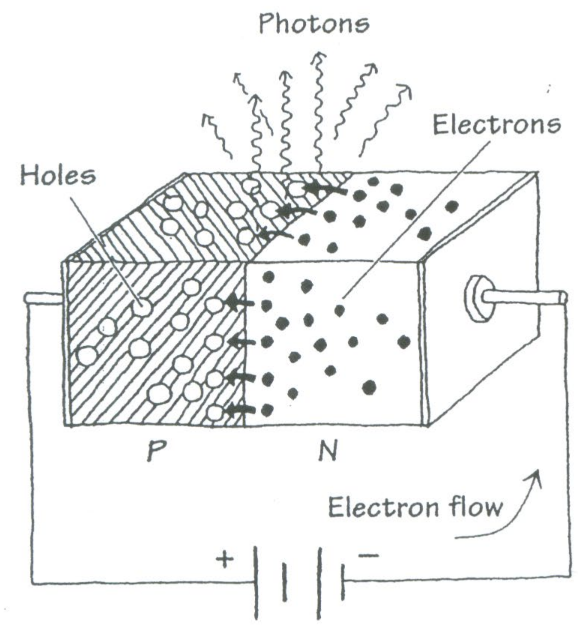
Application: 7-Segment LED Display

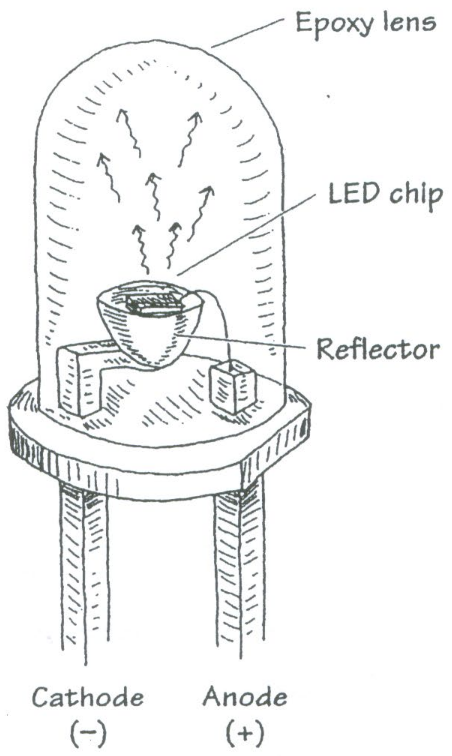
- Used for displaying numbers and other characters.
- 7 individual LEDs are used to make up the display.
- When a voltage is applied across one of the LEDs, a portion of the 8 lights up.
- Unlike liquid crystal displays (LCD), 7-segment LED displays tend to be more rugged, but they also consume more power.



How LED Works

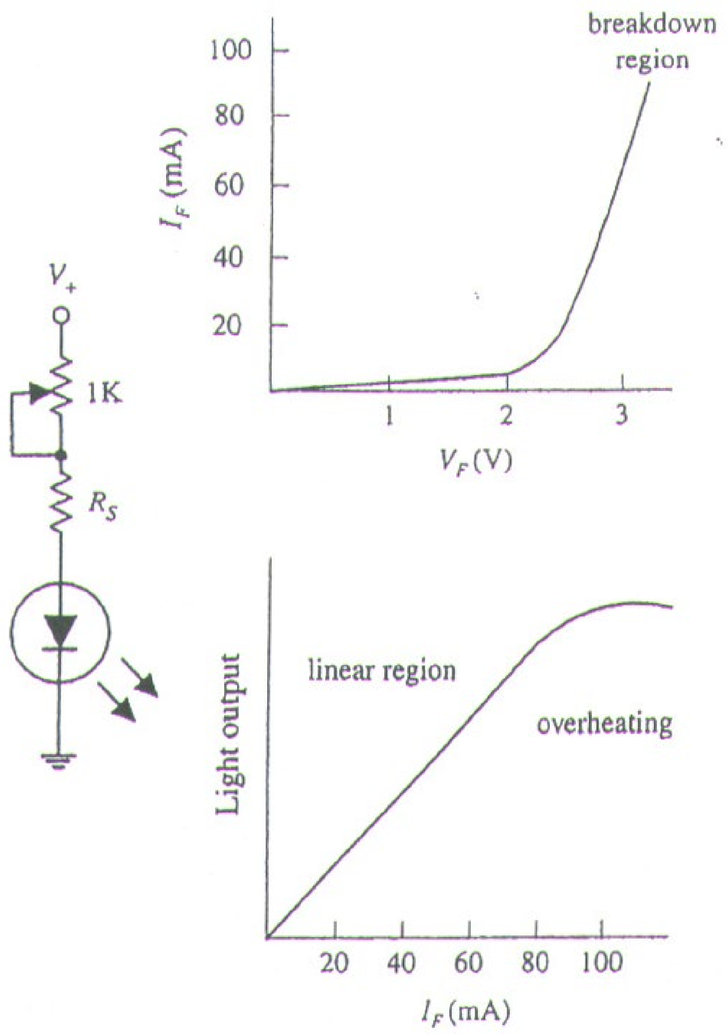
- When the pn junction is forward-biased, electrons in the n side are excited across the pn junction and into the p side, where they combine with holes.
- As the electrons combine with the holes, photons are emitted.
- The pn-junction section of an LED is encased in an epoxy shell that is doped with light scattering particles to diffuse light and make the LED appear brighter.
- Often a reflector placed beneath the semiconductor is used to direct the light upward.





Brightness Control

- The 1-K variable resistor controls the amount of current passing through the LED thus controlling its brightness. We term this as a “LED Dimmer.”
- R_s is used to protect the LED from excessive current. R_s sizing:
- When an LED begins to conduct, the voltage increase gradually, while the current increases rapidly. Too much current will overheat the LED.

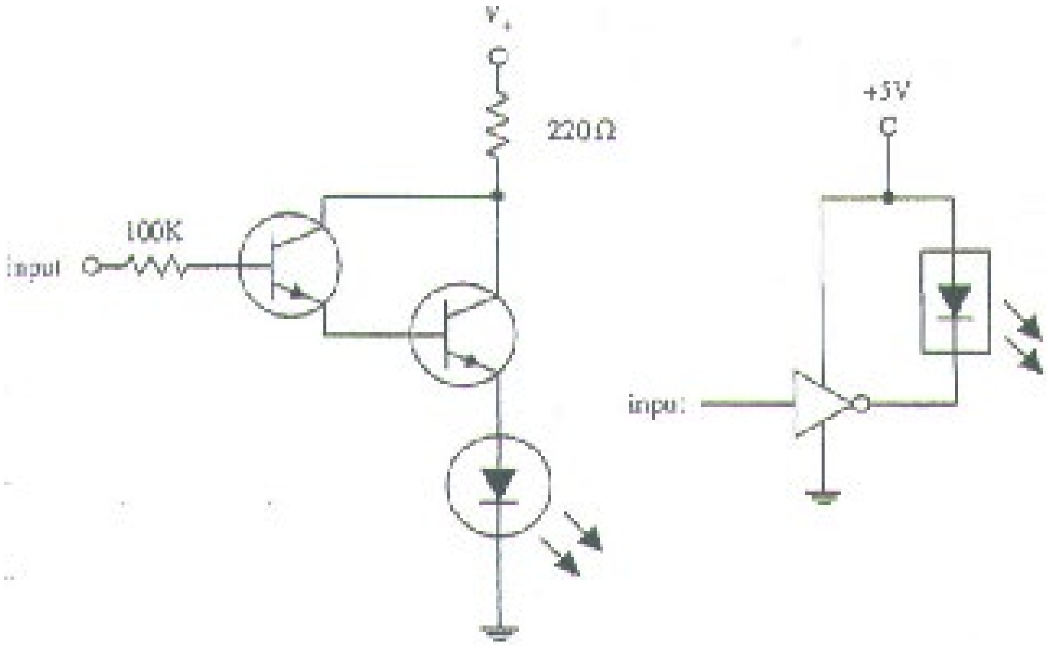


Application: Voltage-Level Indicator

- An LED along with a zener diode can be used to make a voltage-level indicator circuit.
- Whenever V_+ exceeds the breakdown voltage of the zener diode, the zener diode conducts and allows current to pass through the LED.
- Zener diodes come with various breakdown voltages, so it is possible to connect a number of these types of circuits in parallel to form a voltage indicator display

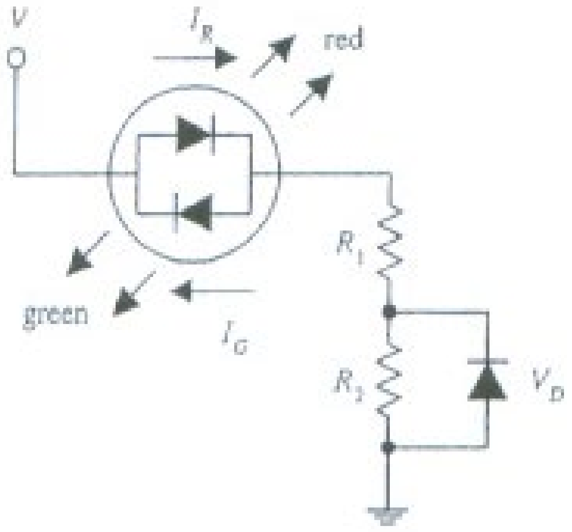
Application: Logic Probe

- An LED can be used to display the status of a logic gate.
- Left Circuit:
  - The output of a logic gate is attached to the input of the left NPN transistor.
  - A high input will turn on the transistors and will light the LED.
  - A low input will turn the LED off.
- Right Circuit:
  - A flasher LED can be used to do the same as above. This circuit works with TTL gates and with high-output CMOS gates.



Application: Tristate Polarity Indicator

- If V is positive dc voltage, the device emits red light.
- If V is a negative dc voltage, the device emits green light.
- If V is a high-frequency ac voltage, the device appears to emit a yellow light.
- R1 and R2 are chosen to protect the LEDs.
- Diode is used to provide reversed-voltage protection when the applied voltage exceeds the maximum reverse voltage.



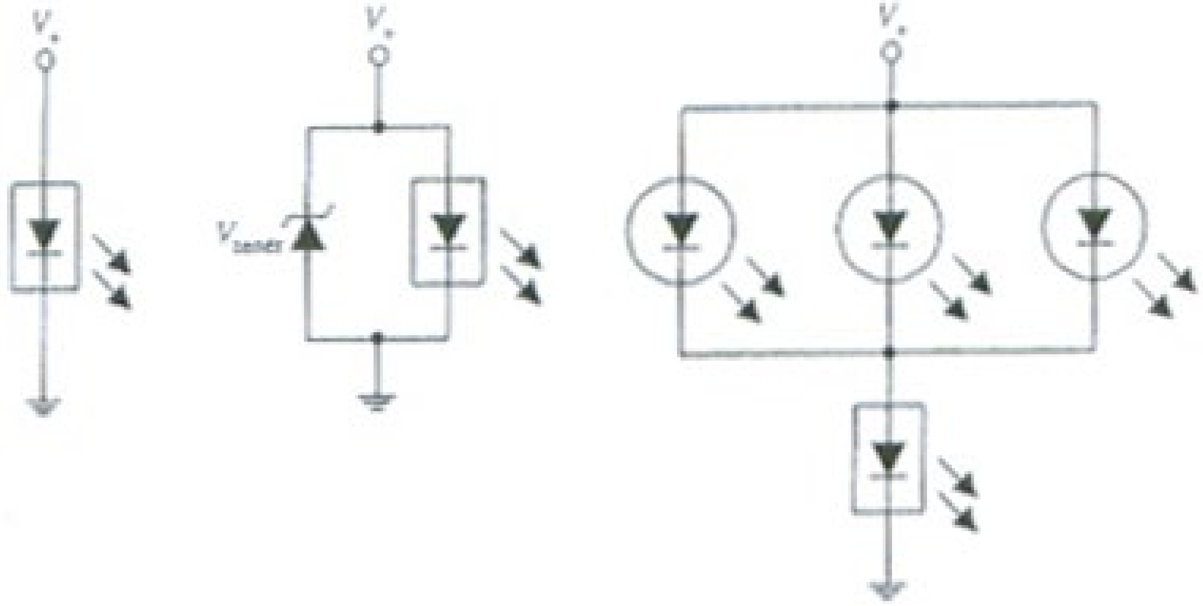
V	Color
+	red
−	green
AC	yellow

$$R_1 = \frac{V - (V_G + V_D)}{I_G}$$

$$R_2 = \frac{V - V_R}{I_R} - R_1$$

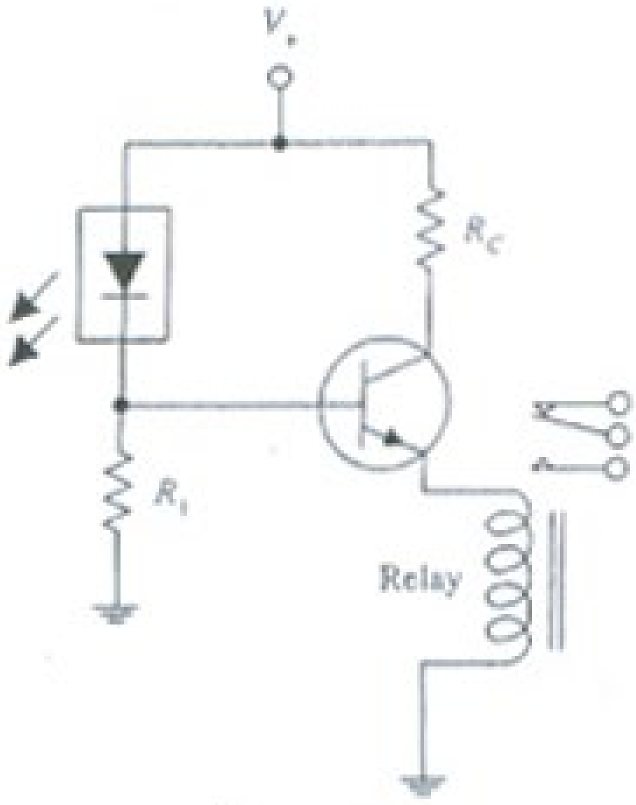
Application: LED Flasher Circuit

- Flasher LED does not require a current-limiting resistor like the other LEDs.
- Typically allowable voltage across flasher LED: 3 to 7 V.
- Flasher LED protection from excessive forward voltage: use a zener diode placed in parallel.
- A single flasher LED as shown in the rightmost circuit can be used to flash a number of ordinary LEDs



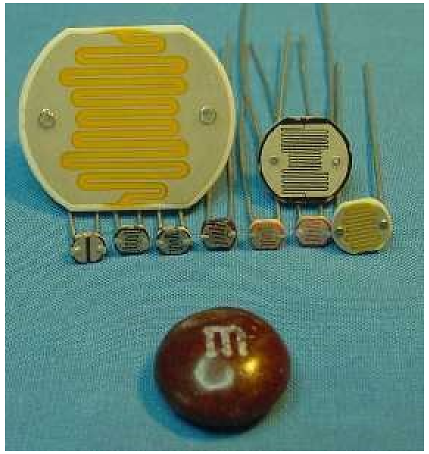
Application: Relay Driver

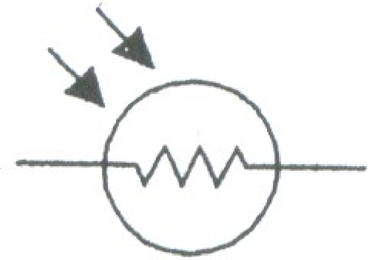
- A flasher LED can be used to supply a series of on/off pulses of current/voltage to the base of a BJT.
- When the flasher LED goes into conduction, the BJT base receives a positive voltage and input current needed to turn it on, thus providing power to drive the relay.
- R_1 sets the biasing voltage for the transistor and R_c sets the collector current.



Photoresistor

- Light sensitive variable resistors.
  - Under dark condition, resistance is quite high (MΩ: called dark resistance)
  - Under bright condition, resistance is lowered (few hundred Ω).
- Response time:
  - When a photoresistor is exposed to light, it takes a few milliseconds, before it lowers its resistance.
  - When a photoresistor experiences removal of light, it may take a few seconds to return to its dark resistance.





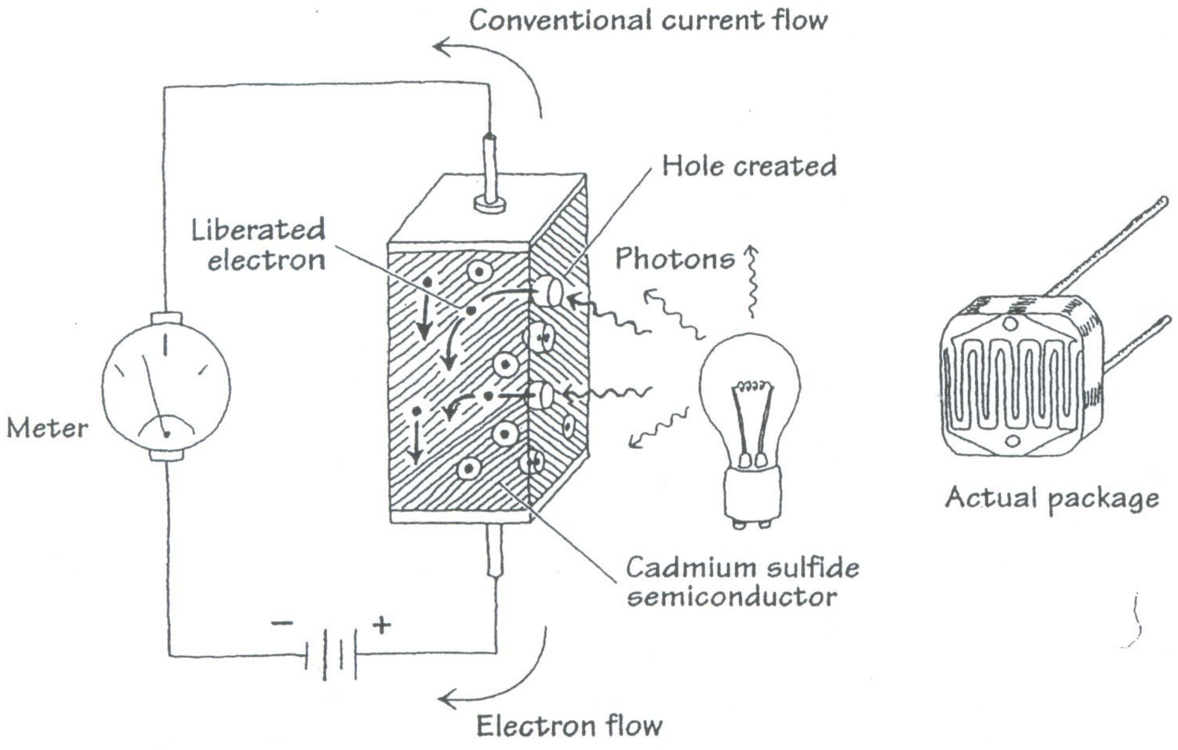
Symbol

Photoresistor

- Some photoresistors respond better to light that contains photons within a particular wavelength of spectrum.
  - Example: Cadmium-sulfide photoresistos respond to light within 400-800nm range.
  - Example: Lead-sulfide photoresistos respond to infrared light.

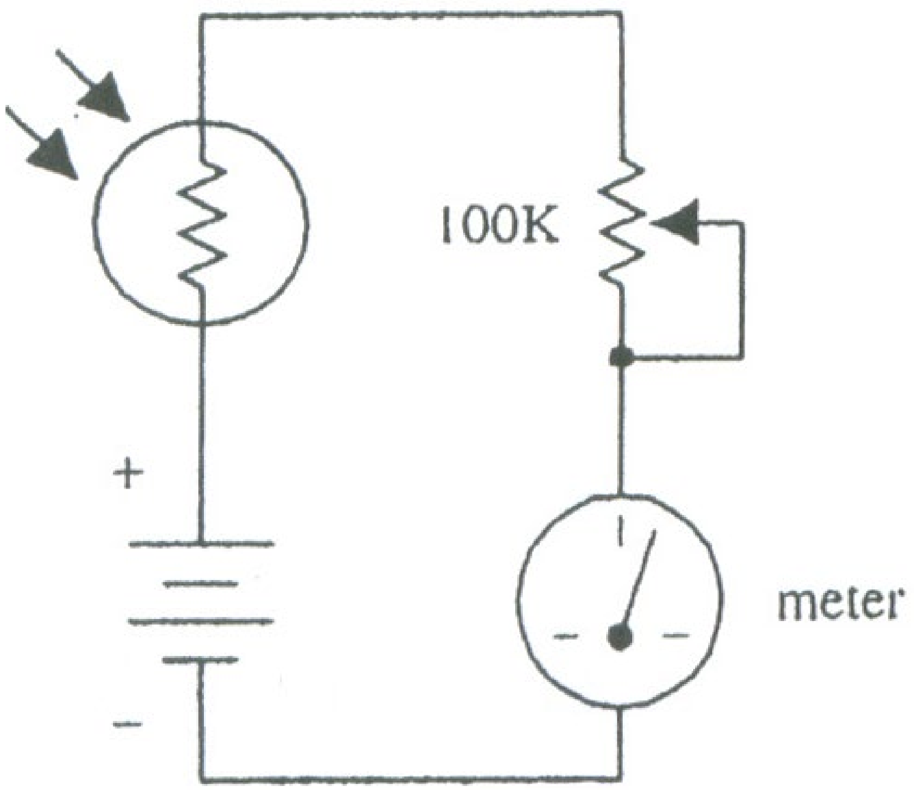
How Photoresistor Works

- Special semiconductor crystal, such as cadmium sulfide or lead sulfide is used to make photoresistors.
- When this semiconductor is placed in dark, electrons within its structure resist flow through the resistor because they are too strongly bound to the crystal's atoms.
- When this semiconductor is illuminated, incoming photons of light collide with the bound electrons, stripping them from the binding atom, thus creating holes in the process.
- Liberated electrons contribute to the current flowing through the device.



Application: Light Meter (Current)

- In dark condition, the photoresistor is very resistive, and little current flows through the series loop; the meter is at its lowest deflection level.
- When an increasingly bright light source shines on the photoresistor. the photoresistor's resistance begins to decrease, and more current begins to flow through the series loop, the meter stats to deflect.
- The potentiometer is used to calibrate the meter.

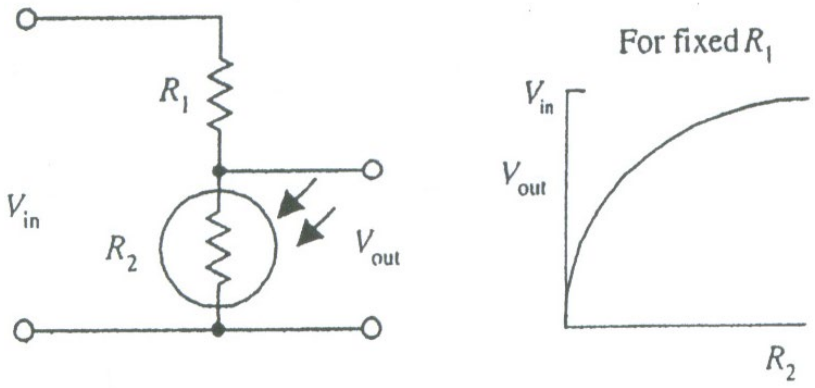


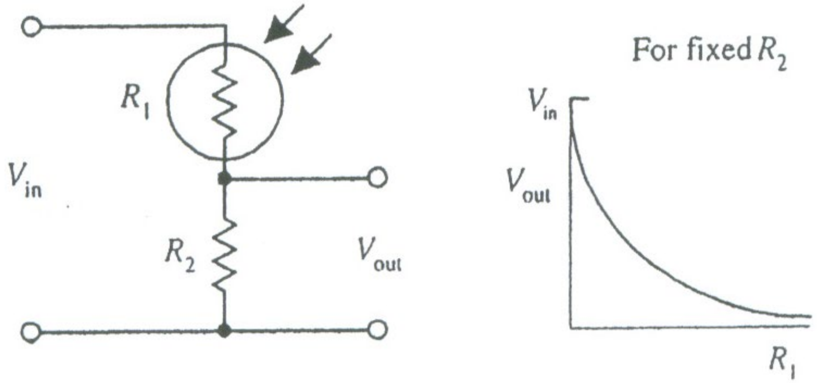
Application: Light Meter (Voltage Divider)

- Voltage-divider circuit output is given by:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

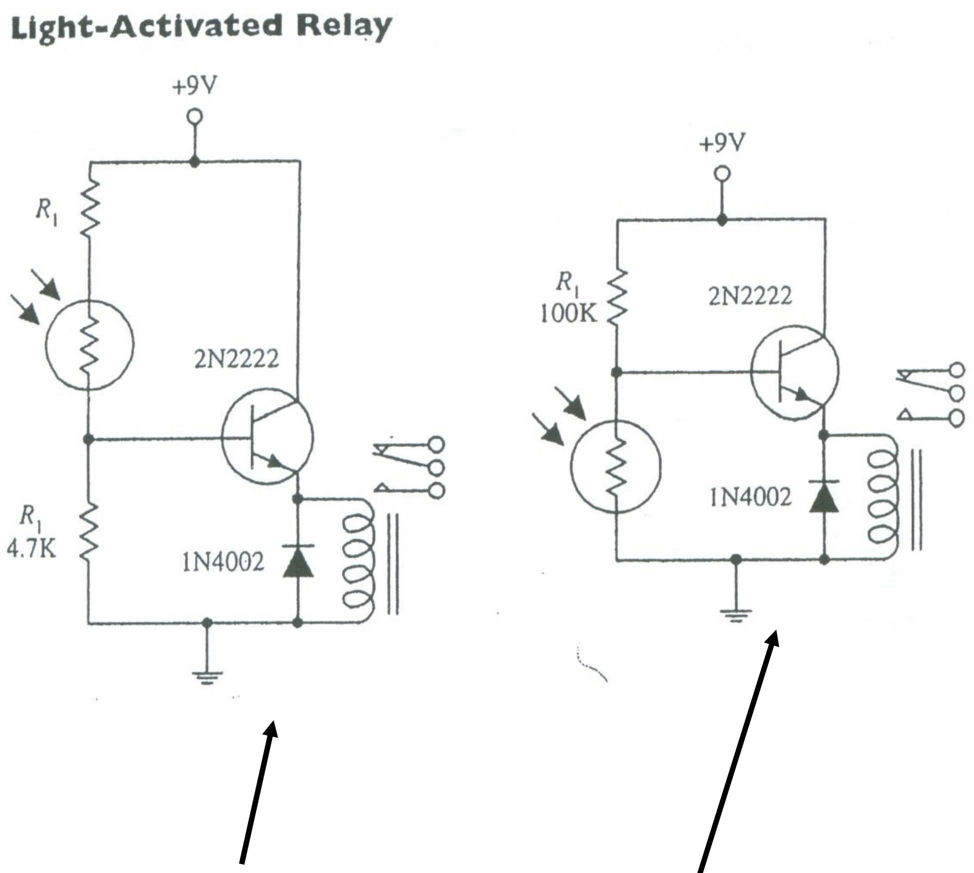
- As the intensity of light increases, the resistance of the photoresistor decreases. As more light falls upon the photoresistor:
    - V_{out} in the top circuit gets smaller.
    - V_{out} in the lower circuit gets larger.





Application: Light Activated Relay

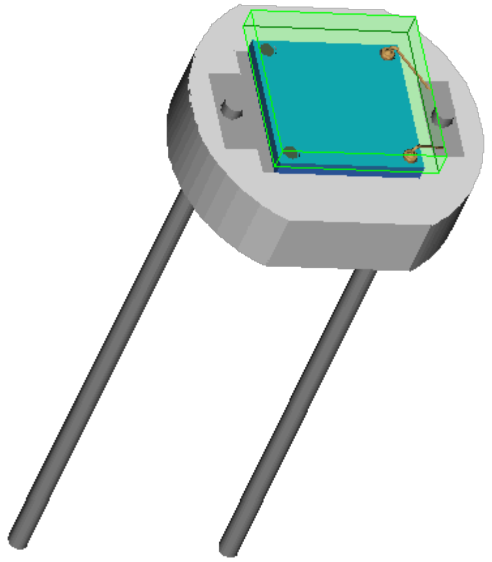
- When the photoresistor is exposed to light, its resistance decreases.
  - Transistor's base current and voltage increase and if the base current and voltage are large enough, the collector-emitter pair of the transistor conducts triggering the relay.
- The value of R_1 in the light-activated circuit should be around 1 KΩ but may have to be adjusted.
- Dark-activated relay works in opposite manner.
- R_1 in the dark-activated circuit (100KΩ) may also have to be adjusted.
- A 6 to 9 V relay with a 500Ω coil can be used in either circuit.

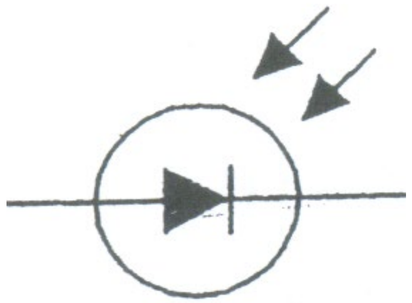


Light activated relay Dark activated relay

Photodiode

- Photodiode is a 2 lead semiconductor device that transforms light energy to electric current.
- Suppose anode and cathode of a photodiode are wired to a current meter.
    - When photodiode is placed in dark, the current meter displays zero current flow.
    - When the photodiode is exposed to light, it acts a a current source, causing current flow from cathode to anode of photodiode through the current meter.
- Photodiodes have very linear light v/s current characteristics.
    - Commonly used as light meters in cameras.
- Photodiodes often have built-in lenses and optical filters.
- Response time of a photodiode slows with increasing surface area.
- Photodiodes are more sensitive than photoresistor.

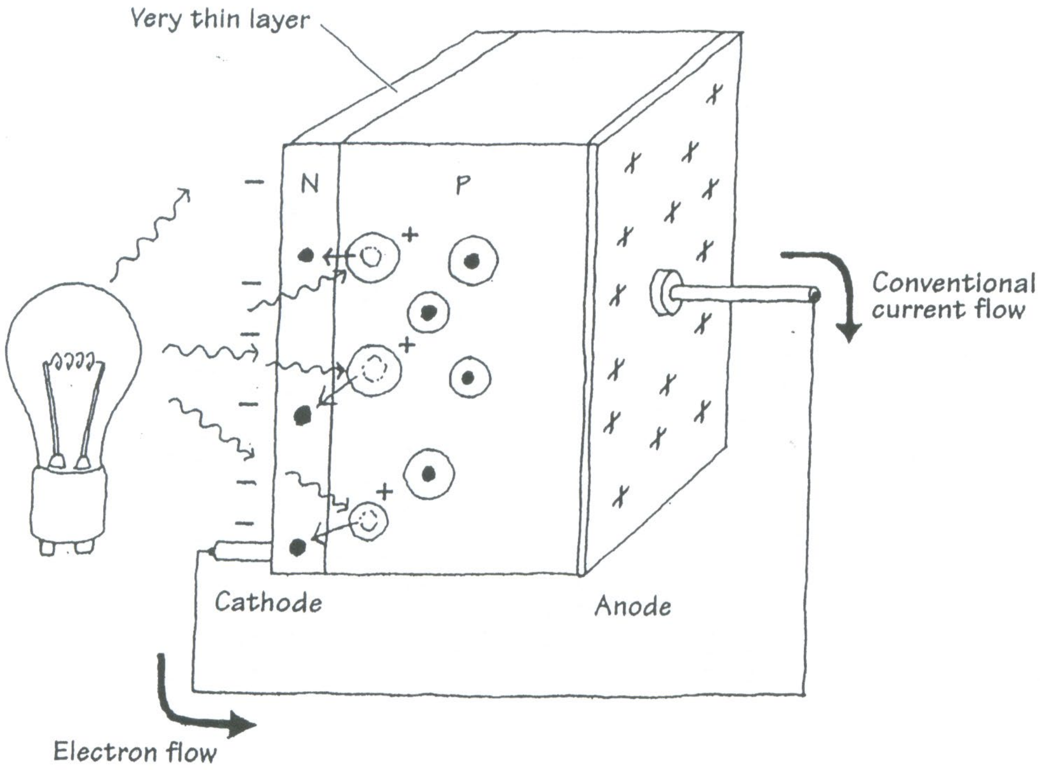




Symbol

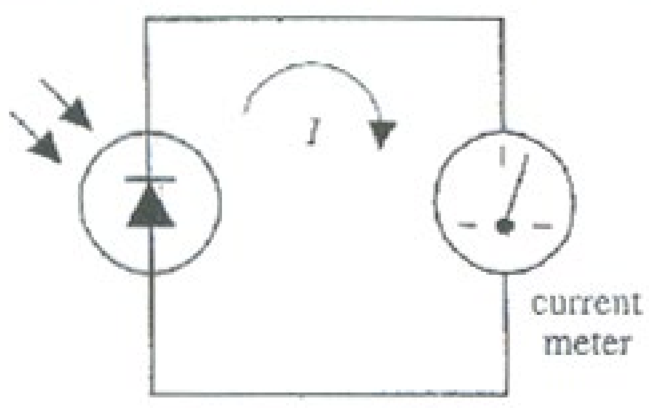
How Photodiode Works

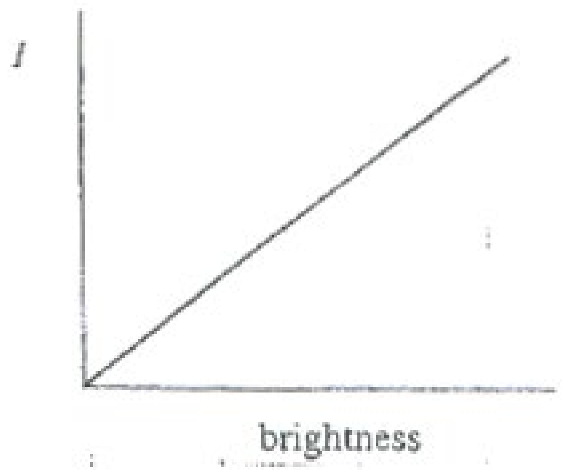
- Photodiode: A thin n-type semiconductor sandwiched with a thicker p-type semiconductor.
- N-side is cathode, p-side is anode.
- Upon illumination, photons pass from the n-side and into the p-side of photodiode.
  - Some photons making it into p-side collide with bound electrons within p-semiconductor, ejecting them and creating holes.
  - If these collisions are close to the pn-interface, the ejected electrons cross the junction, yielding extra electrons on the n-side and extra holes on the p-side.
  - Segregation of +ve and -ve charges leads to a potential difference across the pn-junction.
  - When a wire is connected between the cathode and anode, a conventionally positive current flow from the anode to cathode



Application: Photovoltaic Current Source

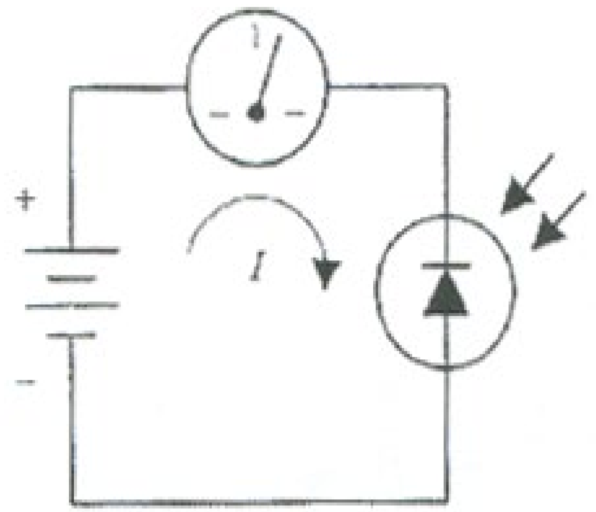
- Photodiode converts light energy directly into electric current that can be measured with meter.
- The input intensity of light and the output current are nearly linear.





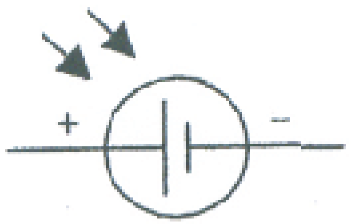
Application: Photoconductive Operation

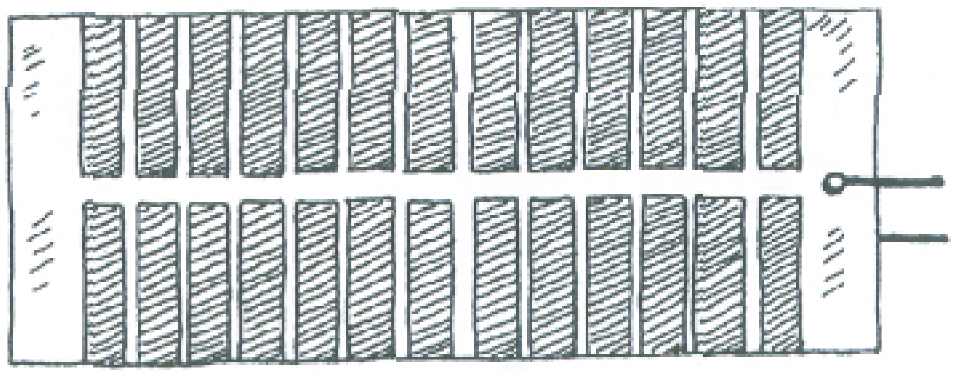
- A single photodiode may not produce enough current needed to drive a particular light-sensitive circuit.
- Incorporate a photodiode along with a voltage source.
- That is, connect a photodiode in reversed-bias with a battery.
- In darkness, a small current called the dark current flows through the photodiode.
- When the photodiode is illuminated, a larger current flows.
- A resistor is placed in series with the diode and battery to calibrate the meter.



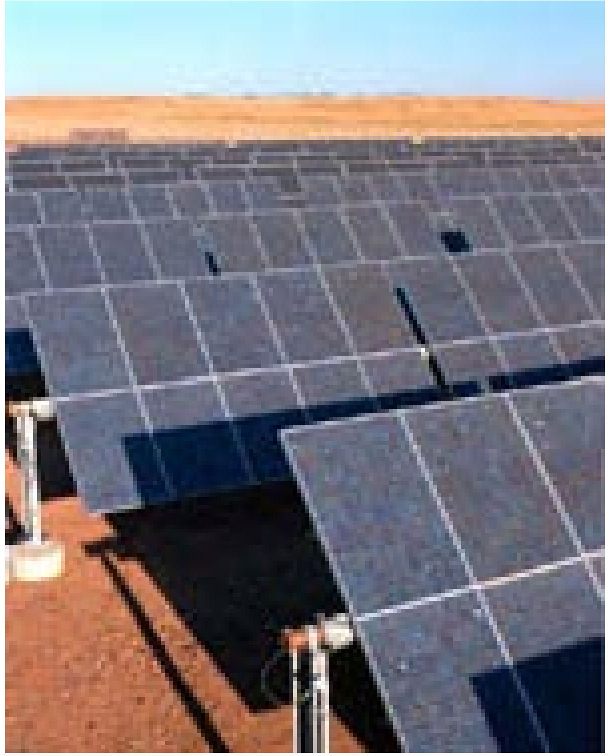
Application: Solar Cell

- Solar cells are photodiodes with very large surface areas.
- Compared to usual photodiodes, the large surface area in photodiode of a solar cell yields
  - a device that is more sensitive to incoming light.
  - a device that yields more power (larger current/volts).
- Solar cells yield more power.
- A single solar cell may provide up to 0.5V that can supply 0.1A when exposed to bright light.



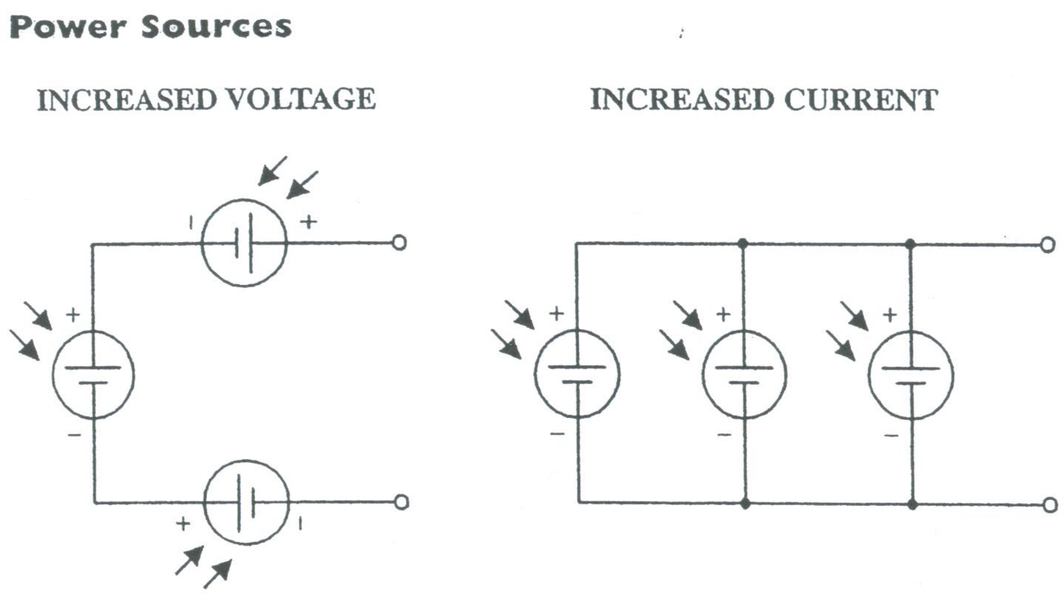


Application: Solar Cell



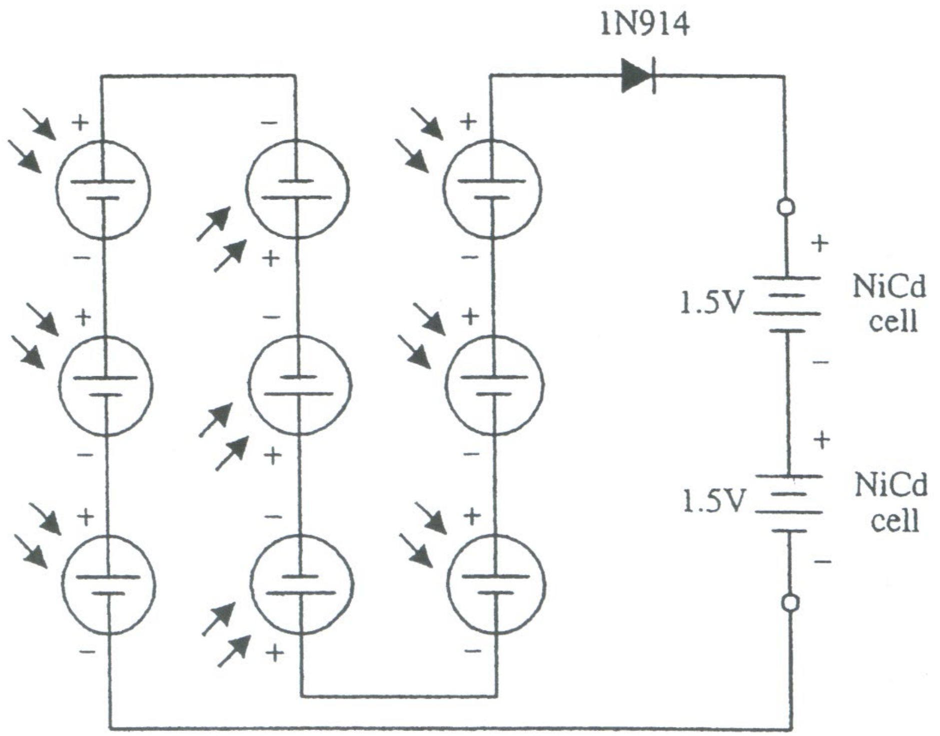
Application: Solar Cell

- Each solar cell produces an open-circuit voltage from around 0.45 to 0.5 V and may generate as much as 0.1 A in bright light.
- Similar to batteries, solar cells can be combined in series or parallel.
- Adding cells in series, yields output voltage that is the sum of the individual cell voltages.
- Adding solar cells in parallel, yields an increased output current *vis-à-vis* a single solar cell.



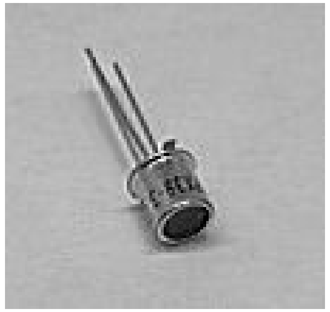
Solar Cell Basic Operation—Battery Charger

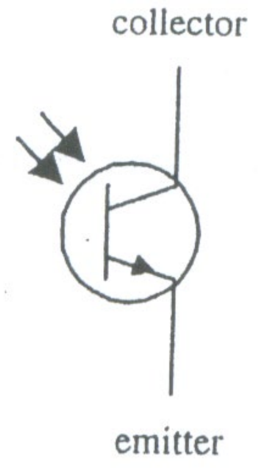
- Nine solar cells placed in series can be used to recharge two 1.5 V NiCd cells.
- The diode is added to the circuit to prevent the NiCd cells from discharging through the solar cell during times of darkness.
- It is important not to exceed the safe charging rate of NiCd cells. To slow the charge rate, a resistor can be placed in series with the batteries.



Phototransistor

- **Phototransistor** is a light sensitive transistor.
- In one common type of phototransistor, the base lead of a BJT is replaced by a light sensitive surface.
    - When base is kept in darkness, the collector-emitter pair of the BJT does not conduct.
    - When base is exposed to light, a small amount of current flows from the base to the emitter.
- Alternatively, one can also use a field-effect phototransistor (Photo FET).
    - Light exposure generates a gate voltage which controls a drain-source current.





Phototransistor

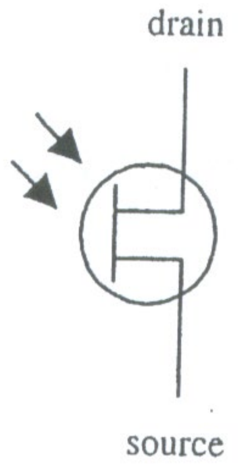
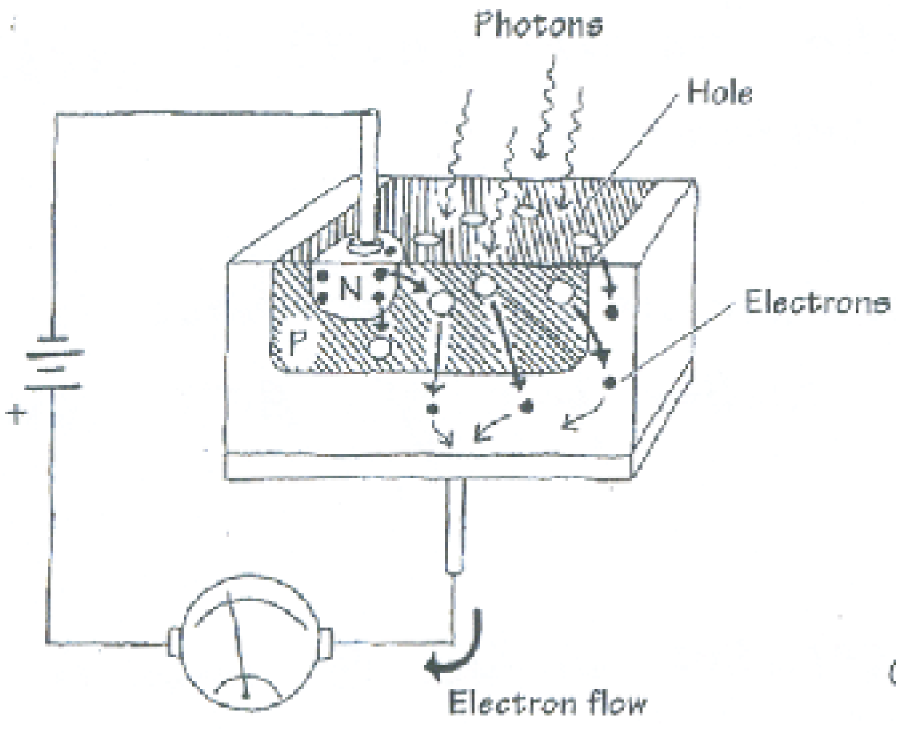
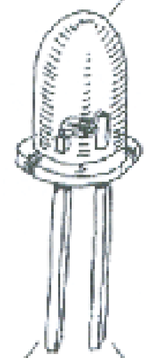


Photo FET

BJT Phototransistor

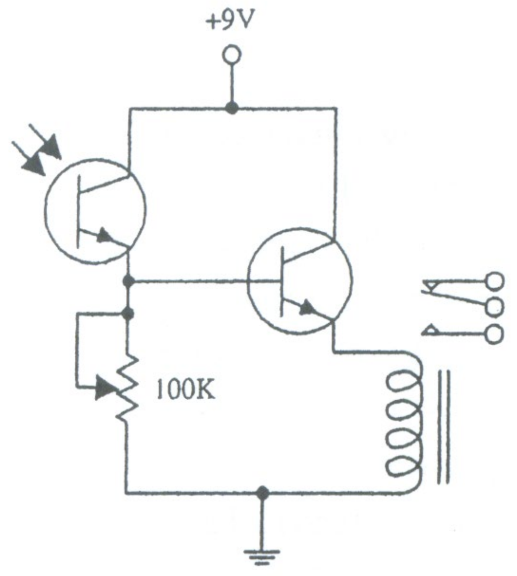
- Extra large p-type semiconductor region that is open for light exposure.
- Photons collide with electrons within the p-type semiconductor, they gain enough energy to jump across the pn-junction energy barrier if the photons are of the right frequency/energy.
- As electrons jump from the p-region into the lower n-region, holes are created in the p-type semiconductor.
- The extra electrons injected into the lower n-type slab are drawn toward the positive terminal of the battery, while electrons from the negative terminal of the battery are draw into the upper n-type semiconductor and across the np junction, where they combine with the holes, the net result is an electrons current that flows from the emitter to the collector.





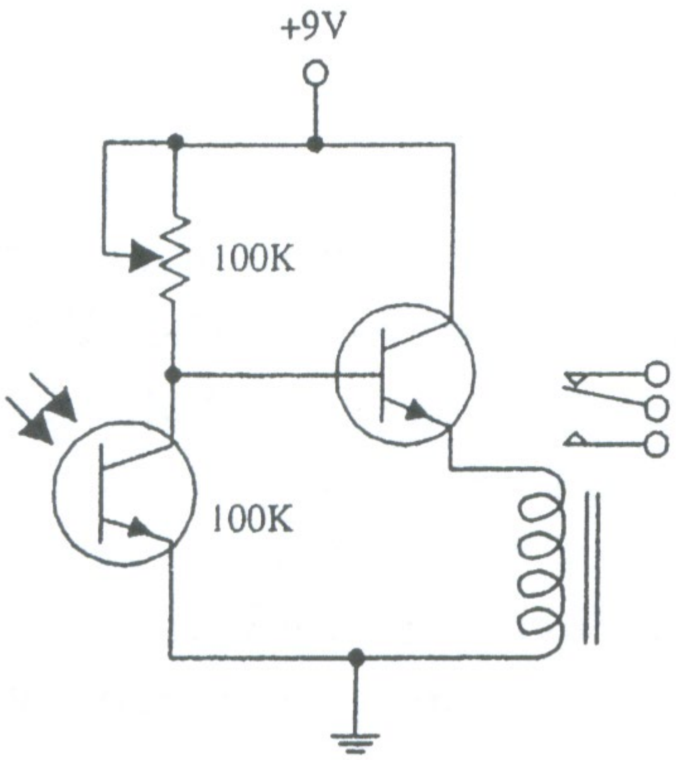
Application: Light Activated Relay

- Phototransistor controls base current supplied to a power-switching transistor that is used to supply current to a relay.
- When light comes in contact with the phototransistor, the phototransistor turns on, allowing current to pass from the supply into the base of the power-switching transistor.
- This allows the power-switching transistor to turns on, and current flows through the relay, triggering it to switch states.
- The 100K pot is used to adjust the sensitivity of device by controlling current flow through the phototransistor.



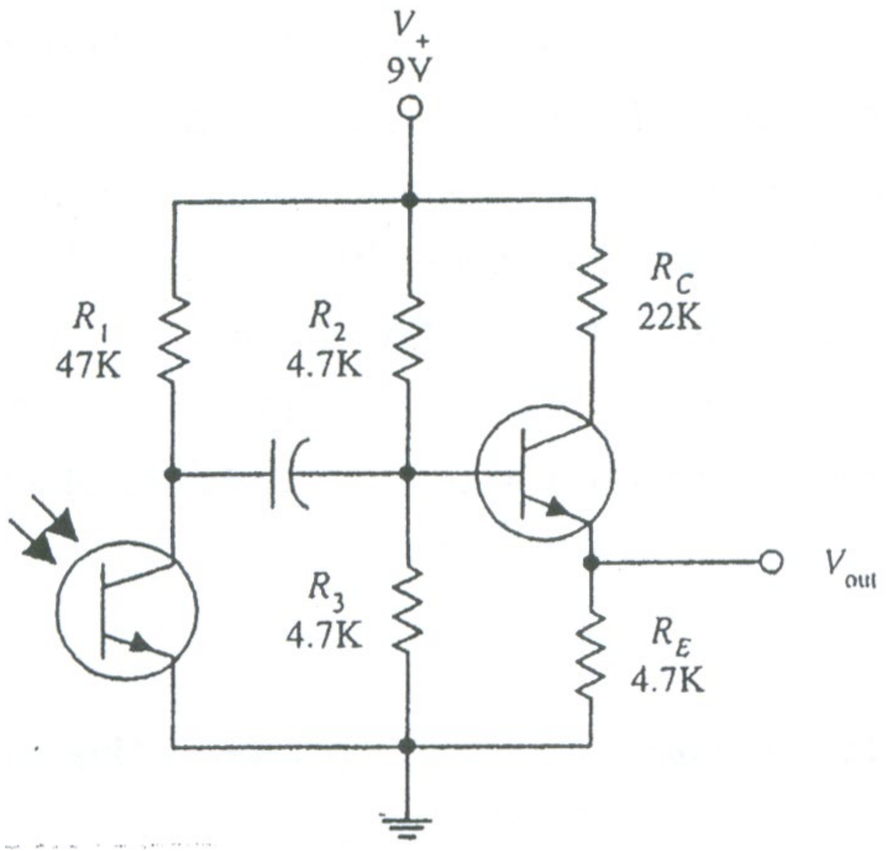
Application: Dark Activated Relay

- Swap the potentiometer and phototransistor so that the relay is activated during the dark instead



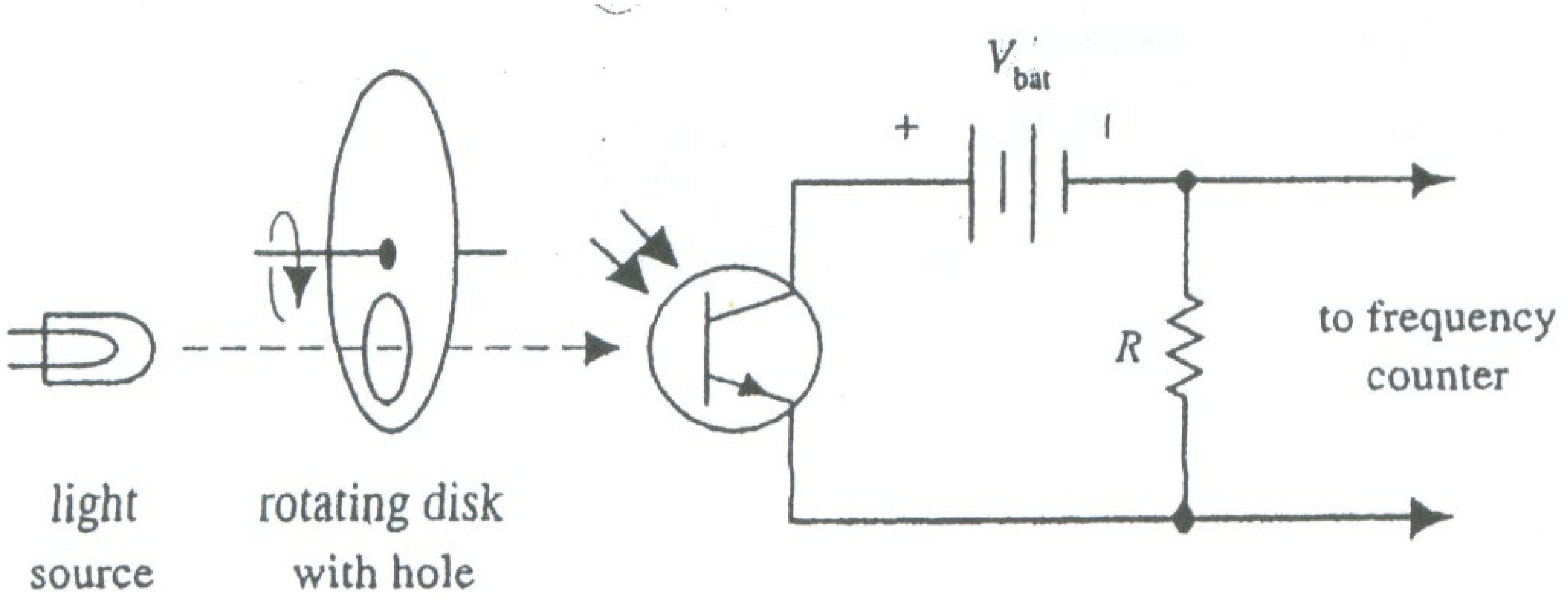
Applications: Receiver

- A phototransistor can be used as a modulated light-wave detector with an amplifier section (current gain amplifier).
- R2 and R3 are used to set the dc operating point of the power-switching transistor.
- R1 is used to set the sensitivity of the phototransistor.
- The capacitor acts to block unwanted DC signals from entering the amplifier section.



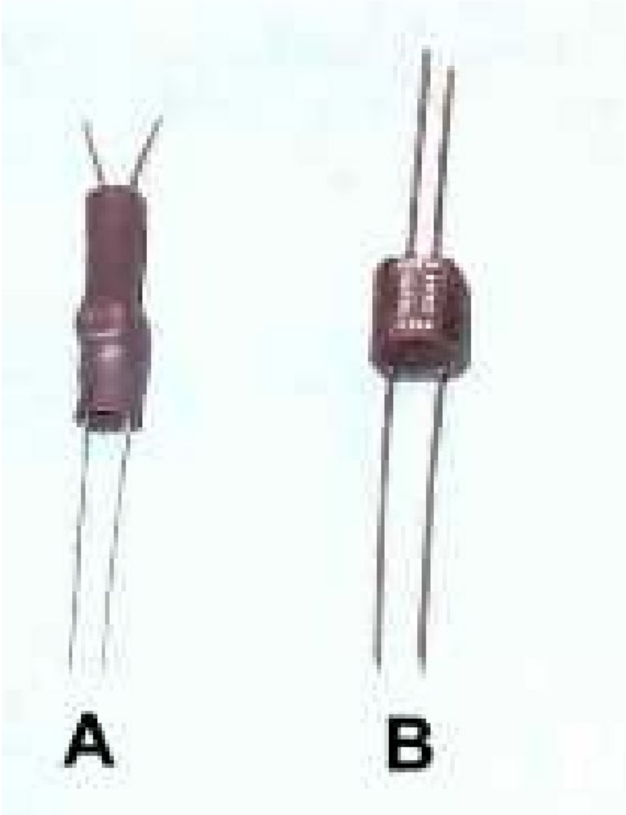
Application: Tachometer

- A phototransistor is being used as a frequency counter or tachometer.
- For the given setup, the disk will allow light to pass through the hole once every revolution and trigger the phototransistor into conduction.
- A frequency counter is used to count the number of electrical pulses generated.



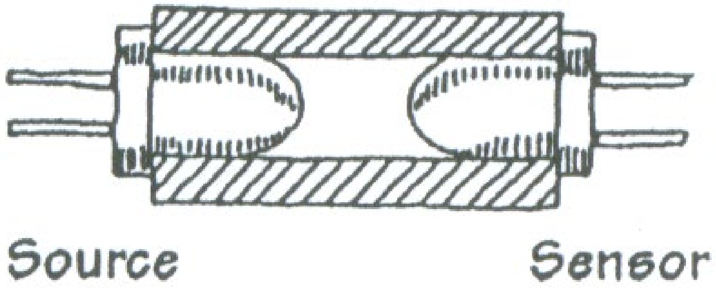
Optoisolators

- **Optoisolator (or optocouplers)** interconnect two circuits via optical (i.e., light) interface.
  - Example: an LED and a phototransistor enclosed in a container isolated from external light.
    - The LED portion of the optoisolator is connected to the source circuit.
    - The phototransistor portion is connected to the detector circuit.
- **Optoisolators** often provide electrical isolation between two separate circuits



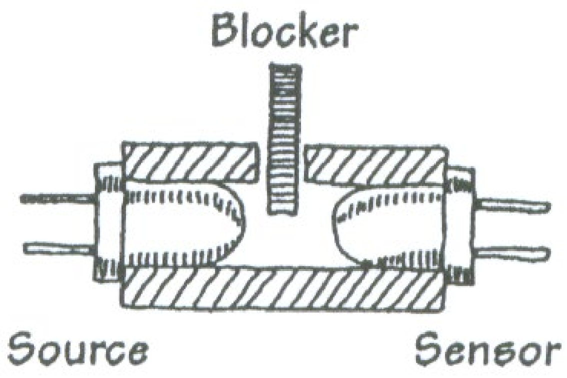
Closed Pair

- Closed Pair: Source and sensor encased in a dark container with both of them facing each other.
- Usage: Electrical isolation, level conversions, and solid-state relaying.



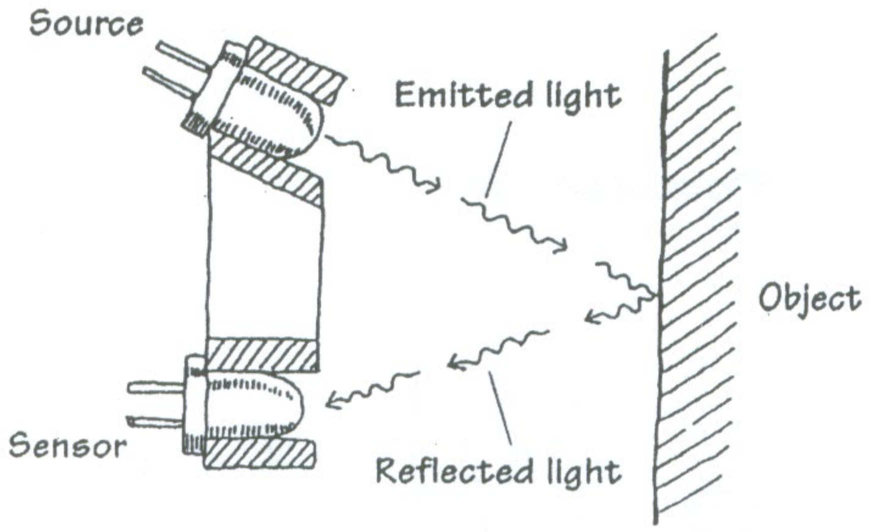
Slotted Pair

- Open slot between source and sensor through which a blocker can be inserted to interrupt light signals.
- Usage: object detection, **bounce free switching**, and vibration detection.



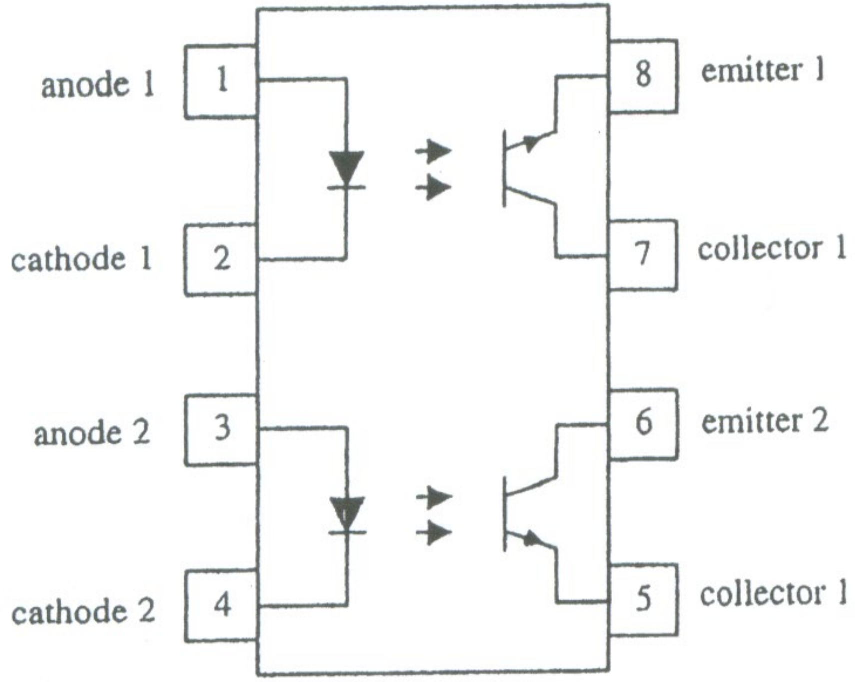
Reflective Pair

- Has a source and sensor arrangement wherein the source signal is sensed by the sensor once it has reflected off an object.
- Usage: object detection, reflectance monitor, tachometer, movement detector. **bounce free switching**, and vibration detection.



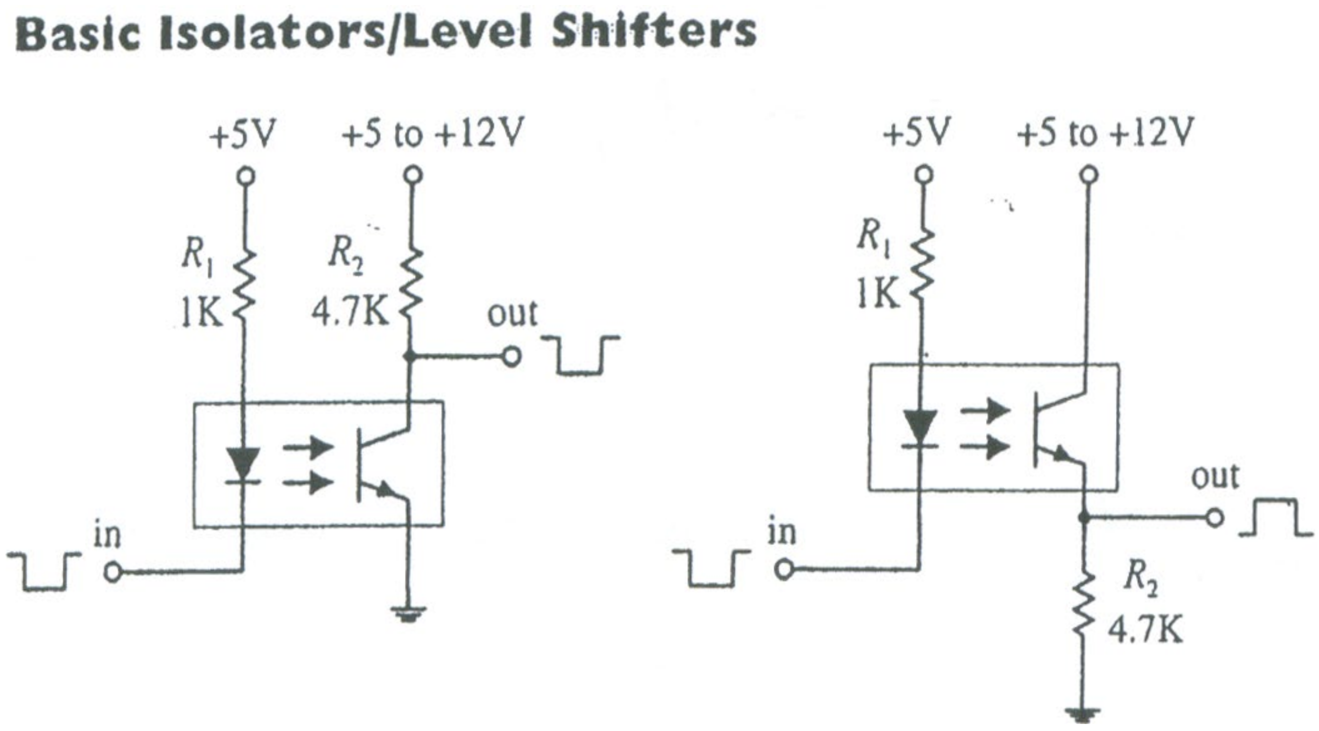
Optoisolators—Integrated Circuit

- Closed-pair optoisolators usually come in integrated package.



Application: Isolator/Level Shifter

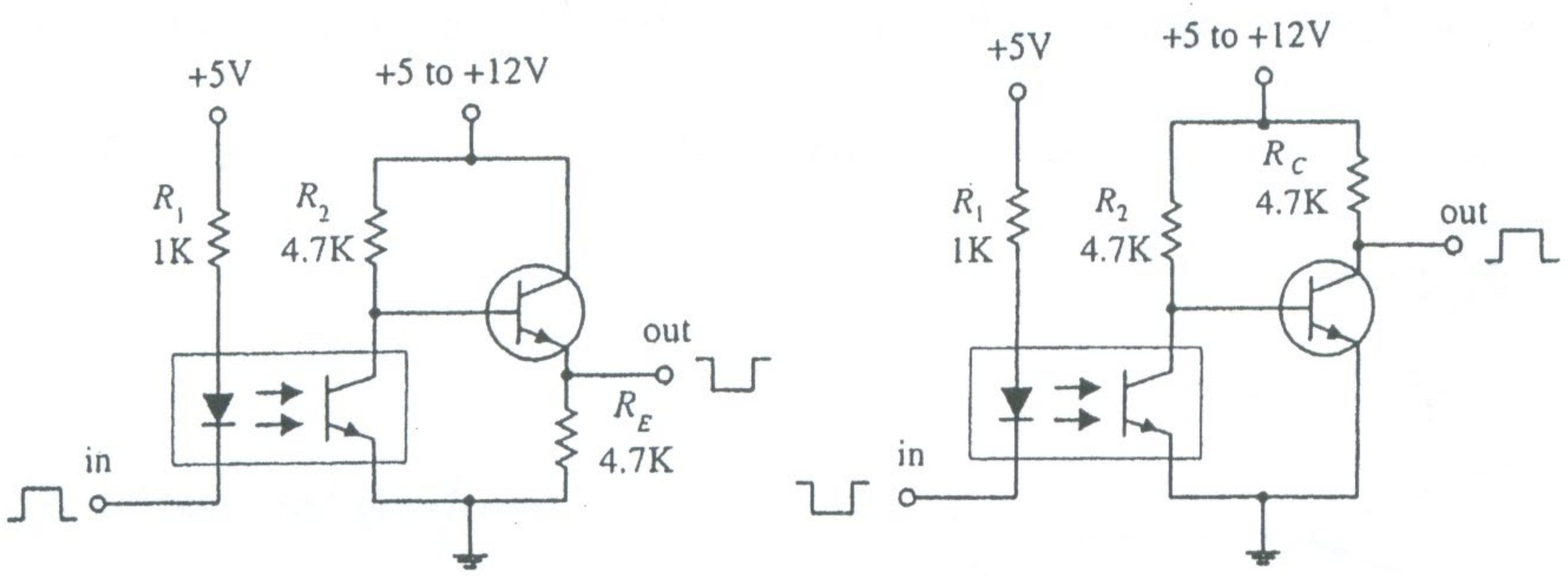
- A diode/phototransistor optoisolator is used to provide:
  - electrical isolation between the source circuit and the sensor circuit
  - DC level shift in the output.
- Left circuit: non-inverted output.
- Right circuit: inverted output



Application: Optocoupler with Amplifier

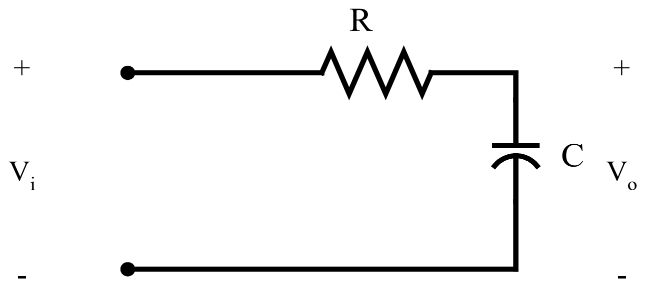
- When the phototransistor section of an optoisolator may not be able to provide enough power-handling capacity to switch large currents:
    - Incorporating a power-switch transistor can solve this problem.

Optocoupler with Amplifier

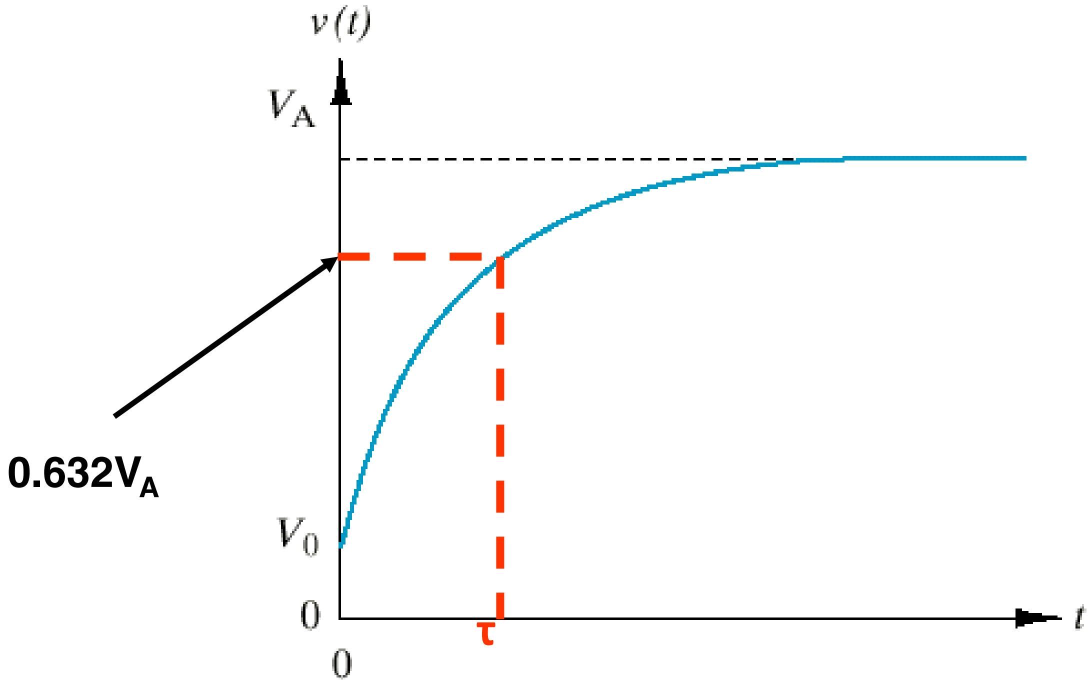


RC Circuit: PBasic RCTIME

- Derive ODE with Kirchoff's Laws



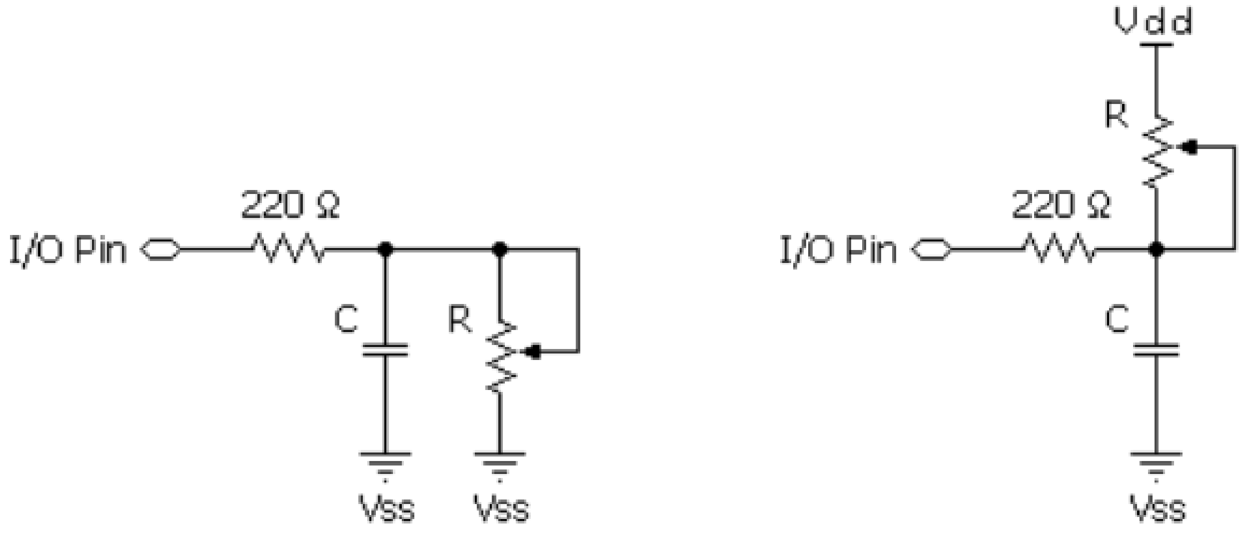
$$\frac{V_o(s)}{V_i(s)} = \frac{1}{RCs+1}$$



- Time constant $\tau = RC$.
- Time constant τ is time at which voltage output in the series RC circuit reaches 63.2% of the applied voltage.

RC Circuit: PBasic `RCTIME`

- https://www.parallax.com/go/PBASICHelp/Content/LanguageTopics/Commands/RCTIME.htm



(A) Use with State = 1 (preferred) (B) Use with State = 0

Hands-on Exercises: Light

What's a Microcontroller? Measuring Light	Chapter 7
Activities #1 and #2	pp. 195-211
Activities #3 – #6	pp. 211-239

Hands-on Exercises: Code

BASIC Stamp Syntax and Reference Manual 2.2	
If … then	pp. 231 – 242
For … next	pp. 191 – 197
Variables	pp. 85 – 86
**	pp. 111 – 112
*/	p. 112
//	pp. 113 – 114
Binary Operators	pp. 109 – 122