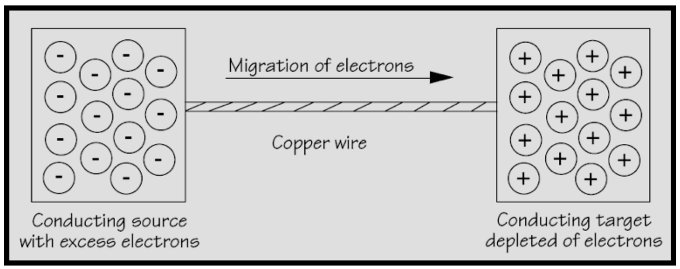
Basic Concepts of Electricity

- Voltage E
- Current I
- Resistance R

Ohm's Law

$E = I R$



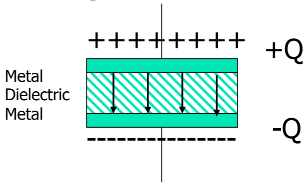
Electric Fields

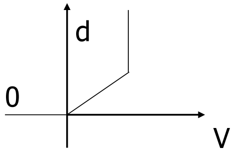
- An electric field applies a force to a charge
  - Force on positive charge is in direction of electric field, negative is opposite
- Charges move if they are mobile
- An electric field is produced by charges (positive and negative charges)
- Electric fields can be produced by time varying magnetic fields (generator, antenna radiation)

Voltage Difference

- Voltage difference is the difference in potential energy in an electric field
- E = V/d
- As you move closer to a positive charge the voltage increases

Capacitor (electric field constant between parallel plates)





Current

- An electric current is produced by the flow of electric charges
- Current = rate of charge movement
  = amount of charge crossing a surface per unit time
- In conductors, current flow is due to electrons
- Conventional current is defined by the direction positive charges will flow
- Direction of electron flow is opposite to direction of conventional current

Resistance

- In materials electrons accelerate in an electric field
- Electrons lose energy when they hit atoms - lost energy appears as heat and light
- The result is that electrons drift with constant velocity (superimposed on random thermal motion)
- Resistance is the ratio Voltage/current

  R = V/I

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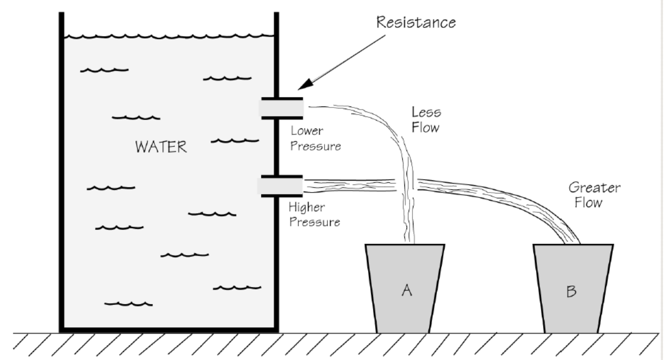
Voltage, Current, and Resistance



Flow = current   Pressure = voltage

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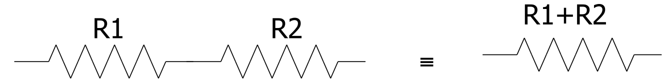
Material Conductivity

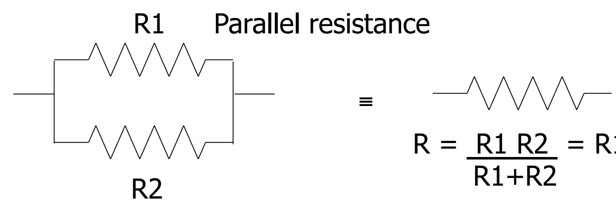
- Conductors - negligible resistance
- Insulators - extremely large resistance
- Semiconductors - some resistance
- Resistors - are devices designed to have constant resistance across a range of voltages

Resistor Combination

Series resistance



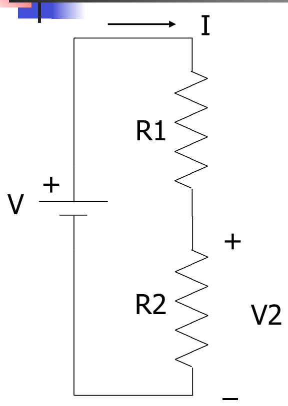
Parallel resistance



$$R = \frac{R1\ R2}{R1+R2} = R1||R2$$

$$1/R = 1/R1 + 1/R2$$

Voltage Divider



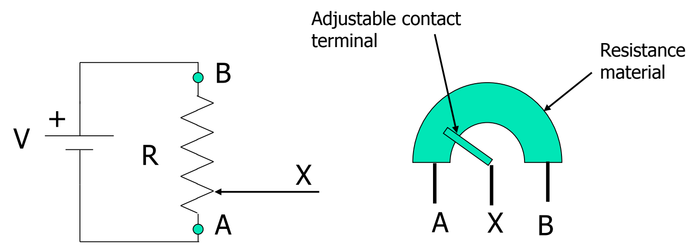
$$V2 = \frac{V\ R1}{R1 + R2}$$

<u>Solution:</u>

<u>Goal: Find V2 given V</u>

- Find V2 in terms of I
- Current through R2 in terms of I
- Voltage across R1
- Find voltage across R1 and R2 using two different methods

Potentiometer (Variable Resistor)



VX = V * Distance AX/Distance AB
(linear potentiometer)

A trimpot is a small variable resistor mounted on a printed circuit board that can adjusted by a small screwdriver to make semi-permanent adjustments to a circuit

Input Transducers

- These are devices that produce electric signals in accordance with changes in some physical effect e.g. convert temperature, light level to a voltage level or resistance
- e.g. microphones, strain gauge, photo-detectors, ion-selective membranes, thermistors
- Sometimes the definition of transducer is that of a device that converts non-electrical energy to electrical energy

Output Transducers

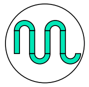
- Devices which convert an electrical quantity into some other physical quantity or effect e.g. relay, loudspeaker, solenoid

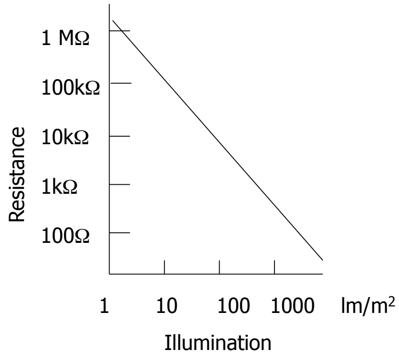
Light Dependent Resistors (LDRs)

- Devices whose resistance changes (usually decreases) with light striking it
- (also called photocells, photoconductors)
- Light striking a semiconducting material can provide sufficient energy to cause electrons to break away from atoms.
- Free electrons and holes can be created which causes resistance to be reduced

LDRs

- Typical materials used are Cadmium Sulphide (CdS), Cadmium Selenide (CdSe), Lead Sulphide
- With no illumination, resistance can be greater than 1 MΩ (dark resistance).
- Resistance varies inversely proportional to light intensity.
- Reduces down to 10-100s ohms
- 100ms/10ms response time





- LDRs have a low energy gap
- Operate over a wide wavelengths (some, into infrared)
- Indium antimonide is good for IR. When cooled is very sensitive, used for thermal scanning of earth' s surface

Capacitors

- A component constructed from two conductors separated by an insulating material (dielectric) that stores electric charge (+Q, -Q)
- As a consequence there is a voltage difference across the capacitor, V
- Capacitance = C = Q/V
- The dielectric material operates to reduce the electric field between the conductors and so allow more charge to be stored for a given voltage

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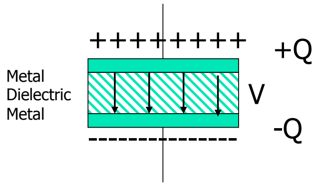
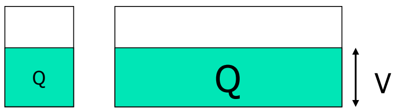
Capacitors



C = Q/V

(Q = CV)

Bucket analogy



A small bucket (capacitor, C)
holds less charge (Q)
for given level (voltage V)
than a large bucket

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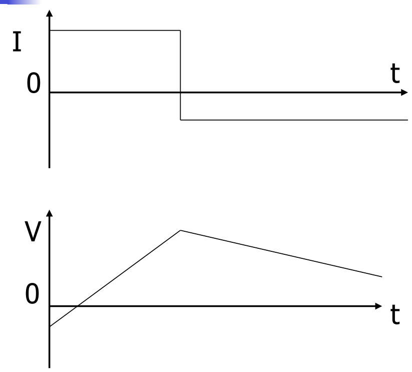
Charging a Capacitor

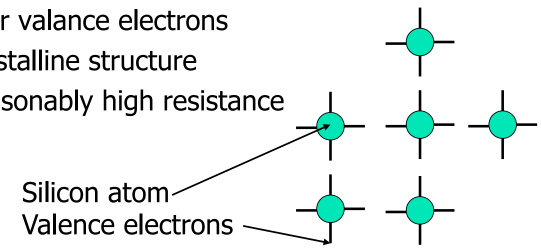


The bucket analogy can be used to describe capacitor charging

When current flows in at a constant rate the voltage increases linearly and vice versa for current flowing out

Semiconductors

- Silicon is used as an example (other semiconductors include Germanium, Gallium Arsenide, Gallium phosphide, indium arsenide, indium phosphide)
- Pure silicon (intrinsic semiconductor)
  - Four valance electrons
  - Crystalline structure
  - Reasonably high resistance

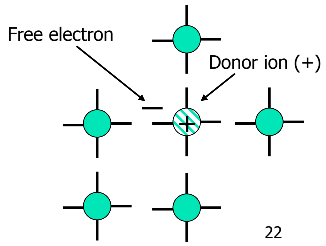


Electrons and holes

- Due to thermal energy some electrons in the valance shell become free
- Create:
  - One free electron +
  - One hole in the valence band that can be filled by electrons from the valance band in an adjacent silicon atom
- Current in silicon can flow due to both movement of electrons and holes

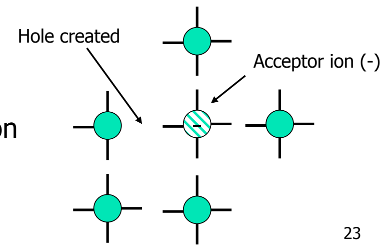
n-type silicon

- Add donor impurities (e.g. Phosphorus, arsenic, indium) with 5 electrons in the valance band
- As only four electrons can bond with neighbouring silicon atoms one free electron is left
- Increases concentration of free electrons
- Reduces concentration of holes (due to increased chance of recombination)
- Resistance reduced



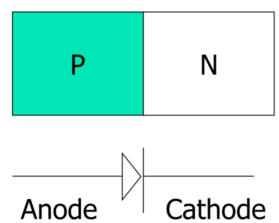
p-type silicon

- p-type silicon is created by adding acceptor impurities which have three valance electrons (e.g. boron)
- This leaves an unbound valance electron in an adjacent silicon atom creating a hole
- Increases concentration of holes
- Reduces concentration of free electrons
- P-type silicon has lower resistance than pure silicon



Diodes

- If a piece of n-type silicon and p-type silicon are joined directly together a diode (di - electrode) device is created

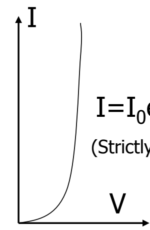


Macro-behaviour

- A diode is a device that allows current flow easily in one direction easily and allows hardly any current flow in the opposite direction

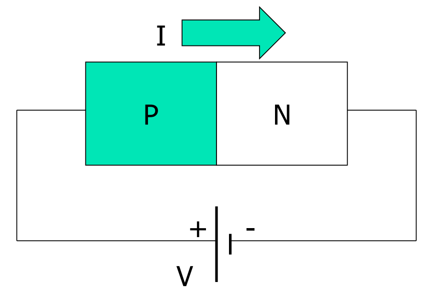
Forward bias

- Current flows easily if the P region is positive with respect to the N region



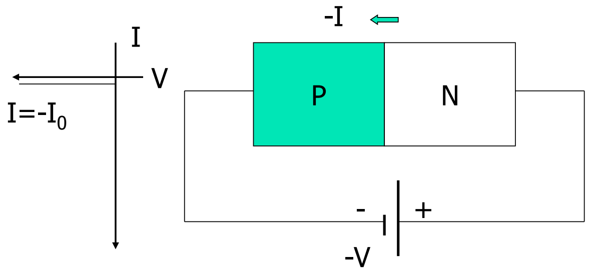
$I = I_0 e^{bV}$

(Strictly $I = I_0(e^{bV} - 1)$)



Reverse bias

- Current hardly flows if the P region is negative with respect to the N region



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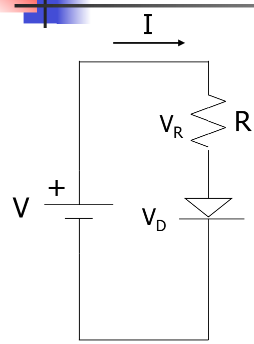
Diode and resistor circuit



Currents and voltages determined by:
(work backwards to find V_D)
1. V_D related to I by diode equation
2. Current in resistor and diode equal
3. V_R = IR
4. voltage across diode and voltage resistor add up to voltage source V

Short cut rule of thumb, V_D is approx 0.6-0.7 volts and $V_R \approx$ V - 0.6
For LEDs V_D is about 1.8 - 4.0 V, depending on colour

Forward biased diode

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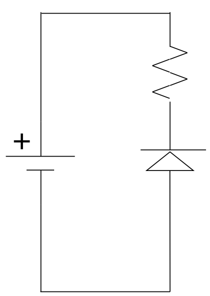
Diode and resistor circuit



Assume no reverse-bias current flows (ideal case)

Therefore no voltage occurs across the resistor

Therefore the full supply voltage appears across the diode

Reverse biased diode

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LEDs

- Light emitting diode
- When an electron moves down from the conduction band to the valence band it loses energy
- In silicon and germanium the energy-momentum relationships mean that this energy is lost heat
- In gallium arsenide it produces a photon

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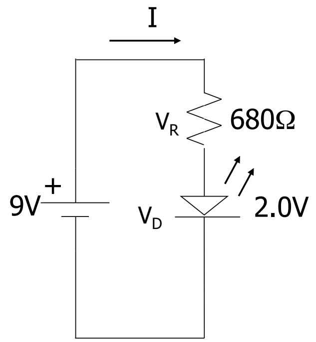
LEDs

- The light intensity is proportional to current
- Pure gallium arsenide produces infrared light
- GaAsP produces red or yellow light
- GaP produces red or green

Circuit design using LEDs

- LEDs behave just like normal diodes except that the forward bias voltages are greater (typically 1.8 - 4.0 V)
- A typical forward bias current of 10-20 mA is used.

Example



$$I = \frac{9 - 2.0}{680}$$

$$= 10.29\ mA$$

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