BITS Pilani
Pilani Campus

Mechatronics (Merged - DEZG516/DMZG511/ESZG511)

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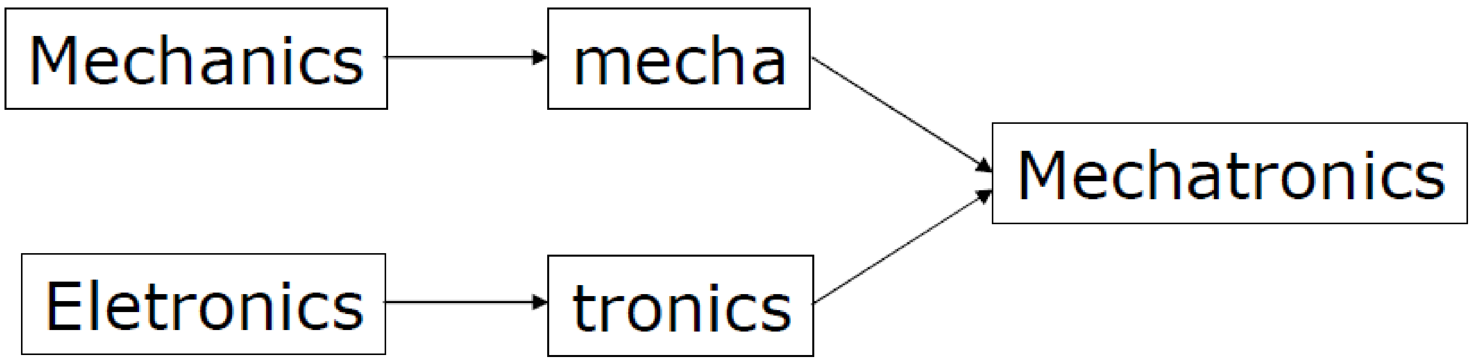
Session I

Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	• Introducing Mechatronics, • Concepts of signal measurement, • controls and output actuation • Mechatronics application examples	T1: Chapter 1, T2: Chapter 1
Post CH			

Session Objectives

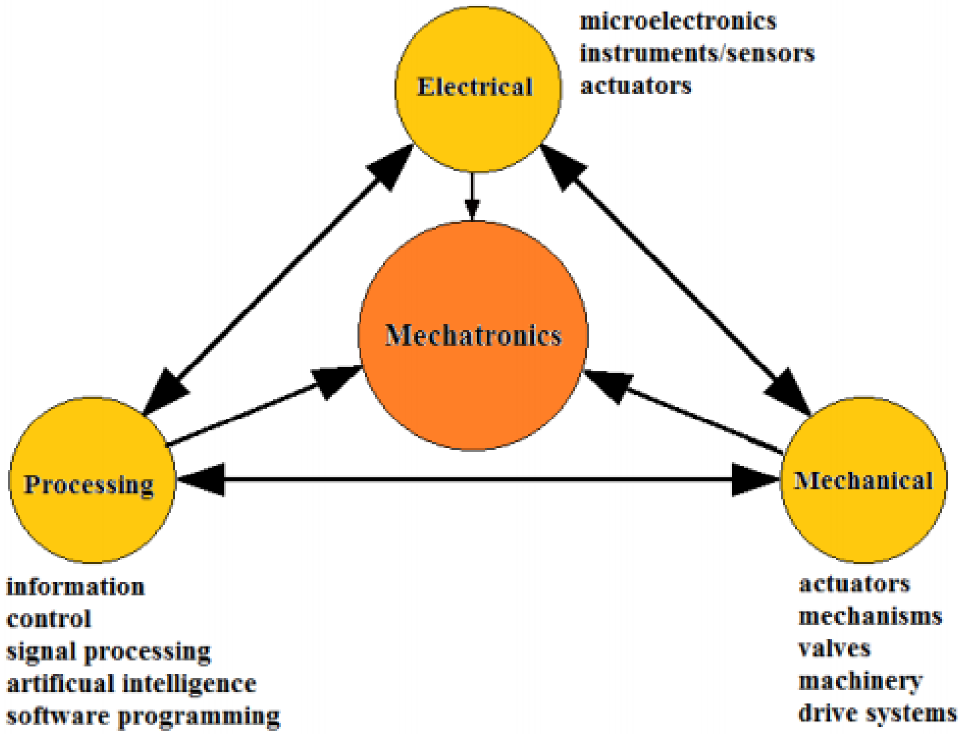
- Define mechatronics and appreciate its relevance to contemporary engineering.
- Identify Mechatronics system and its elements.
- Define elements of general measurement system.
- Describe the various forms and elements of open-loop and closed-loop control systems.
- Recognise the need for models of systems in order to predict their behaviour.

Introduction to Mechatronics



- Integration of electronics, control engineering, and mechanical engineering

What is contains?



These three technologies have many sub-categories:

- Thermodynamics
- Fluid mechanics
- Hydraulics
- Pneumatics
- Electronics
- Electrical machinery
- Micro-electronics
- Logic functions
- Programmable logic controllers
- Software programming
- Instrumentation
- Control and so on.

Introduction to Mechatronics

- Mechatronics is the synergistic integration of
  - sensors, actuators, signal conditioning,
  - power electronics,
  - decision and control algorithms, and computer hardware and
  - software to manage complexity, uncertainty, and communication in engineered systems.

Disciplinary Foundations of Mechatronics

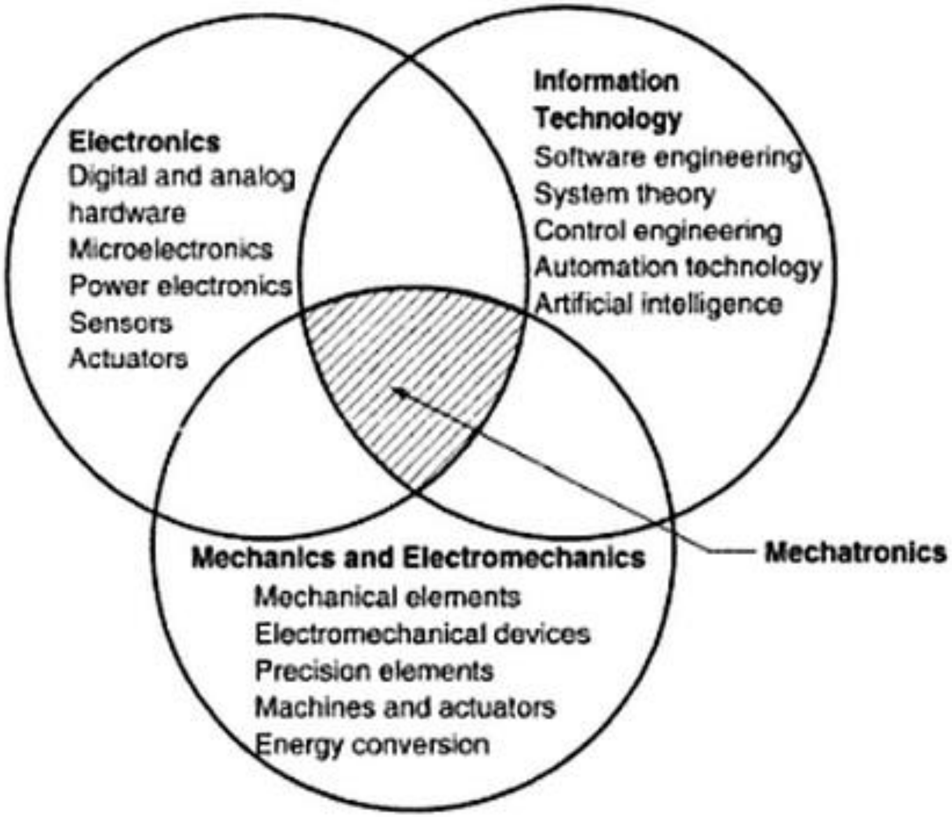
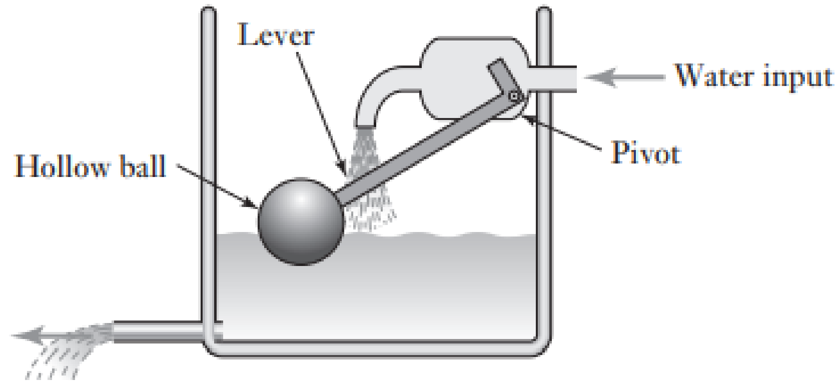
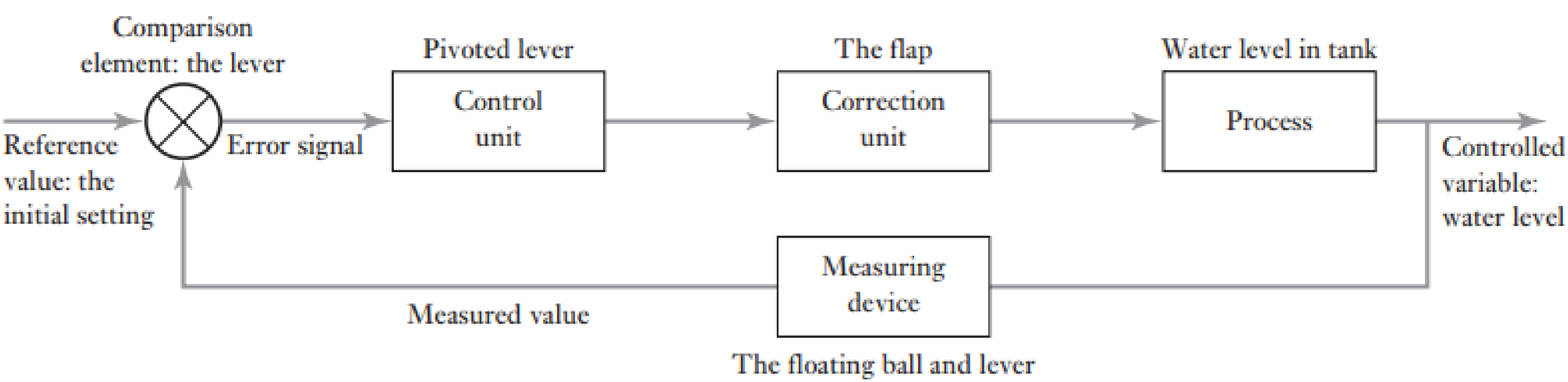


Figure 1.1 | Domain of mechatronics.

Example…

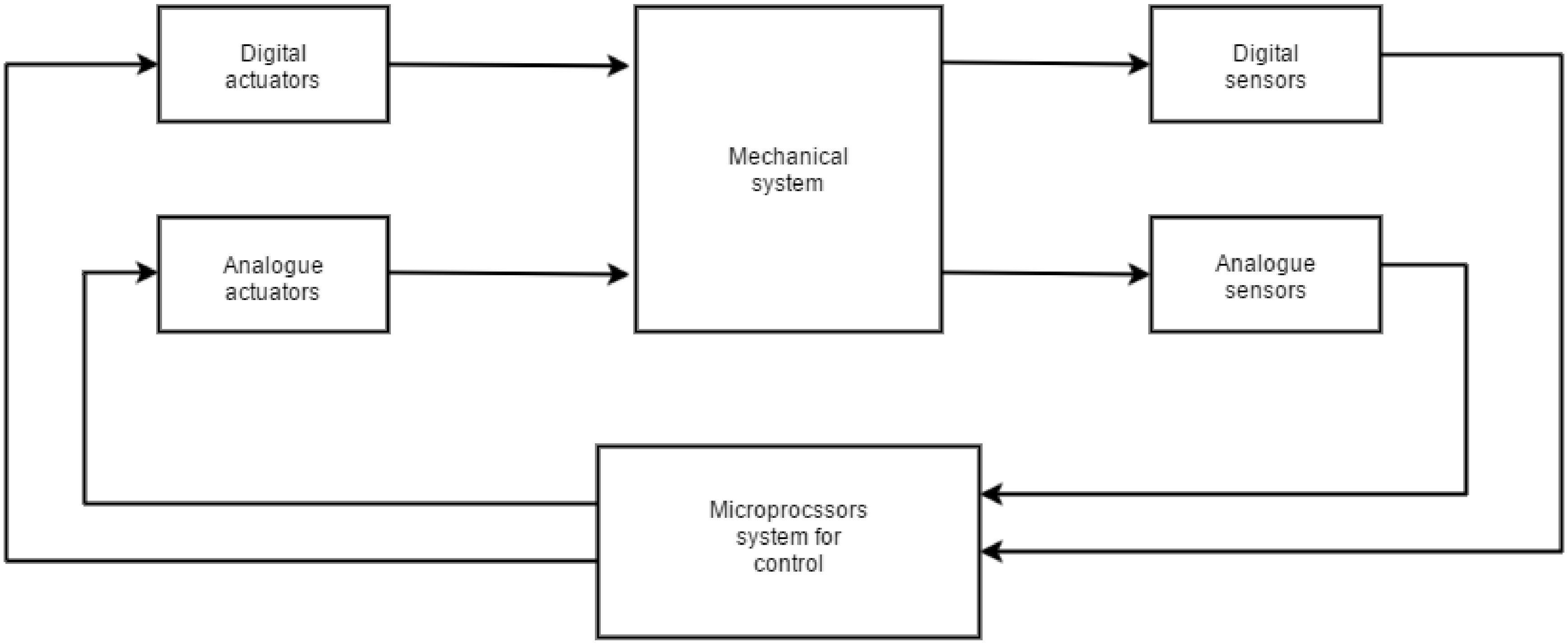


Lever
Water input
Pivot
Hollow ball



Comparison element: the lever
Pivoted lever
The flap
Water level in tank
Control unit
Correction unit
Process
Reference value: the initial setting
Error signal
Controlled variable: water level
Measuring device
Measured value
The floating ball and lever

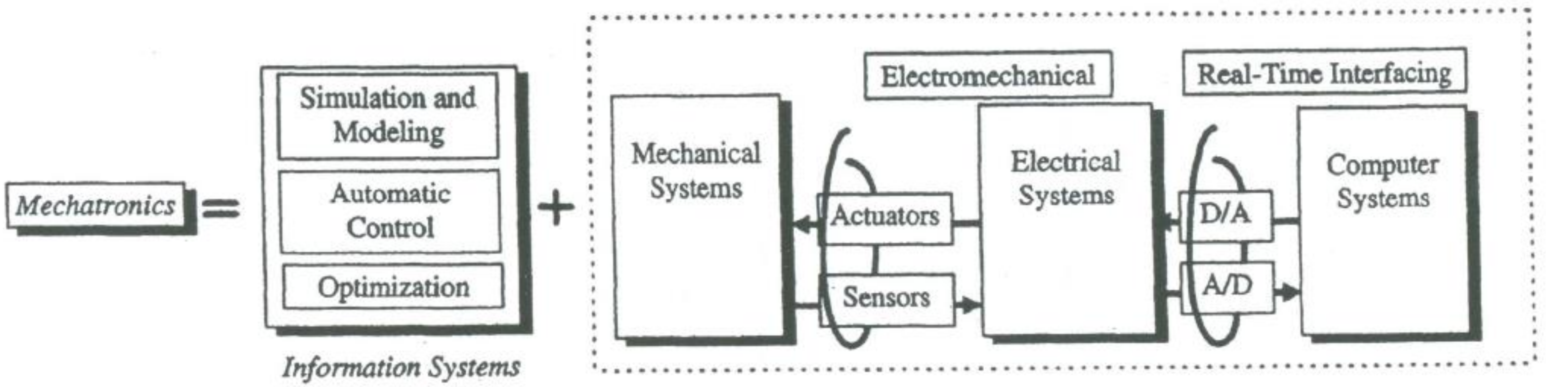
What is it?


Digital
actuators
Analogue
actuators
Mechanical
system
Digital
sensors
Analogue
sensors
Microprocssors
system for
control

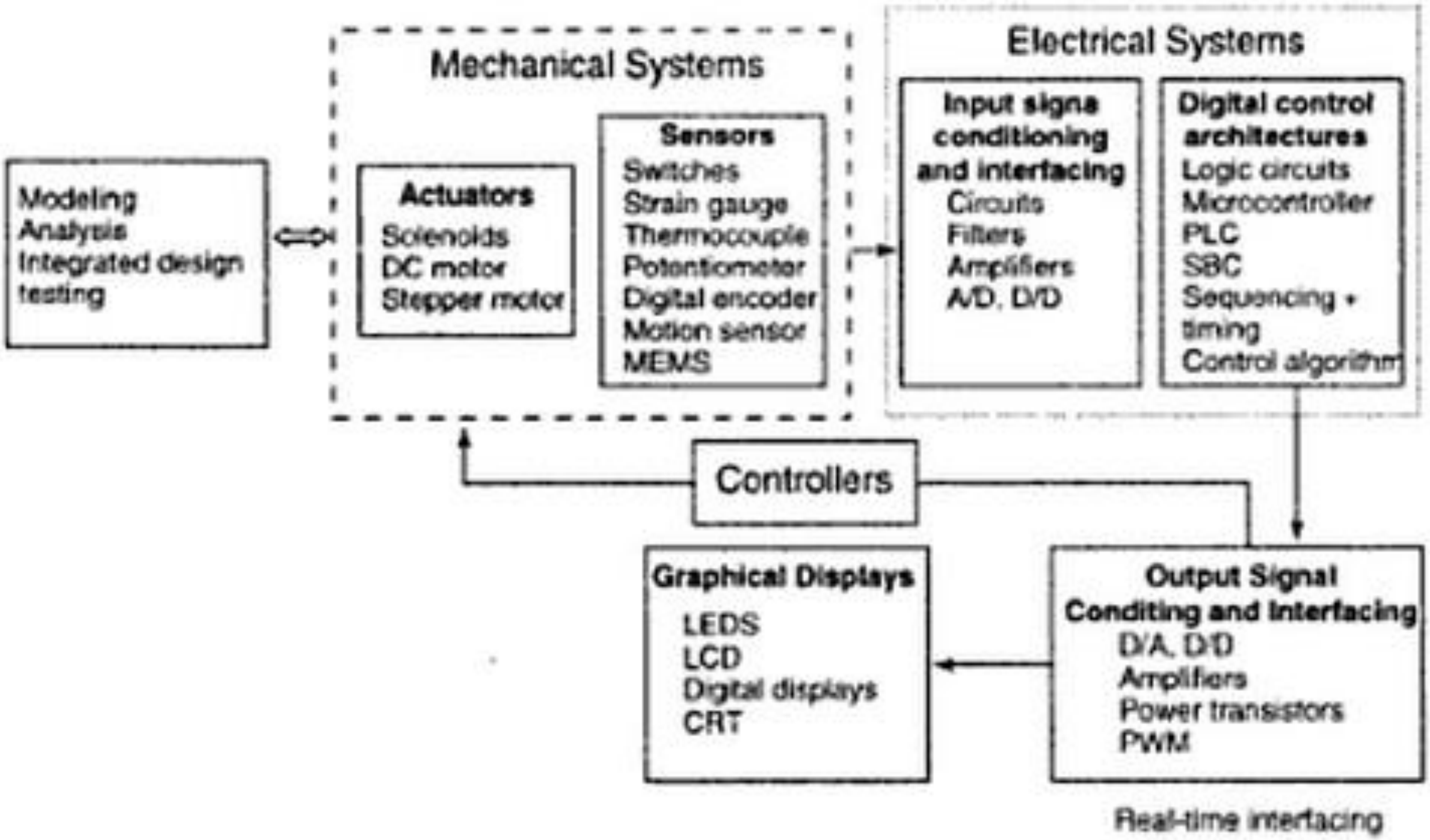
Elements of a Mechatronics system:

1. Digital/Analogue actuators
2. Mechanical system
3. Sensors Digital/Analogue
4. Microprocessor system for control

Key components of Mechatronics system



Key elements of mechatronics system



Design process of mechatronics system

The need Identification

Analysis of problem

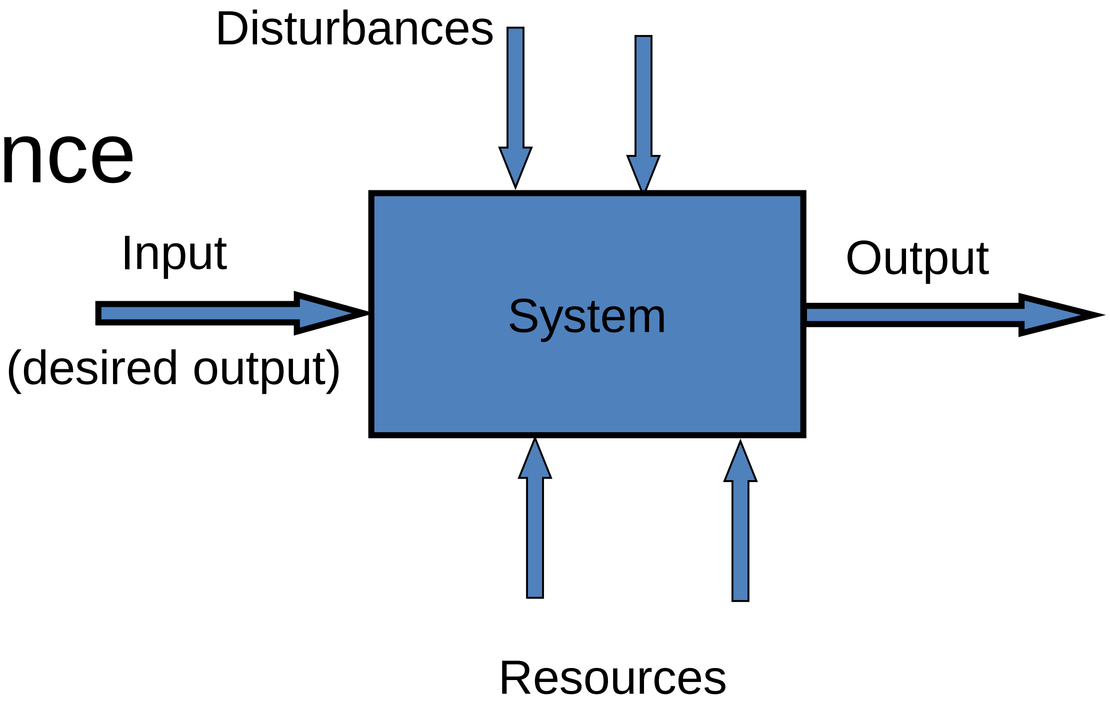
Preparation of specification

Generation of solutions

Selection of optimum solution

System

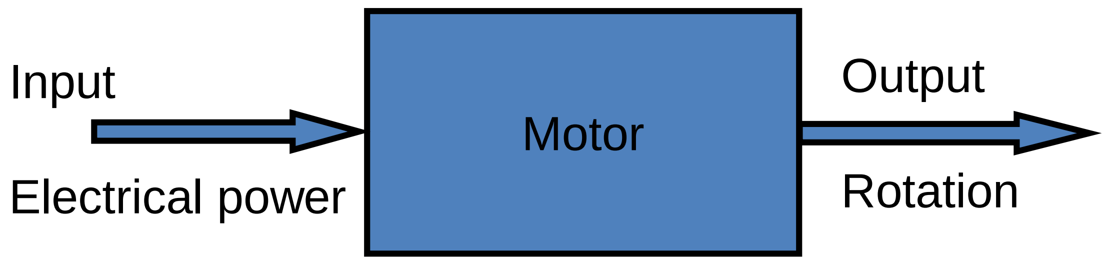
- Input
- Output
- Noise/Disturbance
- Resources

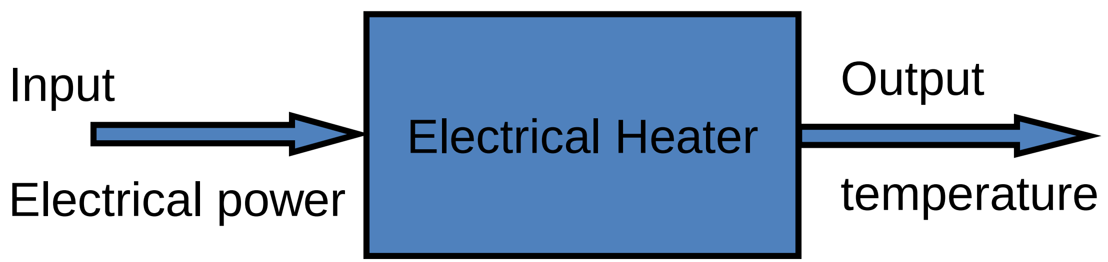


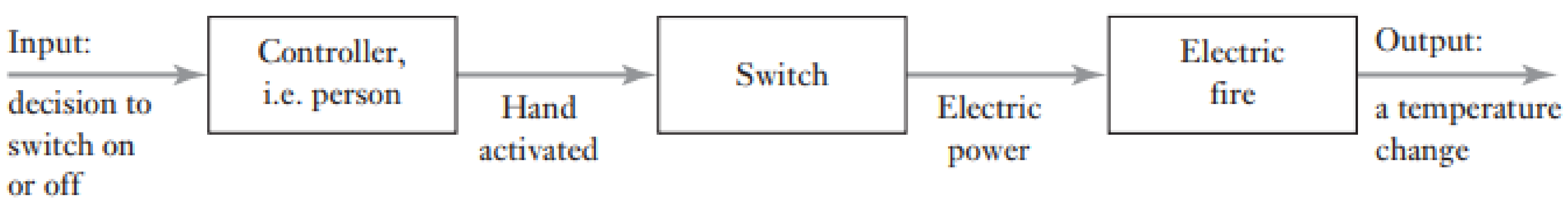
System

- Open loop system
- Closed loop system

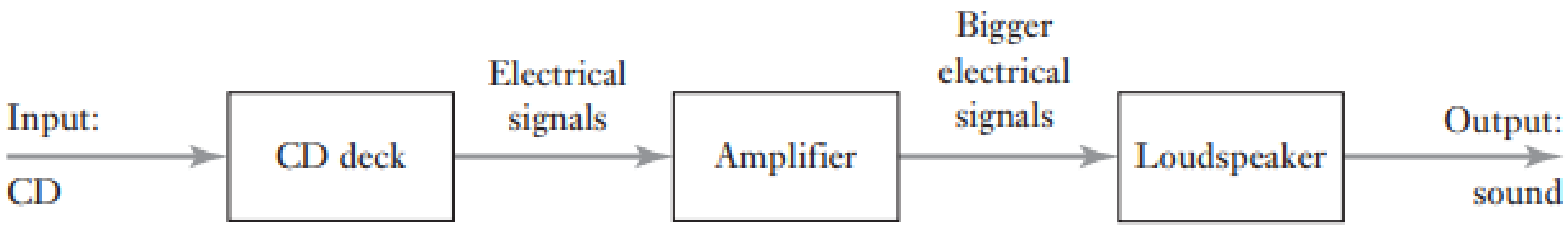
Examples (Open loop)



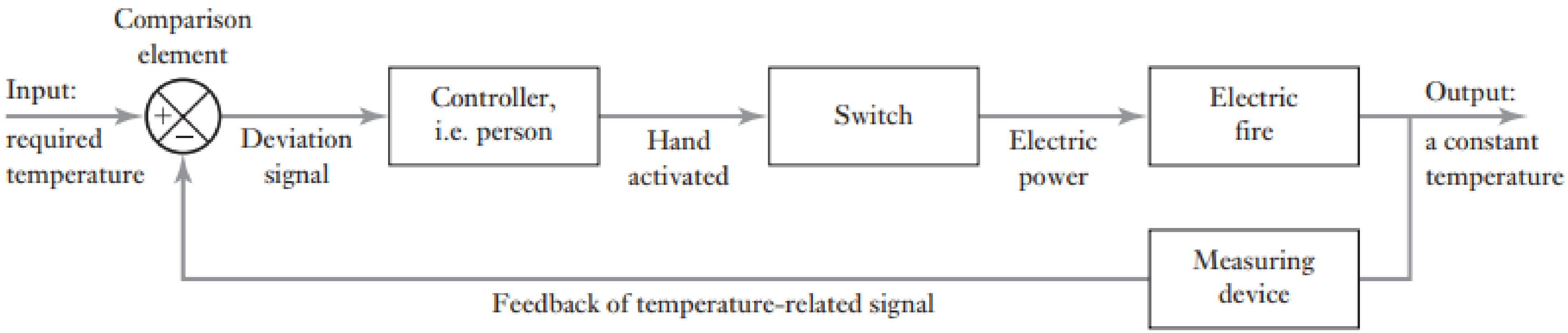




Interconnected open loop system



Closed loop system



Basic elements of a closed loop system

1. Comparison element
2. Control element
3. Correction element
4. Process element
5. Measurement element

Building blocks – Open , Closed loops

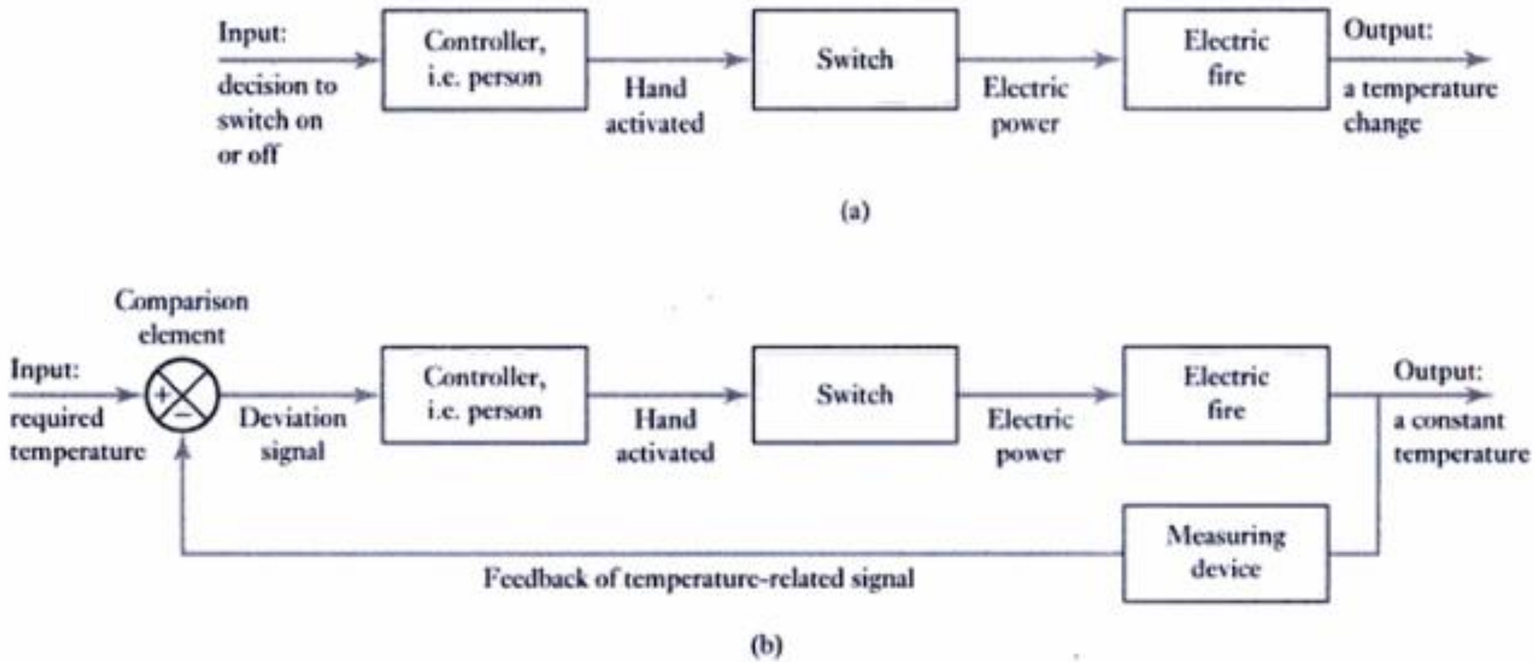
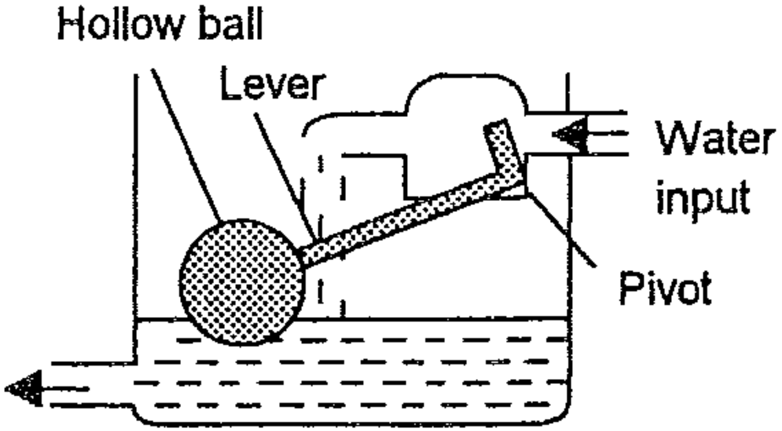


Figure 1.9 Heating a room: (a) an open-loop system, (b) a closed-loop system.

Rice cooker- Steam Open or closed loop?

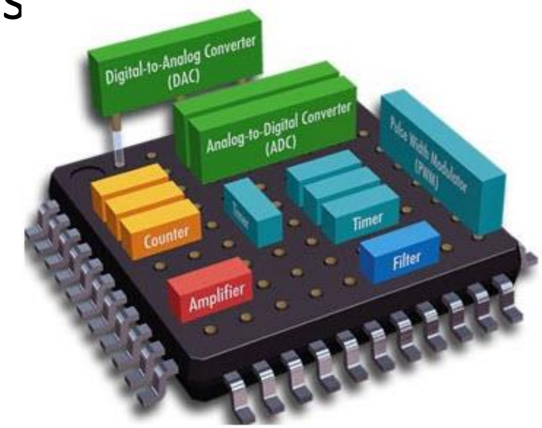
Building blocks - Controls



Controlled variable	–	water level in tank
Reference value	–	initial setting of the float and lever position
Comparison element	–	the lever
Error signal	–	the difference between the actual and initial settings of the lever positions
Control unit	–	the pivoted lever
Correction unit	–	the flap opening or closing the water supply
Process	–	the water level in the tank
Measuring device	–	the floating ball and lever

Building blocks – Mechatronics Systems

- Embedded systems
  - Microcontrollers



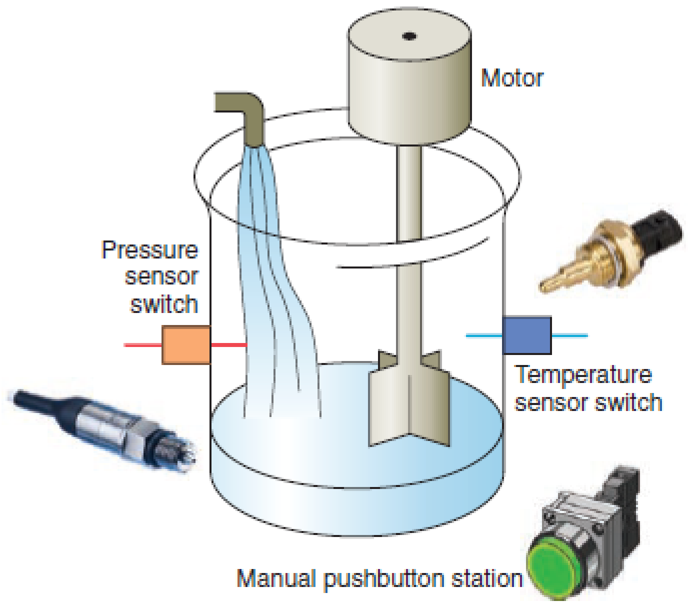
- Controllers –
  – Human
  – Microcontrollers
  – PLC
  – PID

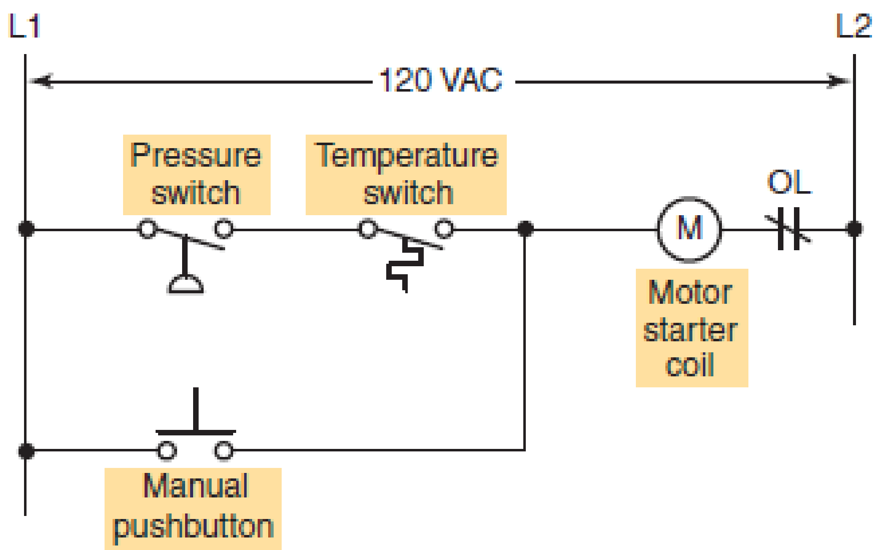
- Modelling of systems
  - Output Response is not instantaneous to input
  - May not be linear
  - Predict the system response

Embedded System

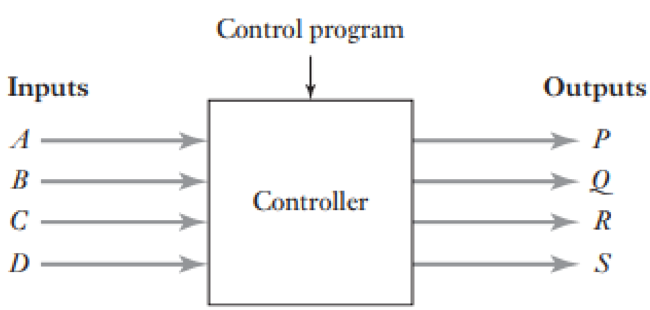
- Microprocessors are embedded in the system
- Microprocessor can be considered as a collection of logic gates and memory elements that are controlled by software
- Controls a range of functions
- It is not designed to be programmed by the end user
- User can’t change what the system does by adding or replacing software

Building blocks - PLCs



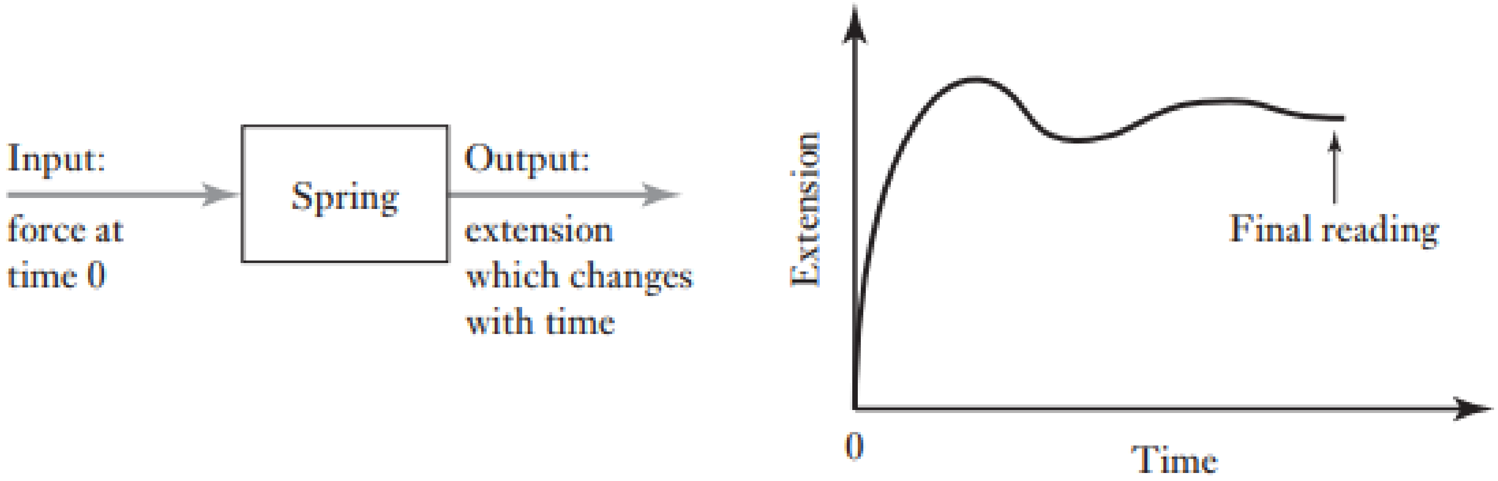


Ladder Diagram

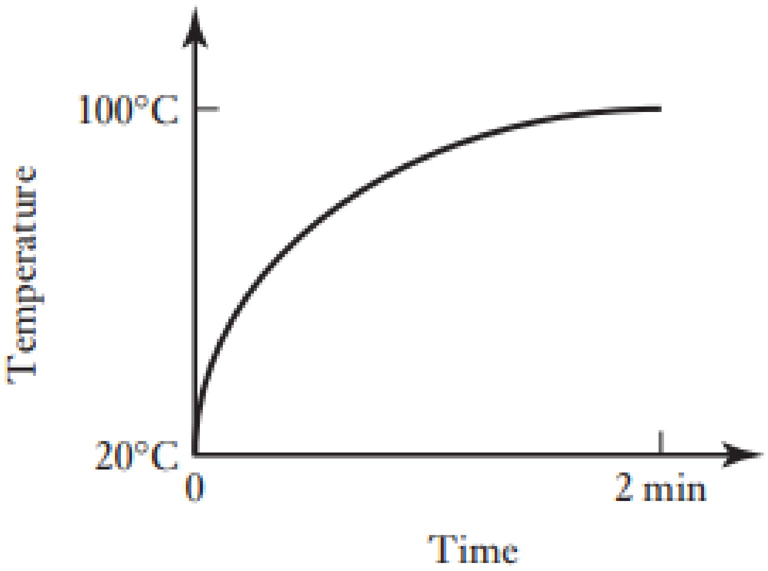


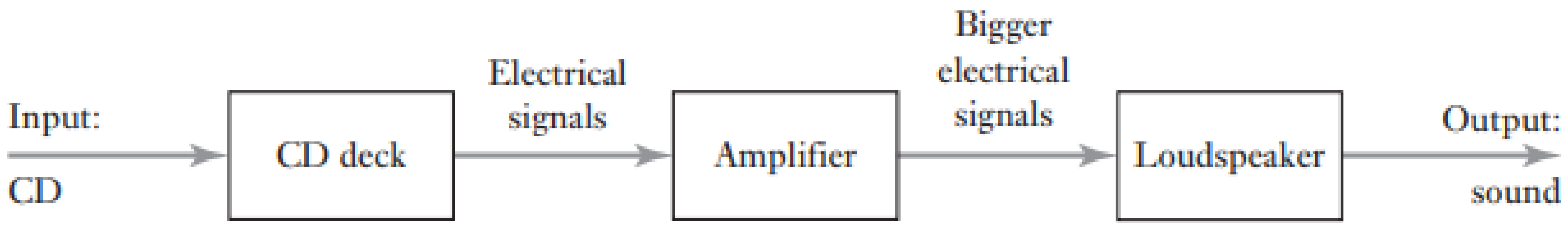
Modeling a System

- It is expressing the relationship between the input and the out put
- Generally described by a differential equation



Modeling a System





Uses of control system

1. Control of variables to some particular value

e.g. temperature control up to 35 degrees

2. Control sequence of events

e.g. washing machine

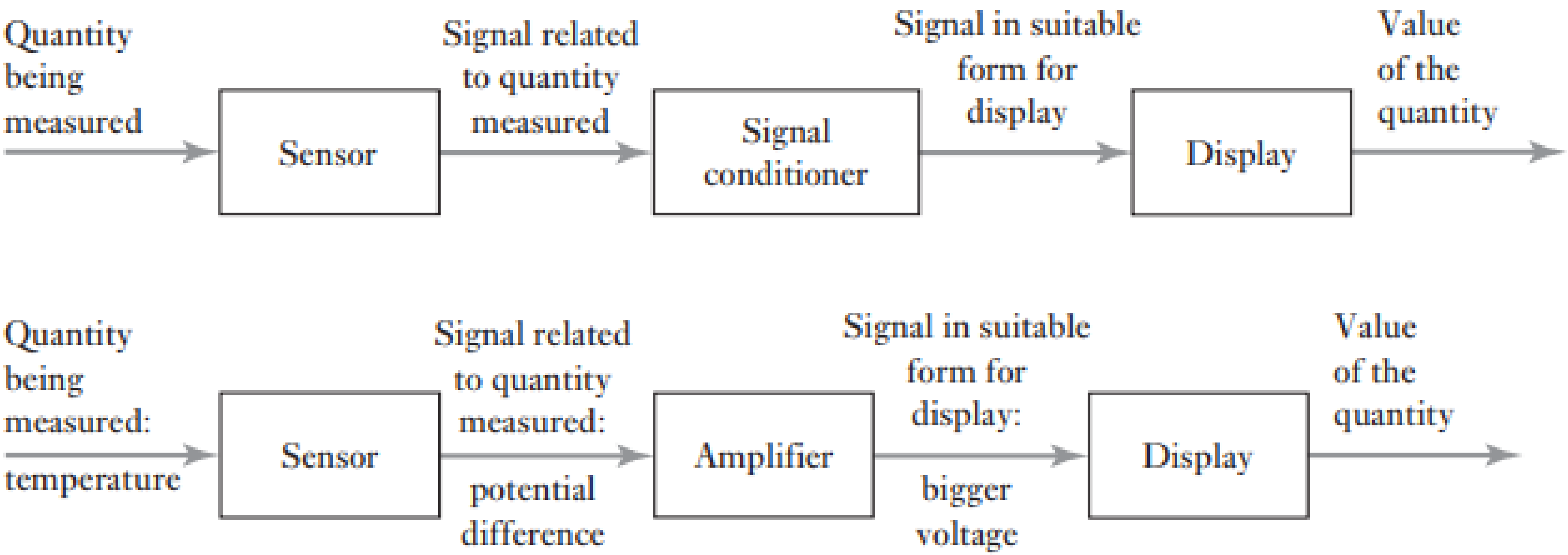
3. Control whether event occur or not eg: a safety lock on a machine where it cannot be operated until a guard is in position

Open loop control system and close loop control system

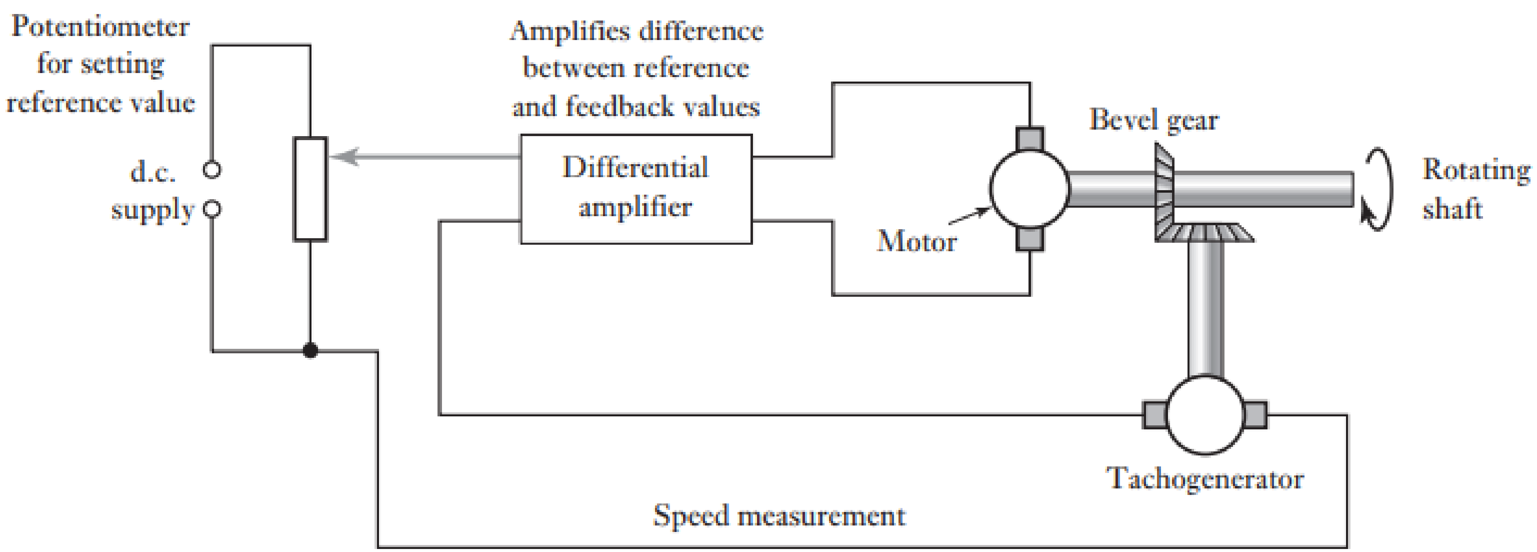
- Domestic toaster. Controller is exercised by a timer. Brownness of the toast is determined by time. There is no feed back to control the degree of browning
- In open loop system the output has no effect on the input.
- Open loop: simple by construction and less costly

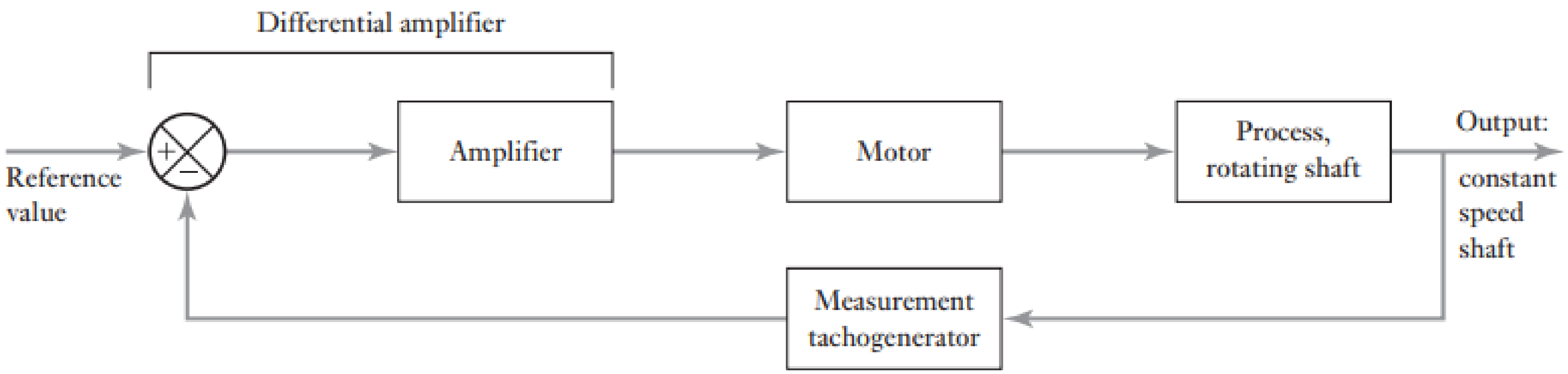
Control systems as measurement system

Control systems as measurement system

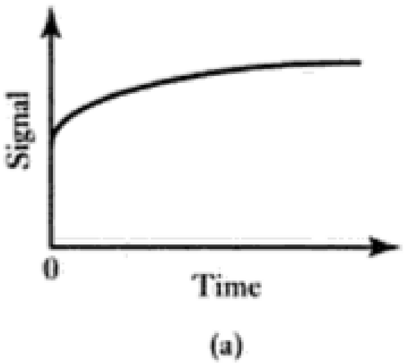


Control systems as measurement system – Speed measurement

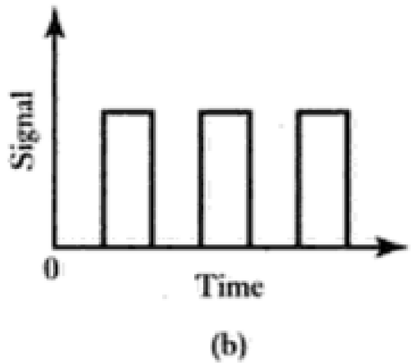




Building blocks - Signals



Analog signal



Digital signal

Analogue	Digital
Advantages	*Advantages*
Produces a more 'faithful' reproduction of the physical quantity.	Can be very immune to noise
Usually simple	Signal can be transmitted over long distances.
Disadvantages	*Disadvantages*
Noise and distortion problems	Output subject to quantity errors from sampling
	Can be complex

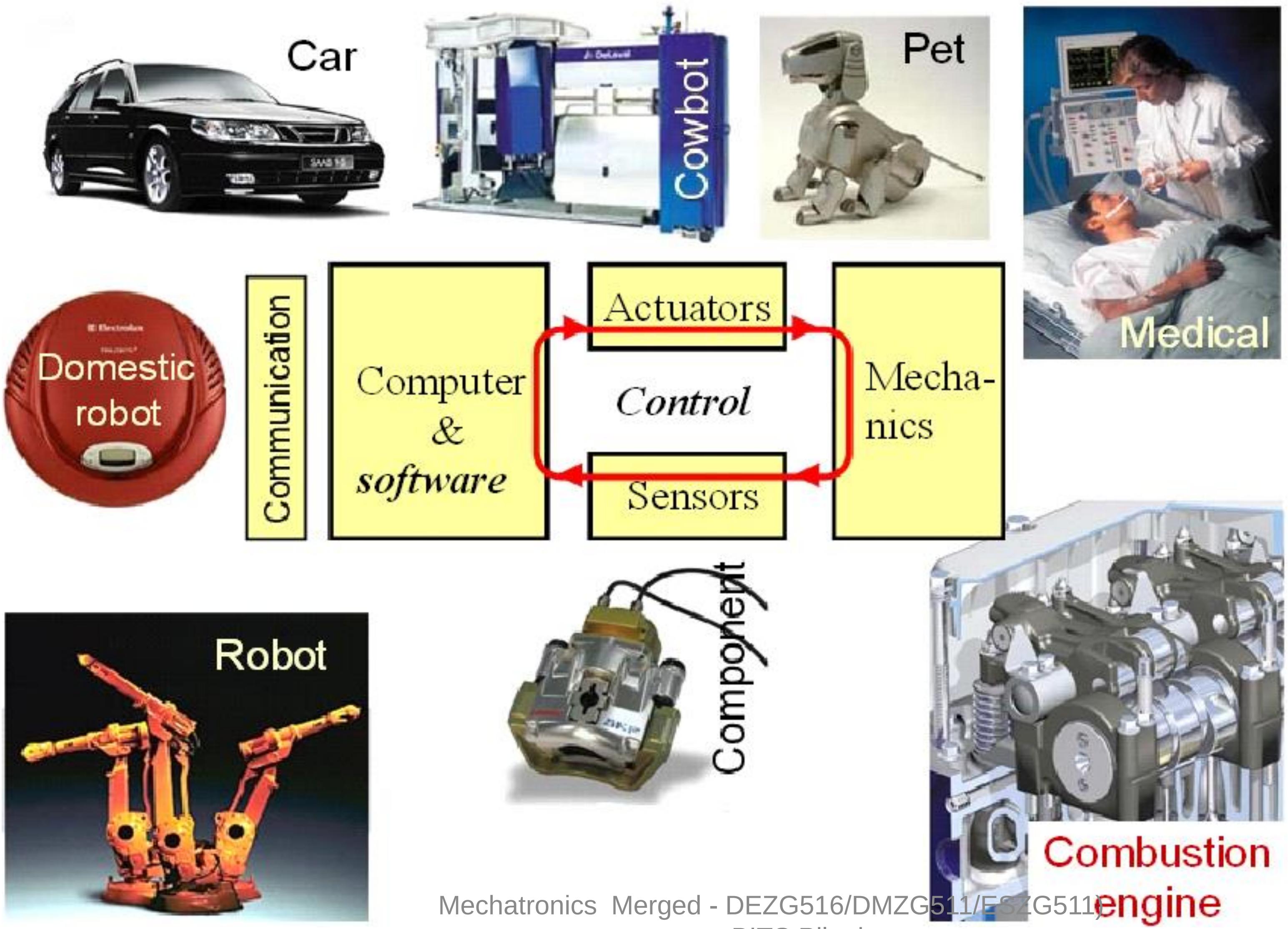
Mechatronics Applications

- Smart consumer products:
  - home security, camera, microwave oven, toaster, dish washer, laundry washer-dryer, climate control units, Refrigerator.
- Medical:
  - implant-devices, assisted surgery, Bio-Mechanics with chip assistance.
- Defense:
  - unmanned air, ground, and underwater vehicles, smart munitions, jet engines, etc.

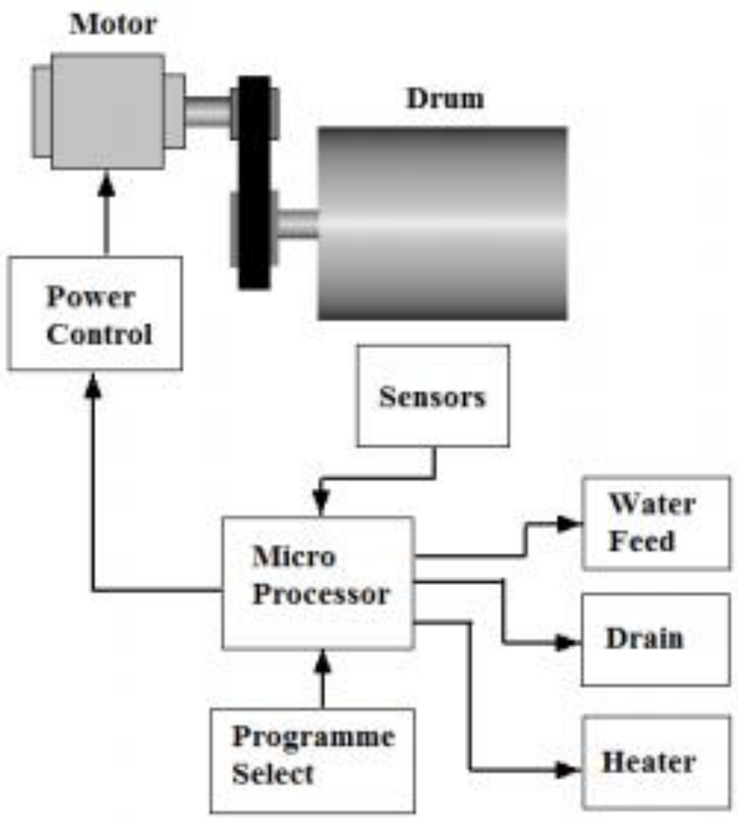
Mechatronics Applications

- Manufacturing:
  – robotics, machines, processes, etc.
- Automotive:
  – climate control, antilock brake, active suspension, cruise control, air bags, engine management, safety, etc.
- Network-centric, distributed systems:
  – distributed robotics, tele robotics, intelligent highways, etc.

Mechatronics products

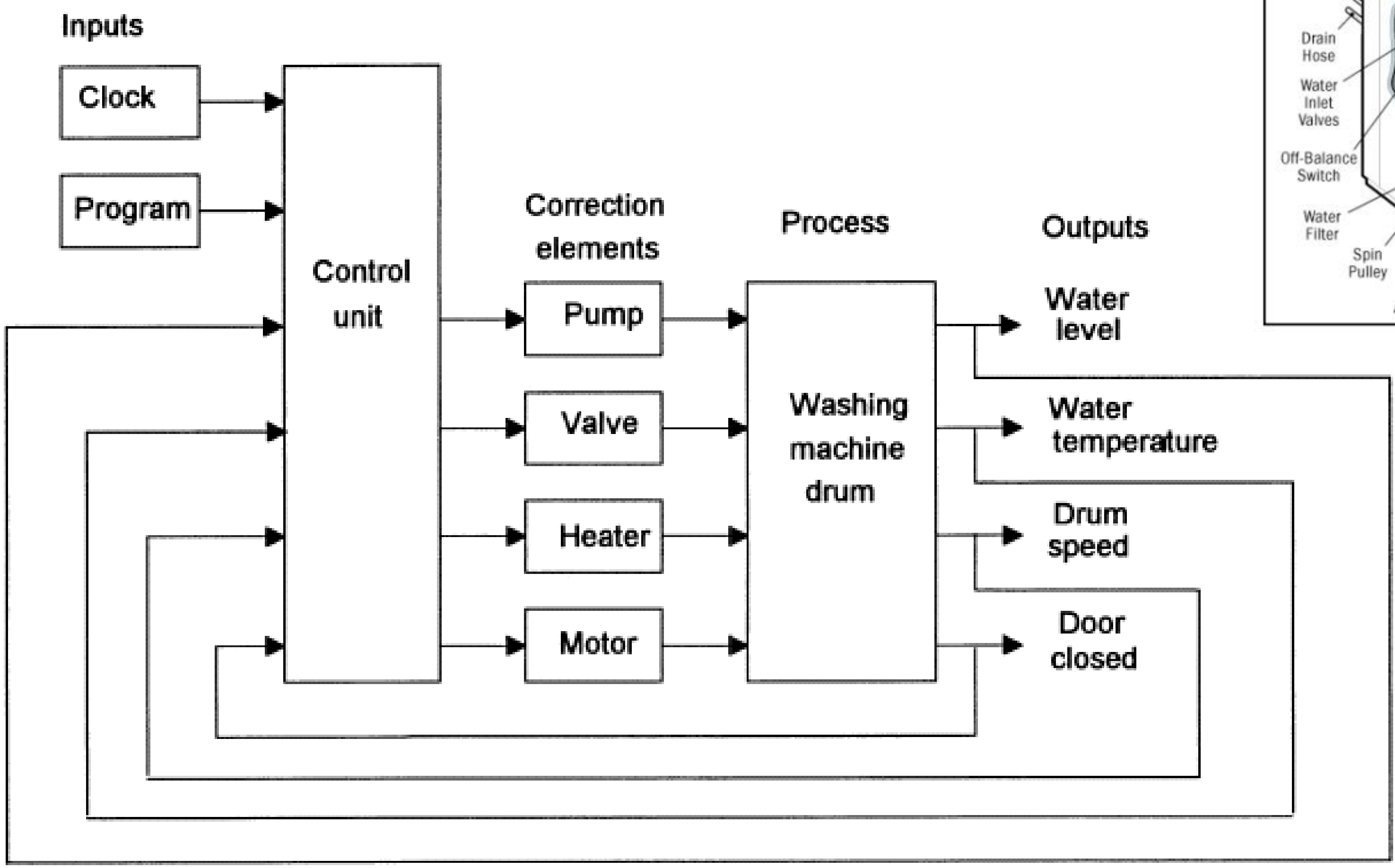


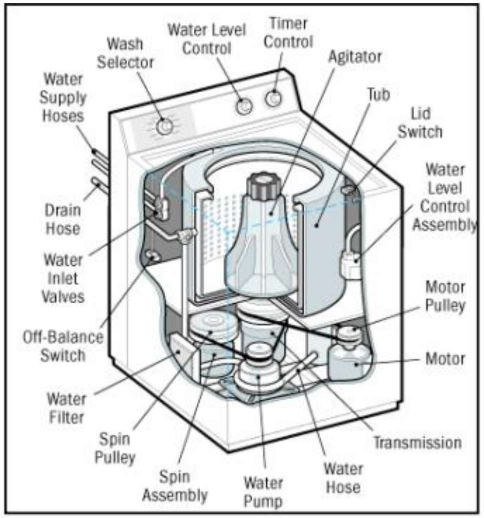
Mechatronics Applications- Washing machine



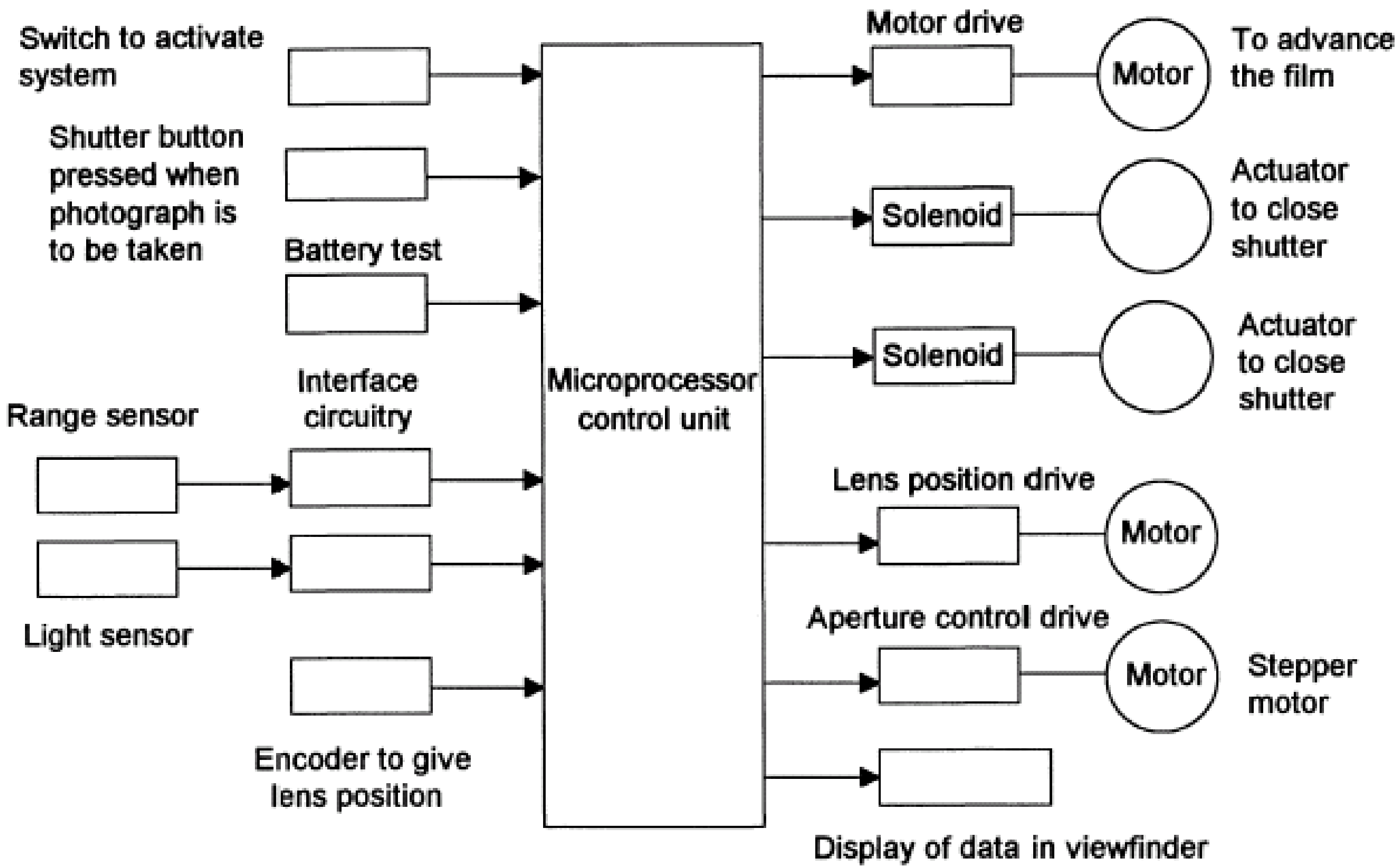
System for an Automatic Washing Machine

Mechatronics Applications- Washing machine

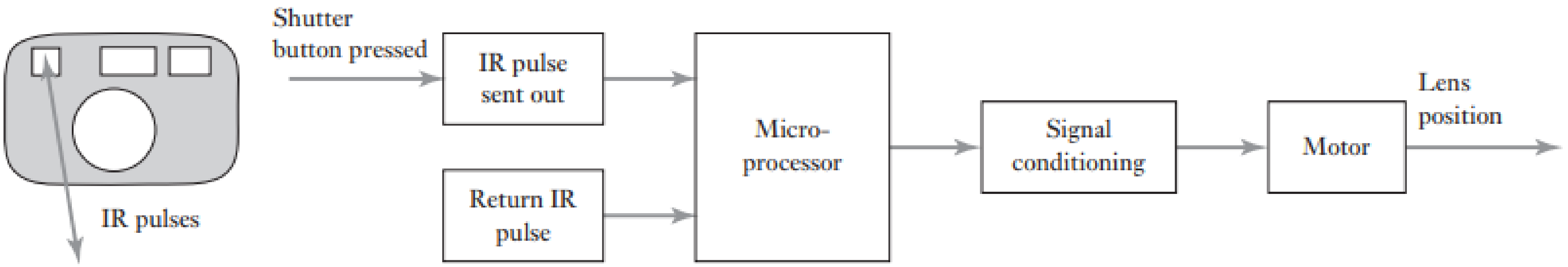




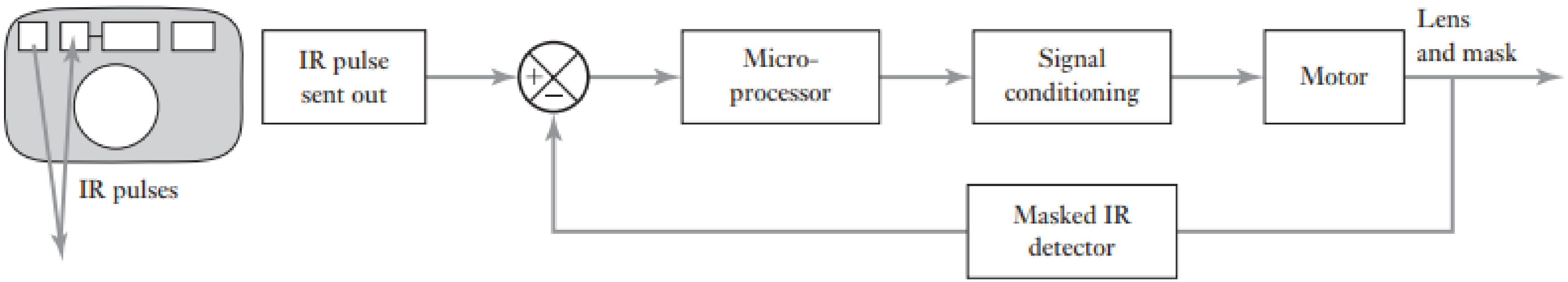
Examples on Control systems (Automatic camera)



Mechatronics Applications- Camera Autofocus

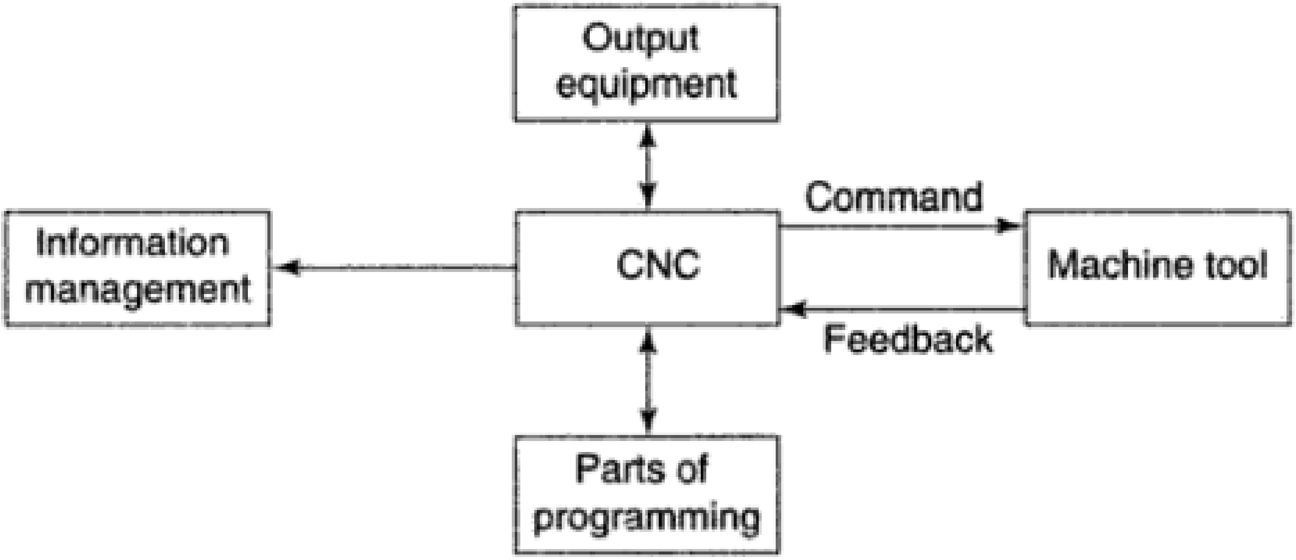


(a)



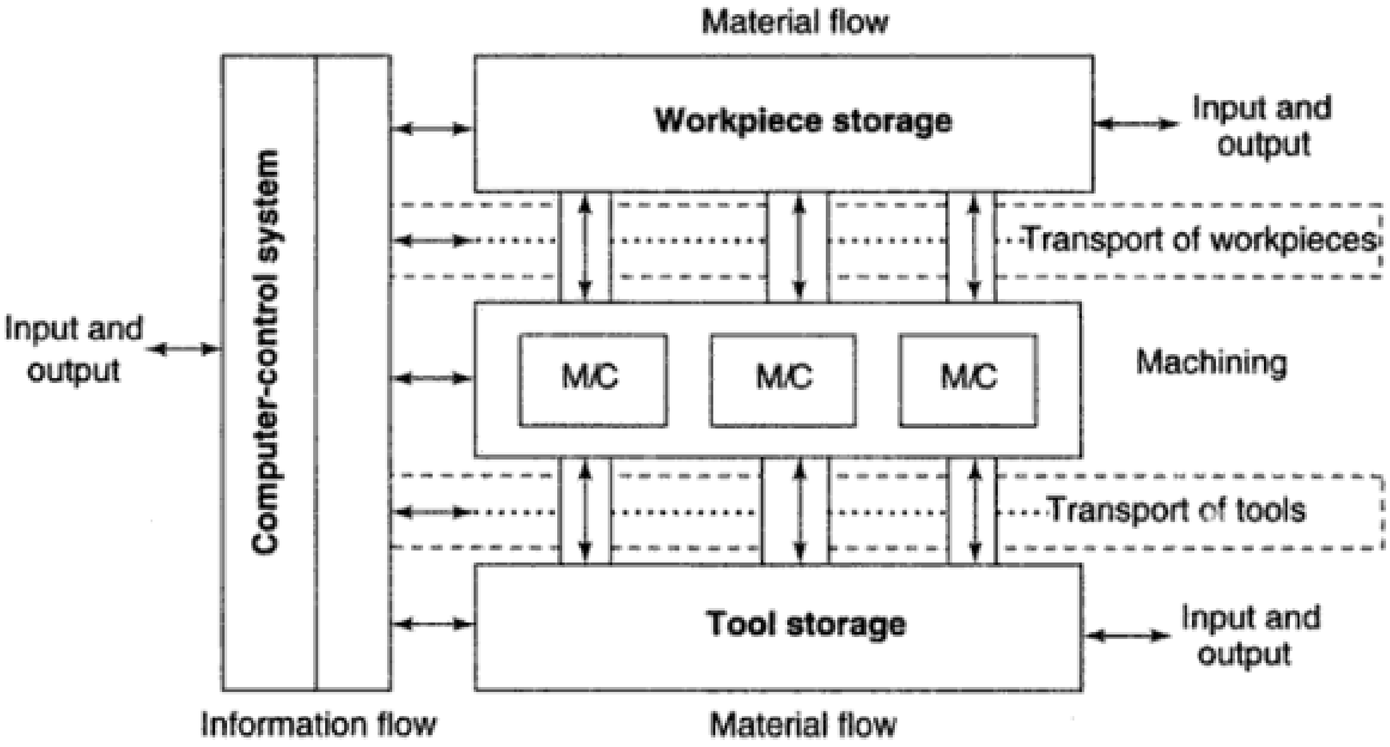
(b)

Mechatronics Applications- CNC machine



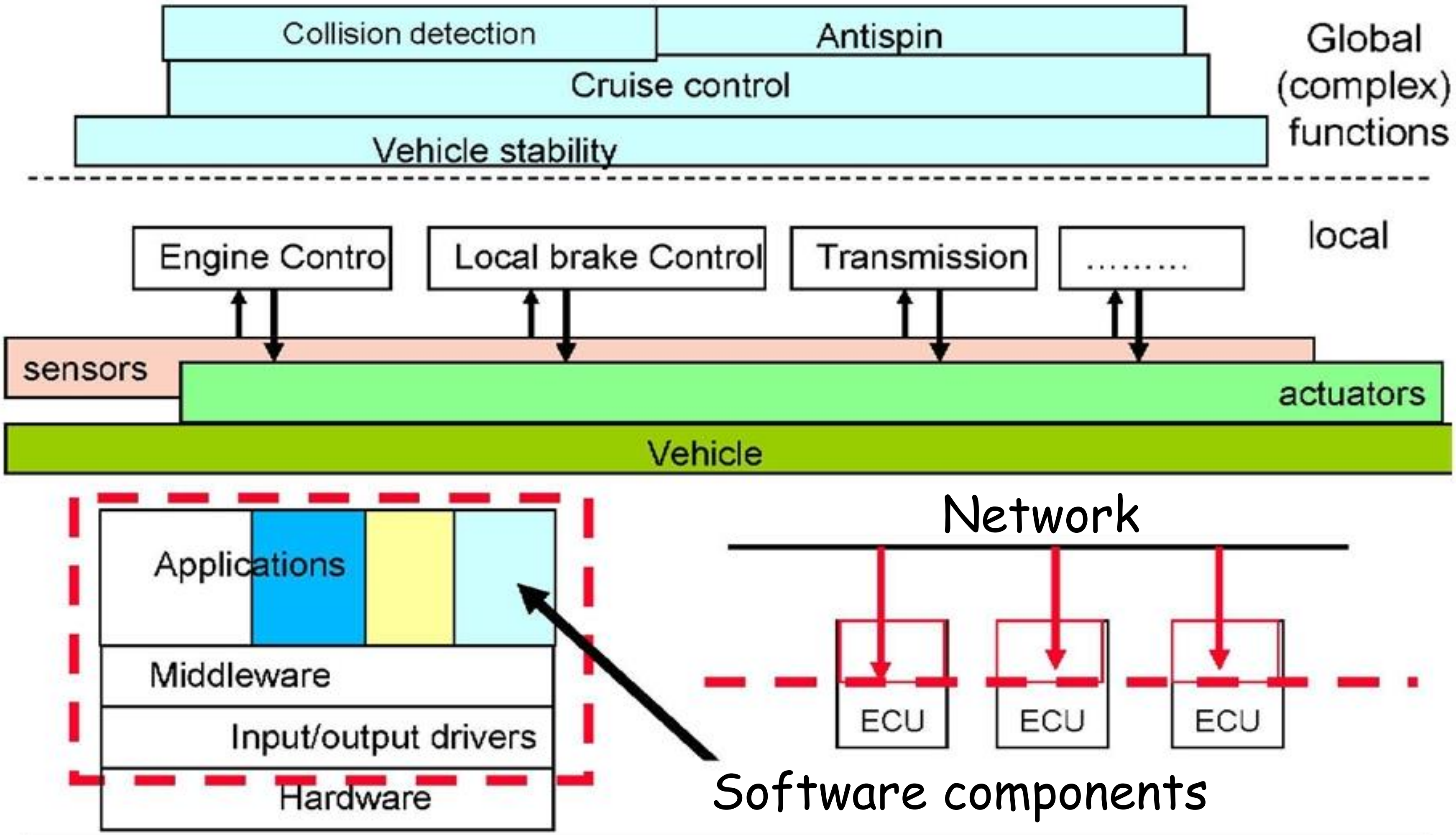
Mechatronics Applications- FMS

▪What is FMS ?



- A flexible manufacturing system is a automated machine cell, consisting of a group of processing workstations, interconnected with automated material handling and storage system.

Automotive Functions - SW and HW



Embedded Software is different from general purpose SW!

Mechatronics Applications- Automotive

- **Five major technology transitions in the auto industry in the next five to ten years:**

1. Gasoline to hybrid to fuel cell to electrical vehicle.
2. Mechanical connection to “Drive-by-wire”
3. Proprietary electrical/hardware/software system to standardized “architectures”
4. Adoption and implementation of IT standards in the technology of the car (XML, Web Services, etc.)
5. “On-demand” to “Always-on” vehicle connectivity to the Internet

Mechatronics Applications- Automotive

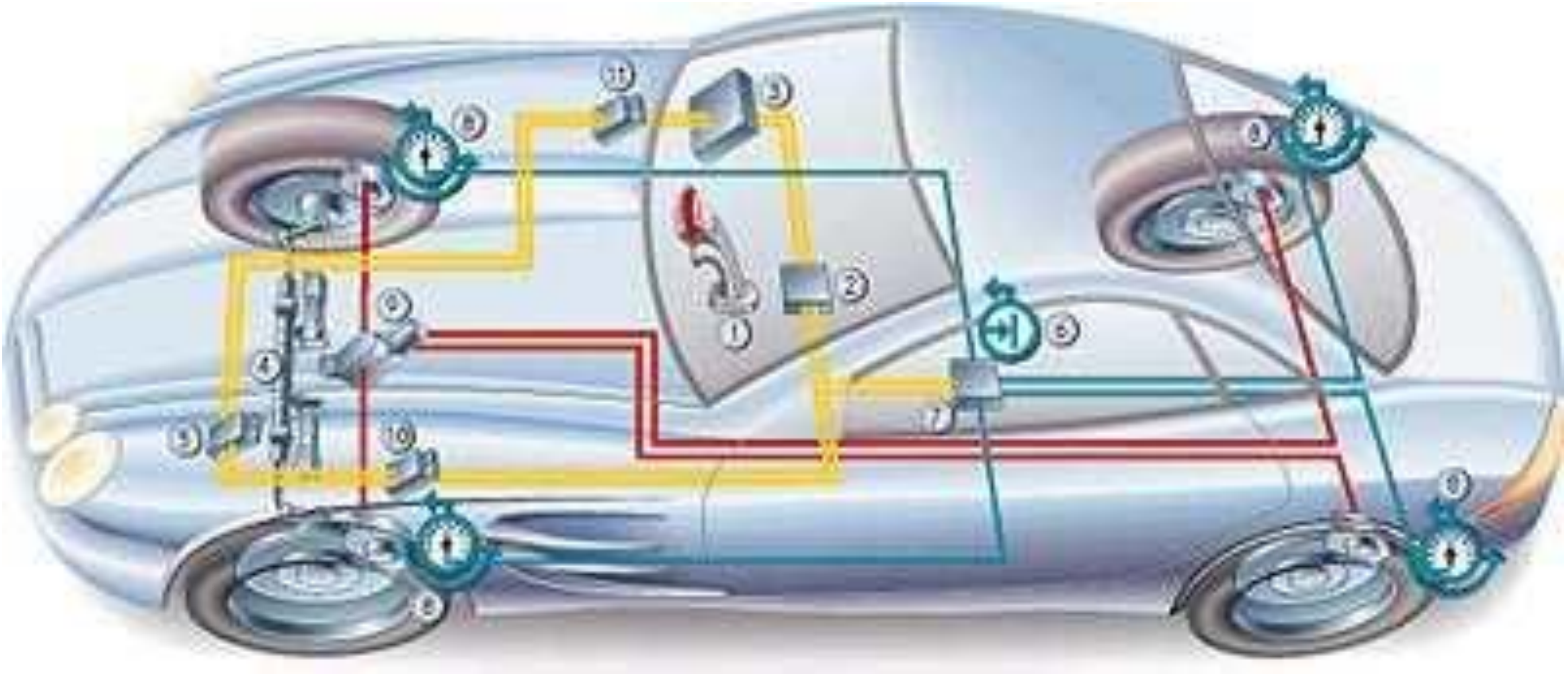
The role of software and electronics

Comfort - Diagnosis – Braking – Active & Passive Safety - Telematics - Anti-Theft Systems - ...

Electronic components and software will, to a large extent, shape tomorrow's vehicles (90% of vehicle innovations)

Mechatronics Applications- Automotive

Drive-by-Wire replaces mechanical connections – push rods, rack & pinion, steering columns, overhead cams, cables – by Mechatronics connections – sensors, actuators, embedded microprocessors, control software



Mechatronics Applications- Automotive EMS

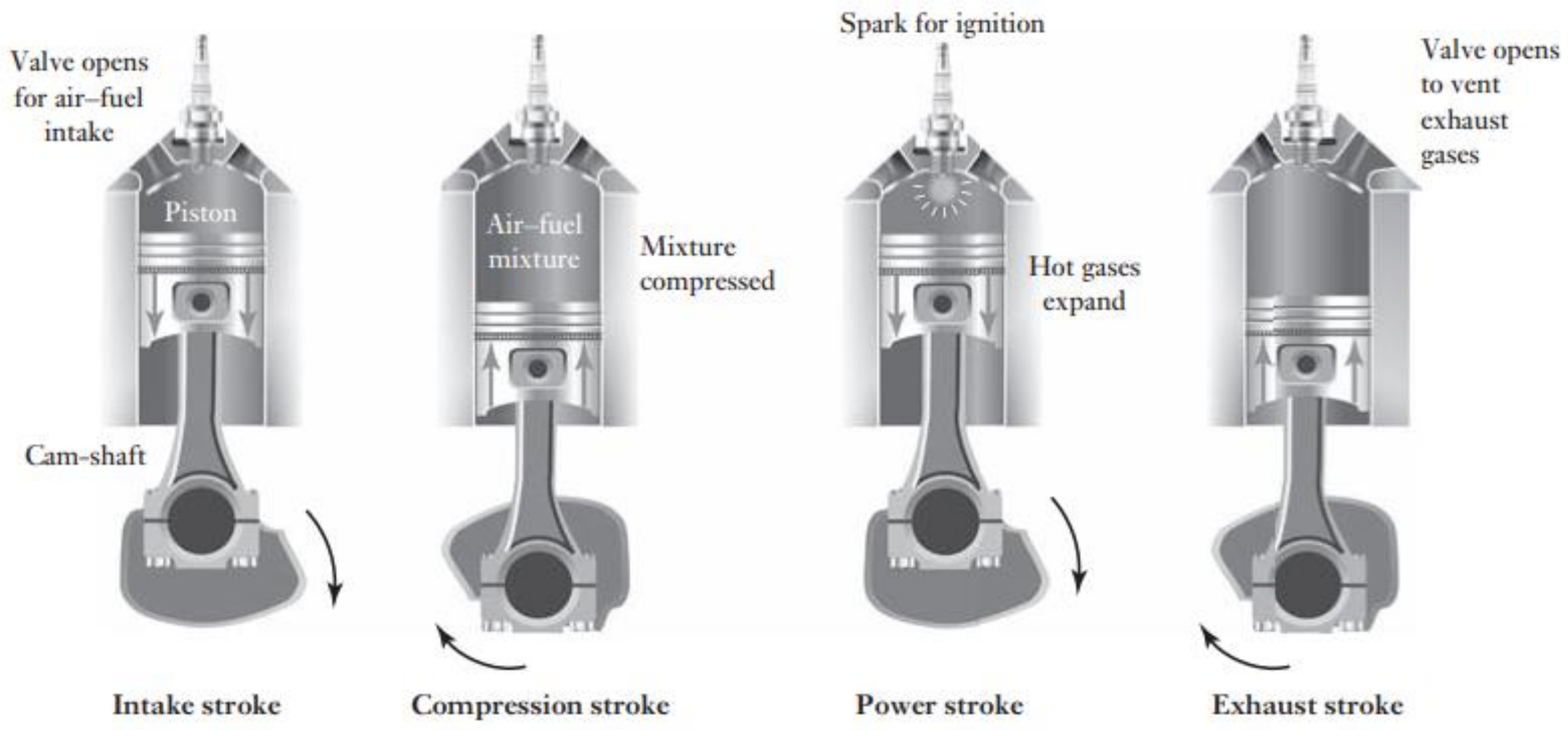


Figure 1.21 Four-stroke sequence.

Mechatronics Applications- Automotive EMS

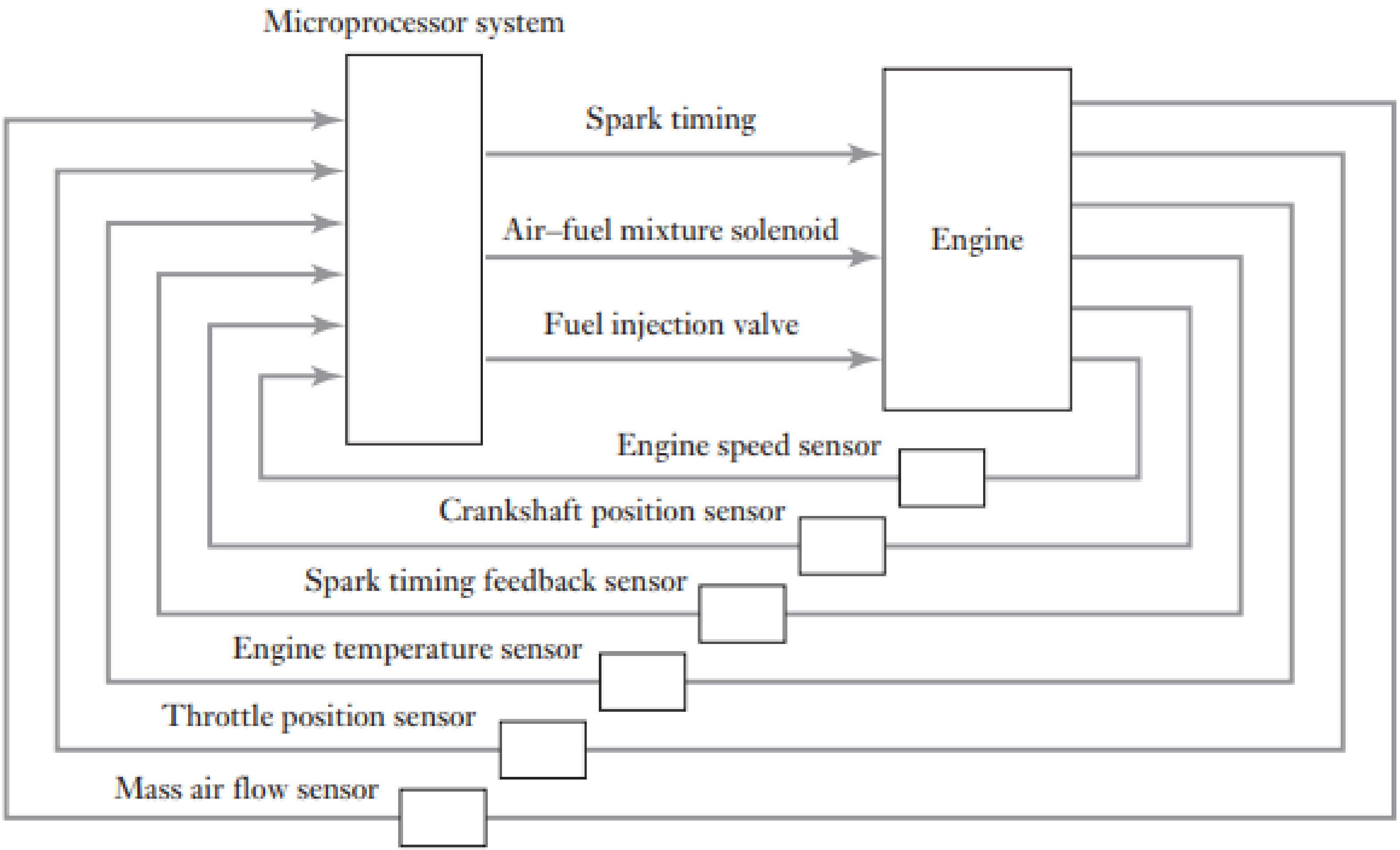


Figure 1.22 Elements of an engine management system.

Mechatronics Applications- Automotive

Second Example: Camless Engines

Cams replaced by actuators and embedded controls

What is the advantage?

Mechatronics Applications- Robotics

The Robot is, of course, the ultimate Mechatronic System

Sense

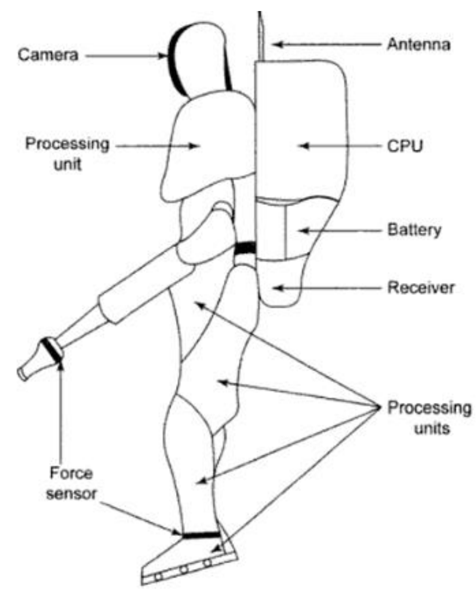
- Retrieve data from sensors
- Apply sensor fusion
- Process images

Think

- Execute navigation & mission planning algorithms
- Implement advanced control loops
- Control a robotic arm

Act

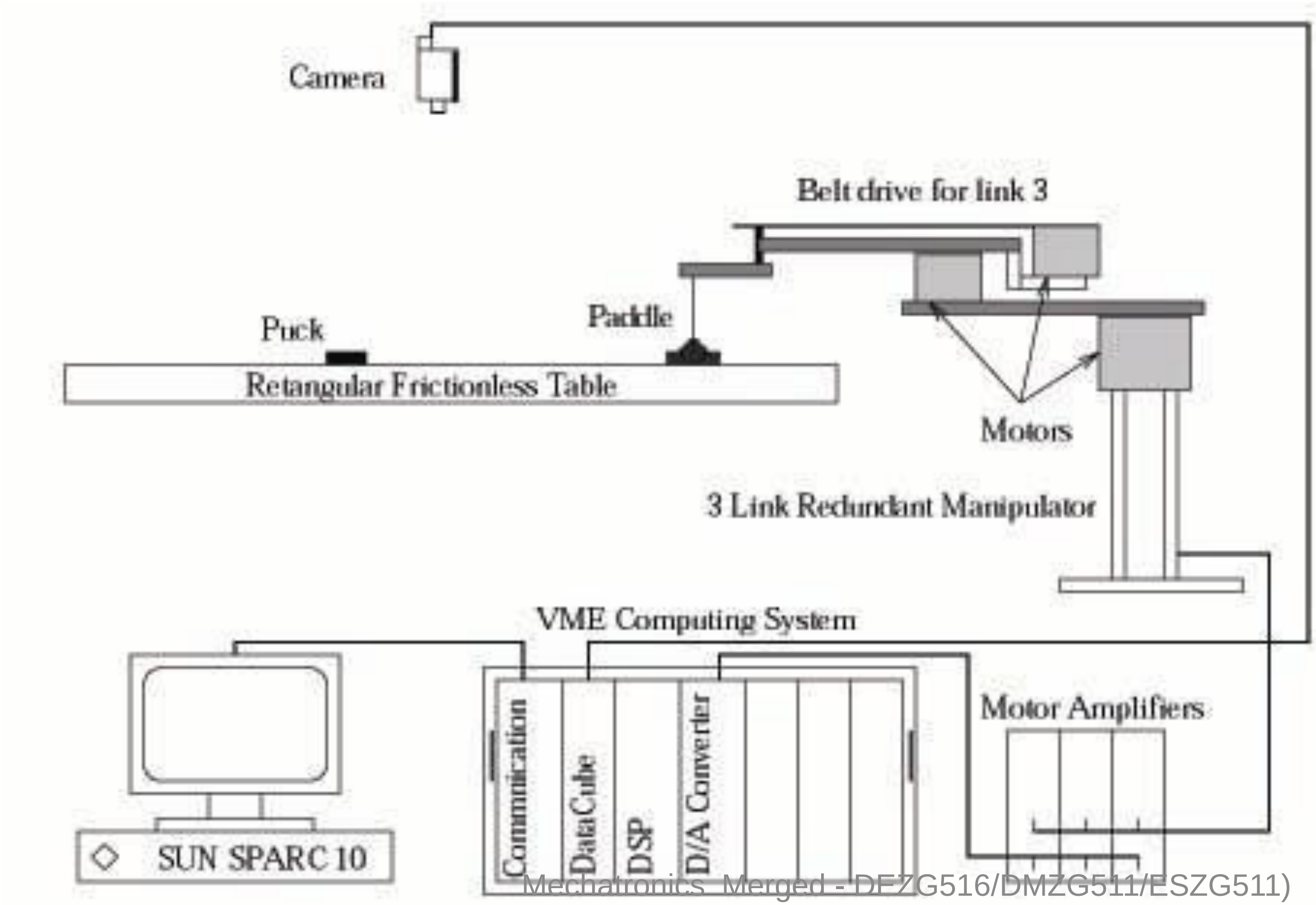
- Connect to motors
- Calculate wheel states
- Simulation
- Deployment to Embedded Hardware



Mechatronics Applications- Robotics

The CSL Air Hockey Playing Robot

•Combines Intelligence Control, Real-Time Vision Sensing and Vision Processing, and Machine Learning



Examples are Everywhere Smart Skis

Temperature Measurement system

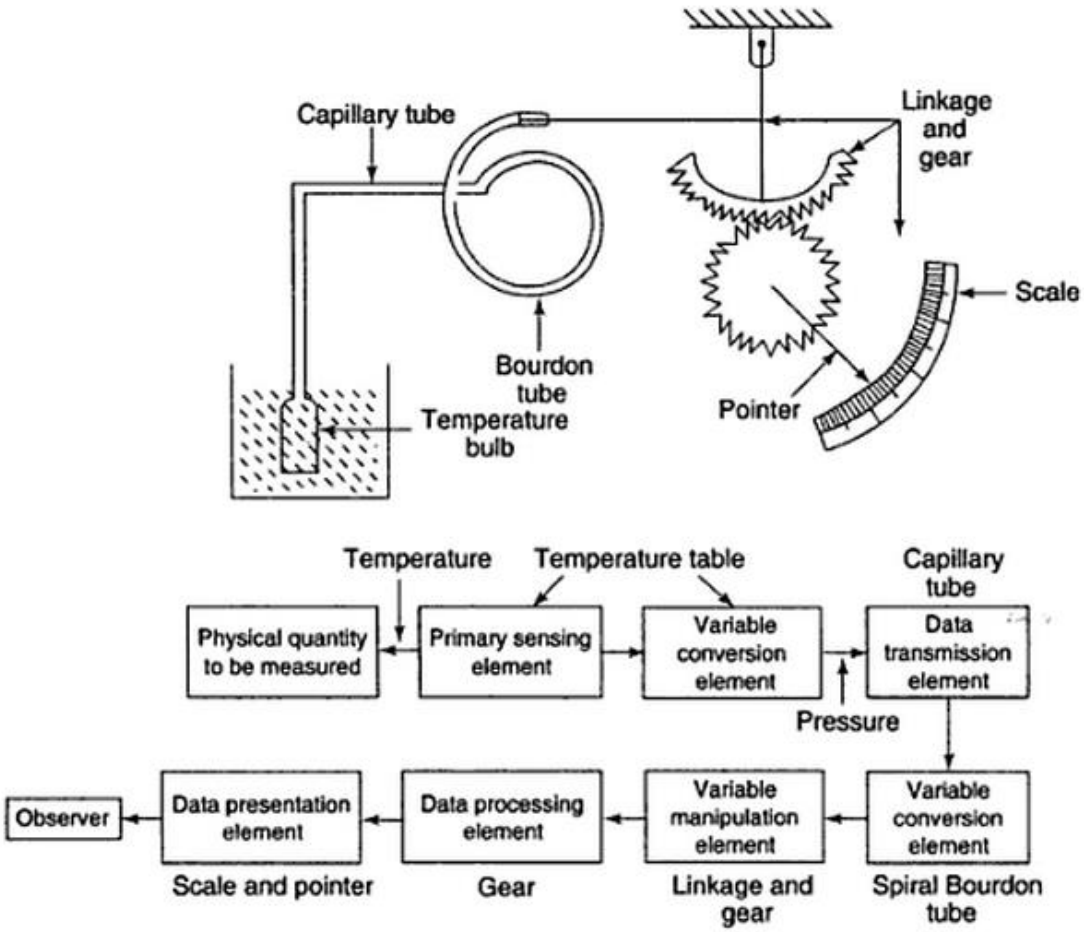


Figure 1.13 | Measurement system of a filled thermal system.

1. primary sensing element;
2. variable conversion element;
3. variable manipulation element;
4. data transmission element;
5. data processing element;
6. data presentation element.

Assignment 1A

1. State steps that might be present in the sequential control of a dishwasher.
2. Compare and contrast the traditional design of a watch with that of the mechatronics-designed product involving a microprocessor.

Session 2 … next week

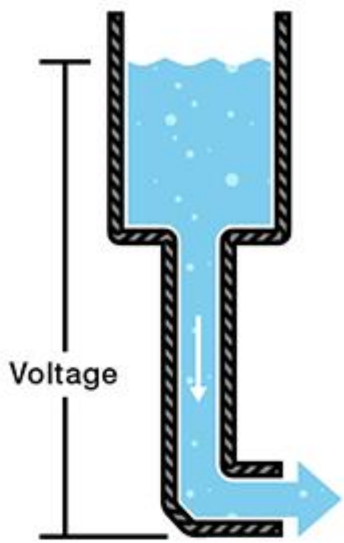
Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	Sensor and Transducers: Definition and performance terminology, Static and dynamic characteristics Sensing physical quantities: Displacement, position and proximity	T1: Chapter 2, T2: Chapter 9
Post CH			Chapter end problems

Thank you

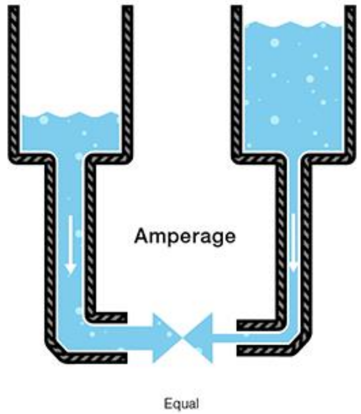
Recap of Fundamentals

(Pre reading material)

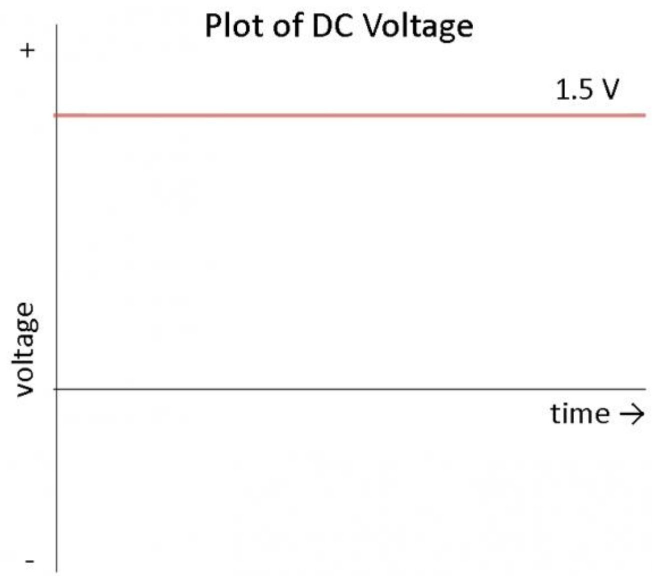
Voltage / Current

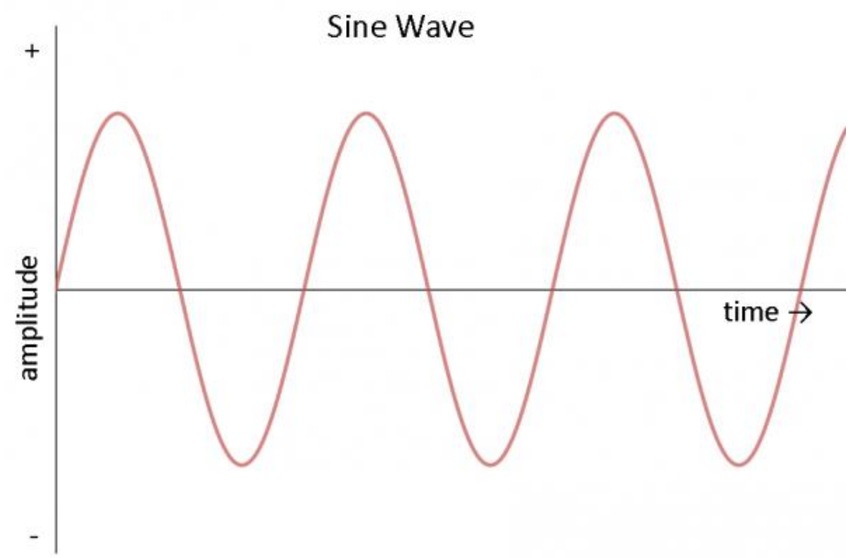


- Water = Charge
- Pressure = Voltage
- Flow = Current (Charge per unit time)



Voltage / Current





AC Voltage

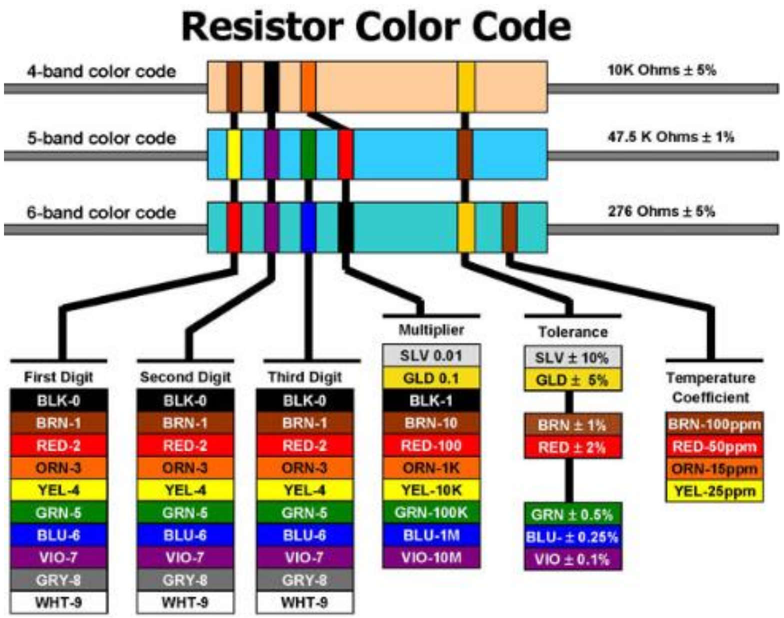
Resistance

A **resistor** is a dissipative element that converts electrical energy into heat. **Ohm's law** defines the voltage-current characteristic of an ideal resistor:

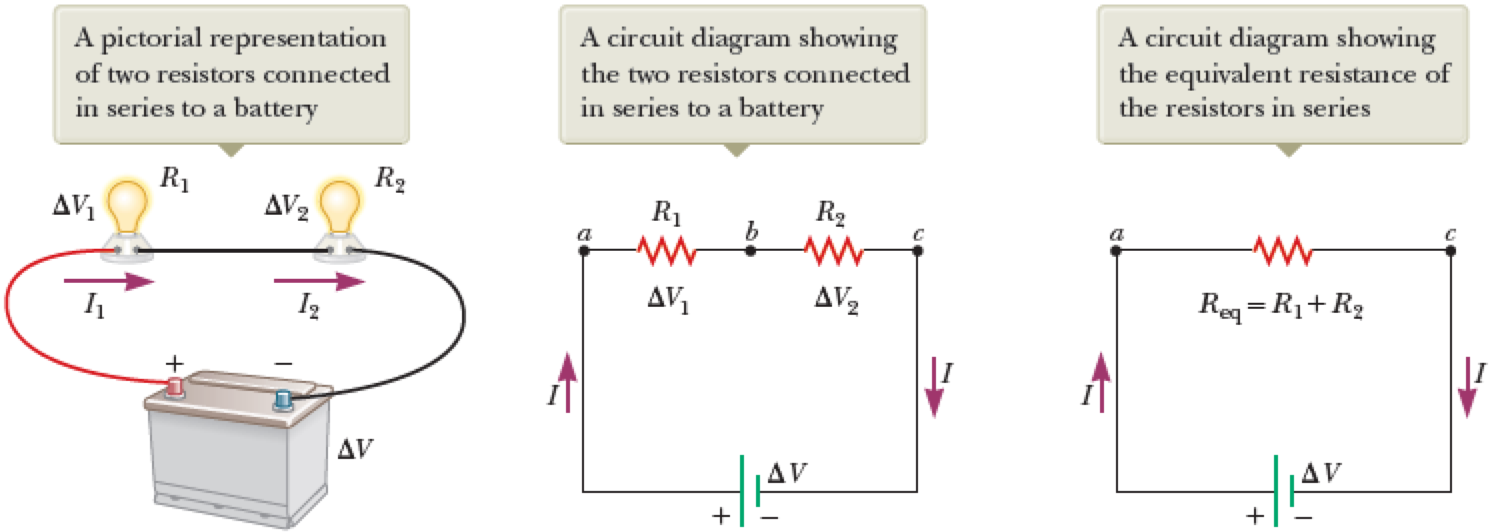
$$V = IR$$

$$R = \frac{\rho L}{A}$$

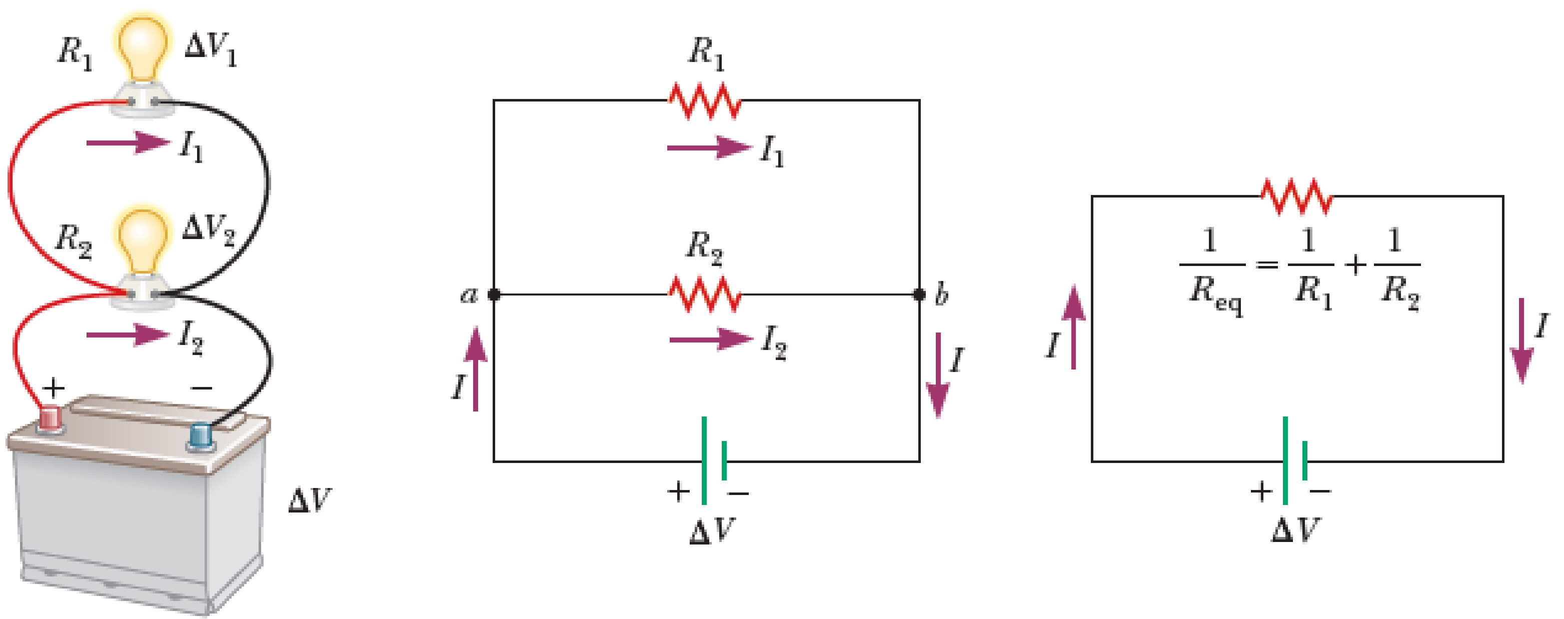
Color	Digit	Multiplier	Tolerance (%)
Black	0	10^0 (1)	
Brown	1	10^1	1
Red	2	10^2	2
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	0.5
Blue	6	10^6	0.25
Violet	7	10^7	0.1
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
(none)			20



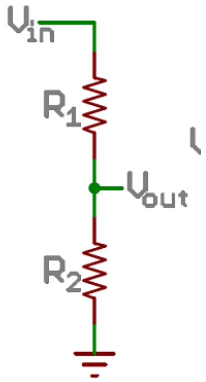
Resistances in Series

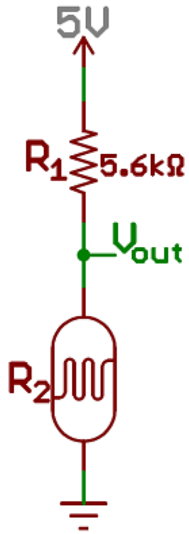


Resistances in Parallel



Voltage divider circuit

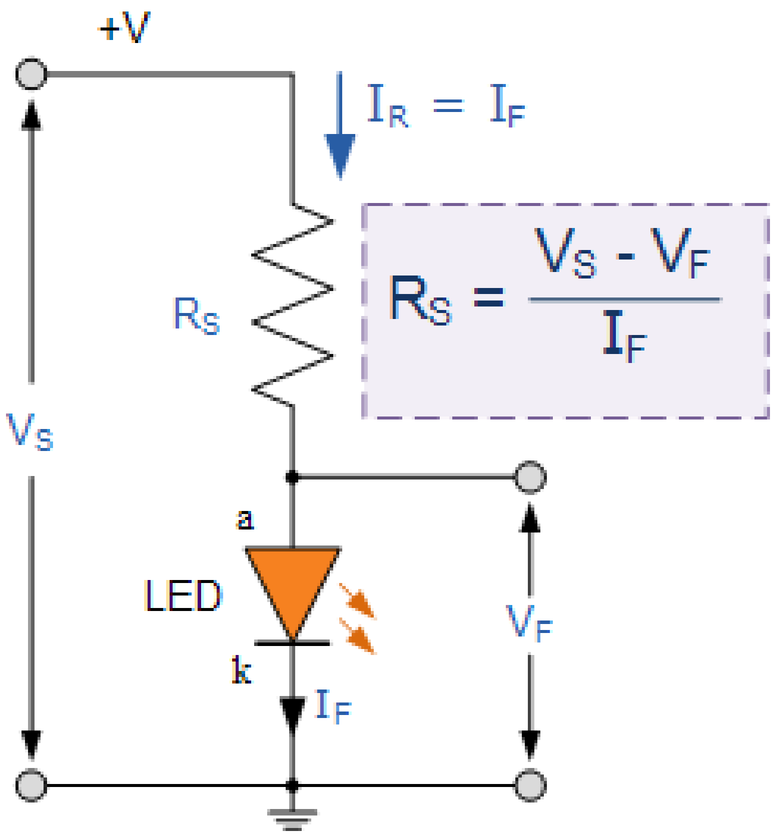




$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

Light Level	R_2 (Sensor)	R_1 (Fixed)	Ratio $R_2/(R_1+R_2)$	V_{out}
Light	1kΩ	5.6kΩ	0.15	0.76 V
Dim	7kΩ	5.6kΩ	0.56	2.78 V
Dark	10kΩ	5.6kΩ	0.67	3.21 V

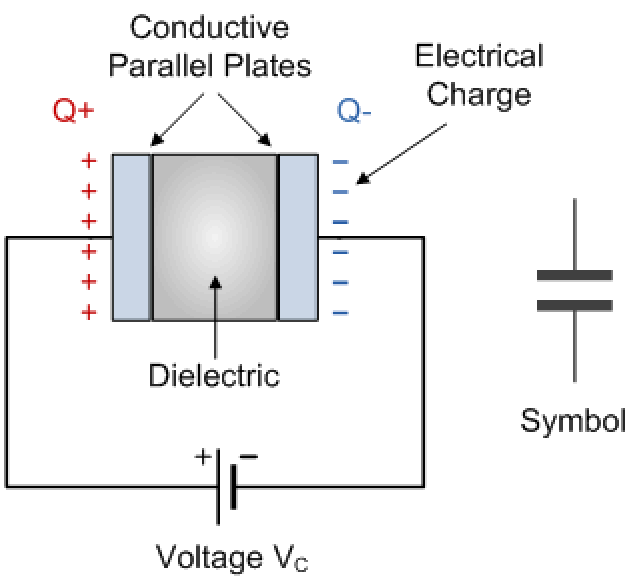
Voltage divider circuit

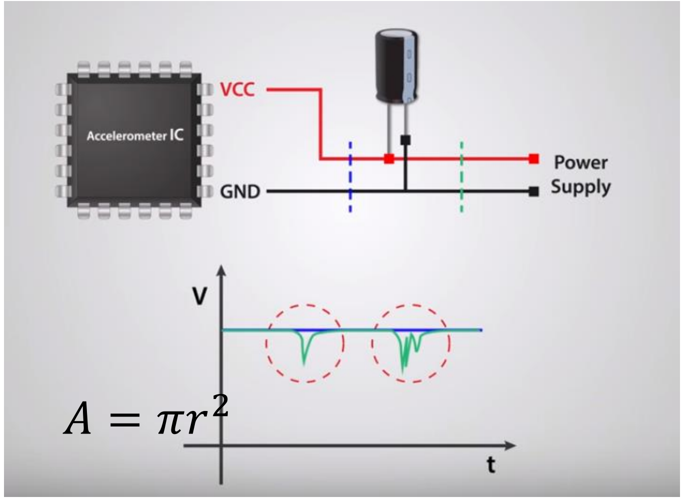


An amber coloured LED with a forward volt drop of 2 volts is to be connected to a 5.0v stabilised DC power supply. Using the circuit calculate the value of the series resistor required to limit the forward current to less than 10mA

$$R_S = \frac{V_S - V_F}{I_F} = \frac{5v - 2v}{10mA} = \frac{3}{10 \times 10^{-3}} = 300\Omega$$

Capacitor





$$C = \frac{Q}{V}$$

Q= C x V

C = Q/V

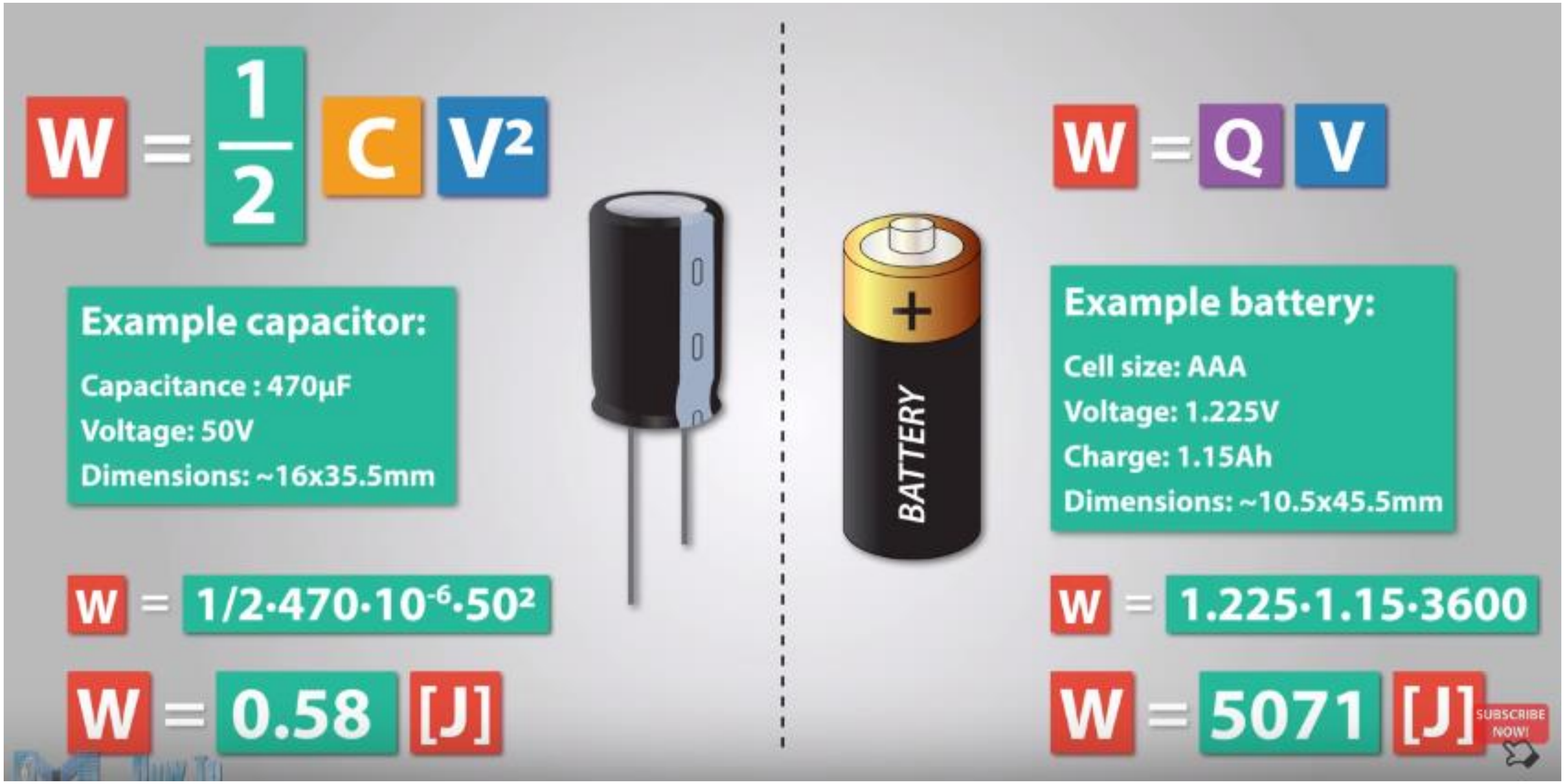
$\frac{dQ}{dt}$ = C x dv/dt

C is Capacitance in Farad
Q is charge in Columb
V - Volts

$$I(t) = C\,\frac{dV}{dt}$$

$$W = \left(\frac{1}{2}\right) * C * V^2$$

Capacitor



W = 1/2 C V²
Example capacitor:
Capacitance : 470µF
Voltage: 50V
Dimensions: ~16x35.5mm
W = 1/2·470·10⁻⁶·50²
W = 0.58 [J]
BATTERY
W = Q V
Example battery:
Cell size: AAA
Voltage: 1.225V
Charge: 1.15Ah
Dimensions: ~10.5x45.5mm
W = 1.225·1.15·3600
W = 5071 [J]
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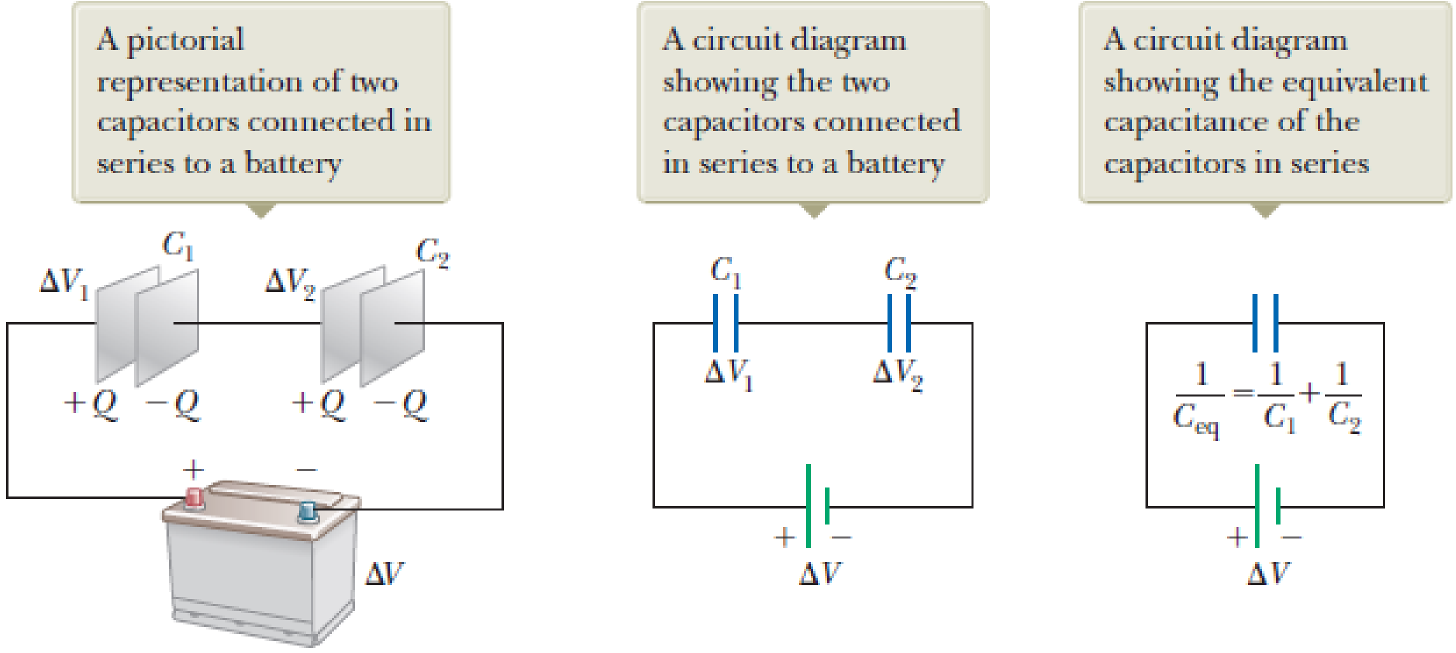
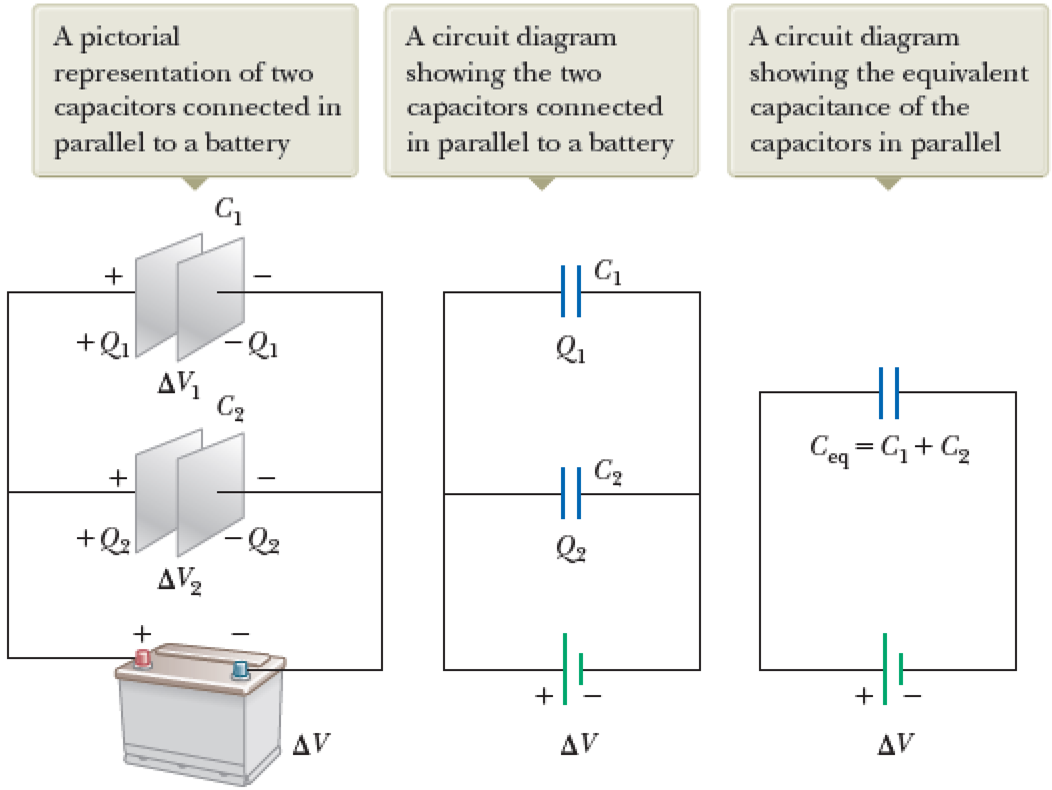
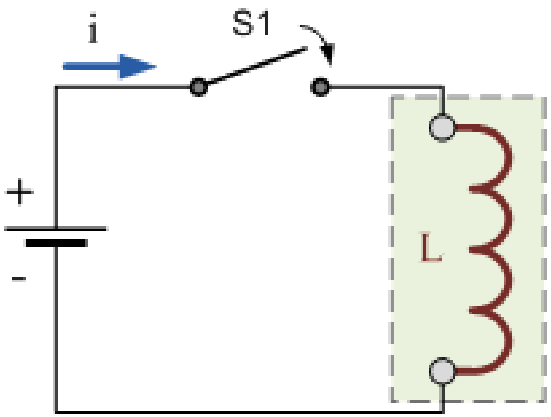
Capacitors in Series



Capacitors in Parallel



Inductors



Used as filters, motors, transformers etc,

An inductor opposes the rate of change of current flowing through it due to the build up of self-induced energy within its magnetic field.

$$V_L(t) = \frac{d\phi}{dt} = \frac{dLi}{dt} = -L\frac{di}{dt}$$

Φ- Magnetic flux (Weber)

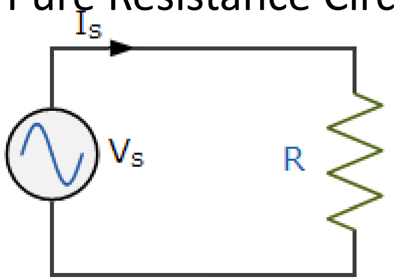
L – Inductance (Henry)

i- Ampere

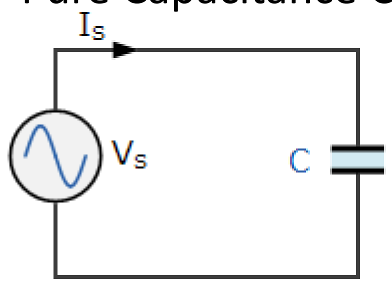
V - Voltage

Circuits

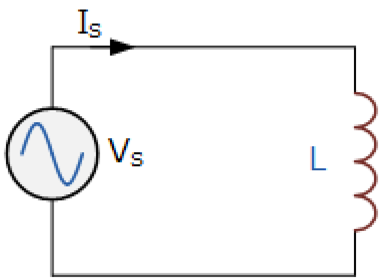
Pure Resistance Circuit



Pure Capacitance Circuit



Pure Inductive Circuit



$$Z = \frac{V_R}{I_R} = R$$

$$X_C = \frac{V_C}{I_C} = \frac{1}{2\pi f C}$$

$$X_L = \frac{V_L}{I_L} = 2\pi f L$$

$$I_S = \frac{V_S}{R}$$

$$I_S = \frac{V_S}{X_C}$$

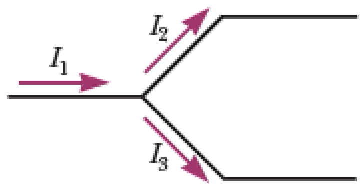
$$I_S = \frac{V_S}{X_L}$$

Unlike Resistor which just impedes the current (Constant Ohms), Capacitor and inductor impede currents (Variable ohms) based on frequency of power supply

Kirchoff's Law

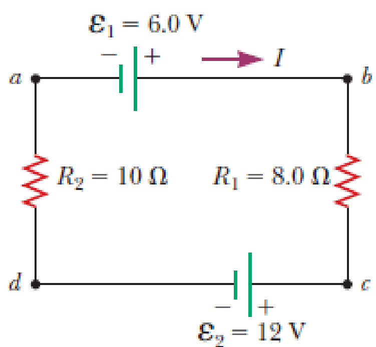
1. Junction rule. At any junction, the sum of the currents must equal zero:

$$\sum_{\text{junction}} I = 0 \qquad \textbf{(28.9)}$$



2. Loop rule. The sum of the potential differences across all elements around any closed circuit loop must be zero:

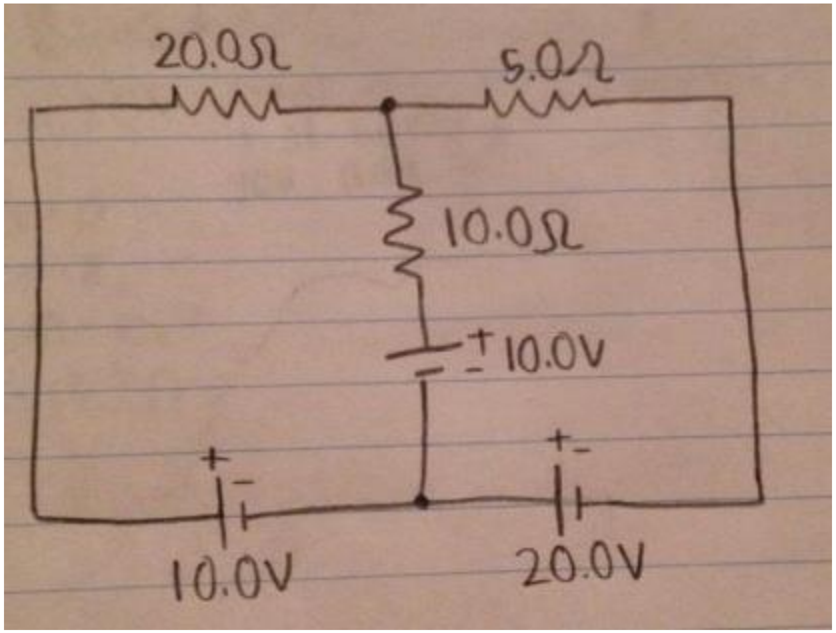
$$\sum_{\text{closed loop}} \Delta V = 0 \qquad \textbf{(28.10)}$$

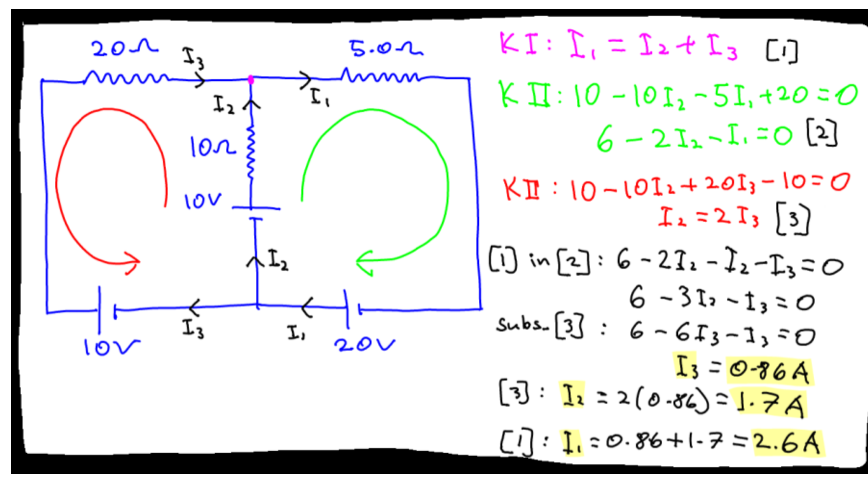


$$\sum \Delta V = 0 \ \rightarrow\ \mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0$$

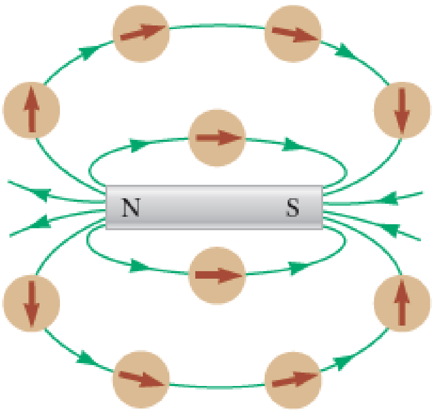
$$(1)\quad I = \frac{\mathcal{E}_1 - \mathcal{E}_2}{R_1 + R_2} = \frac{6.0\ \text{V} - 12\ \text{V}}{8.0\ \Omega + 10\ \Omega} = \boxed{-0.33\ \text{A}}$$

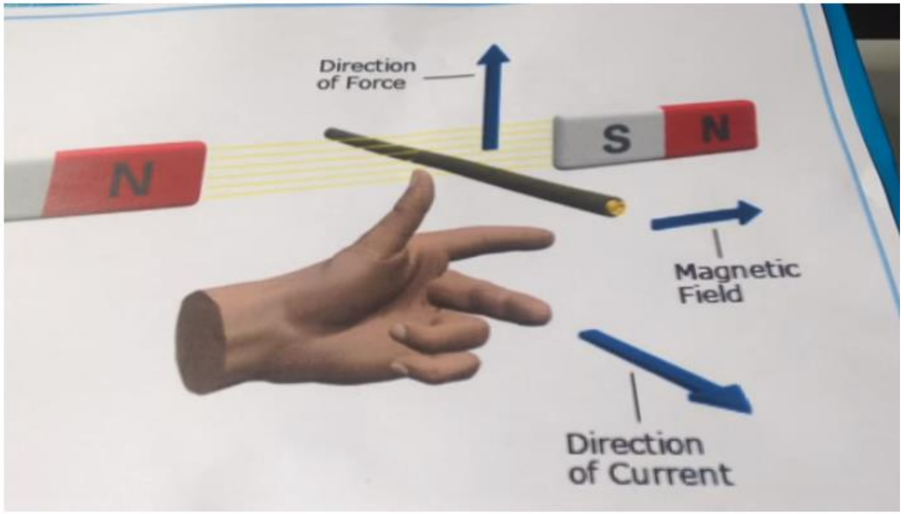
Kirchoff's Law



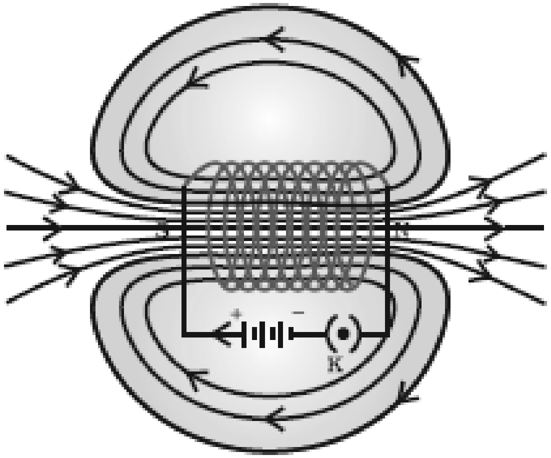


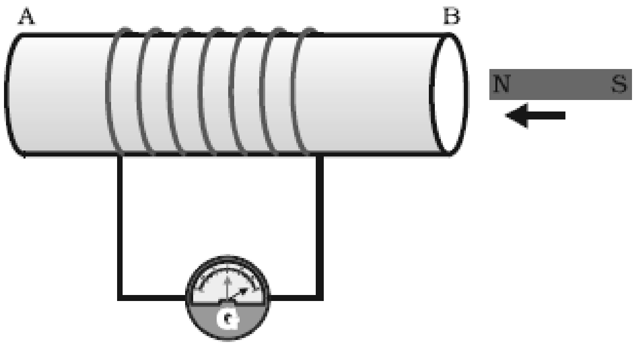
Magnetic field



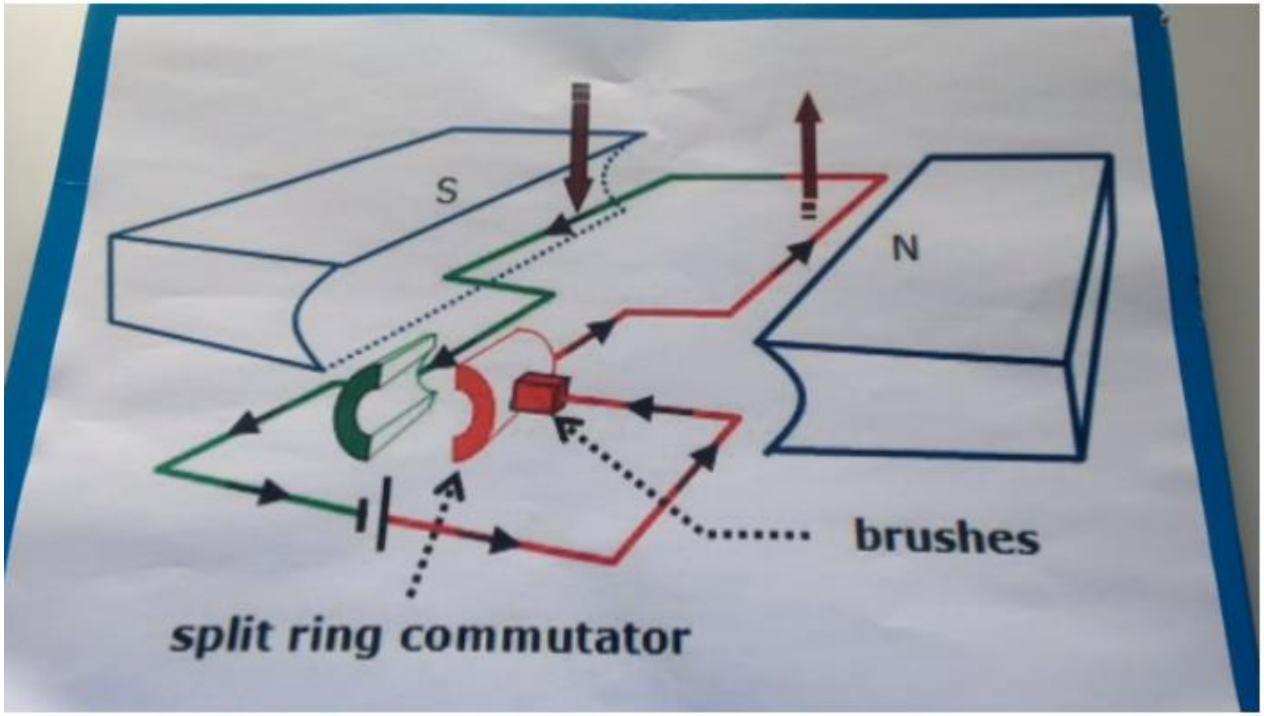


Magnetic field

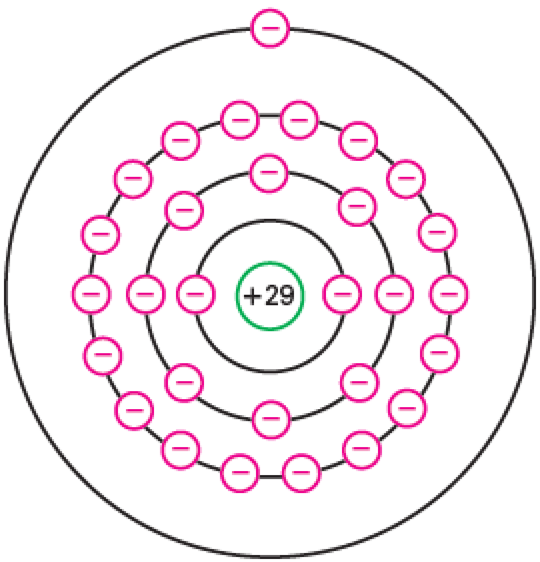




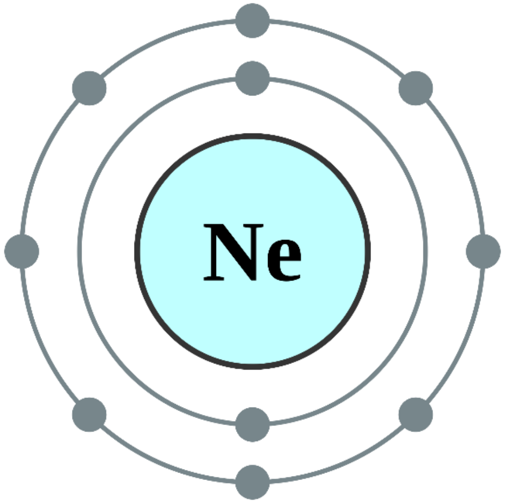
DC motor



Conductor / Insulator



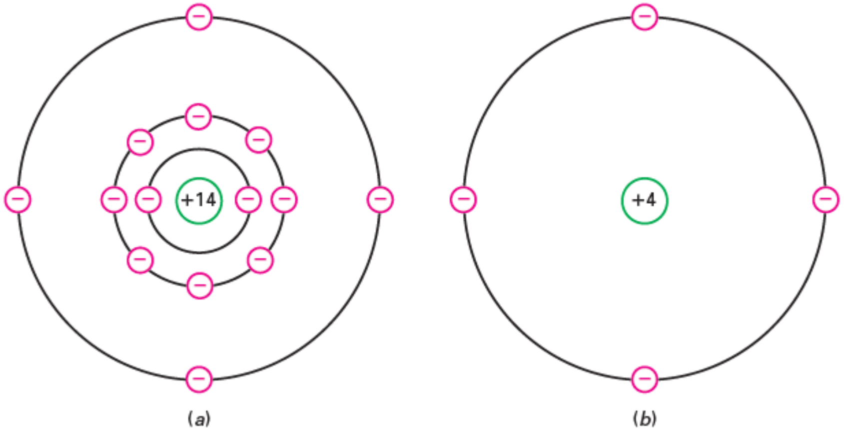
Copper atom, Good conductor – One electron in outer most orbit



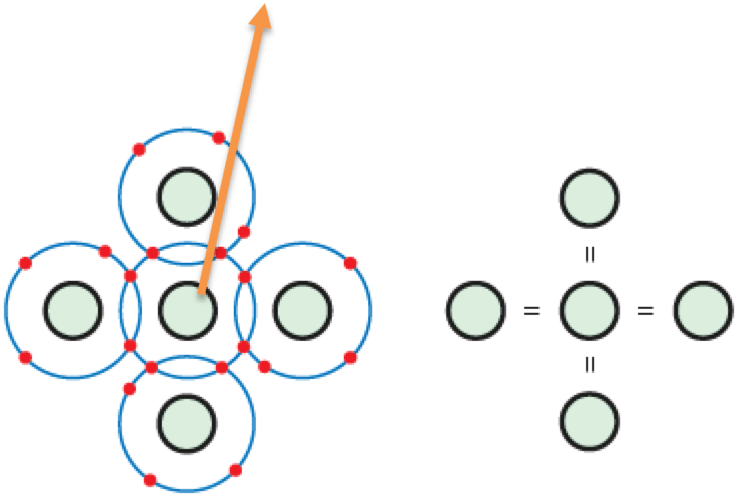
Neon atom, Poor conductor – Eight electrons in outer most orbit

Semi conductor

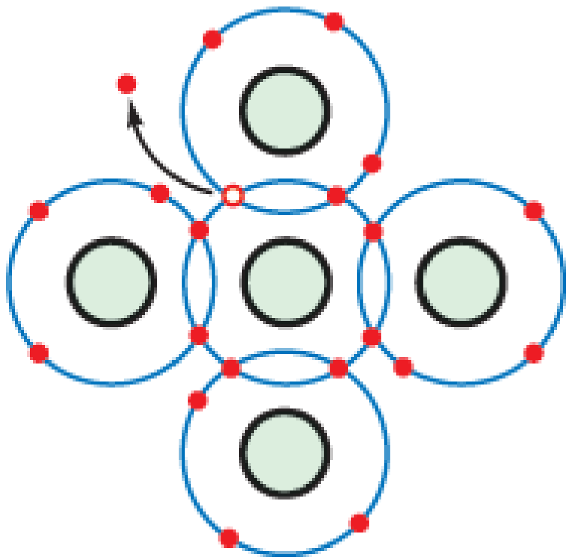
Figure 2-3 (a) Silicon atom; (b) core diagram.

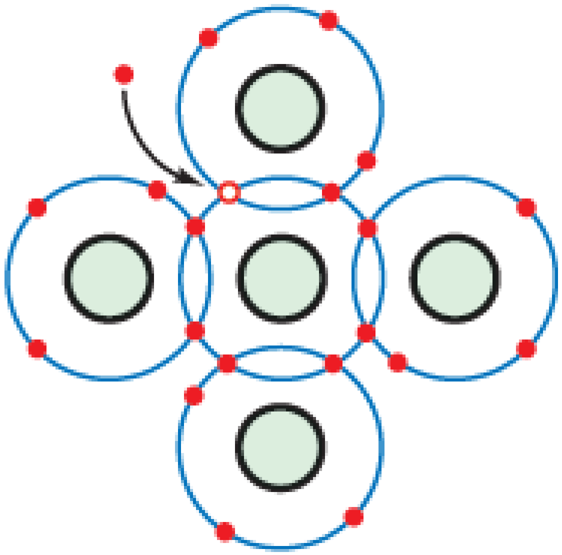


Silicon Atom in the center surrounded by other 4 silicon atoms sharing one electron with center atom



Semi conductor

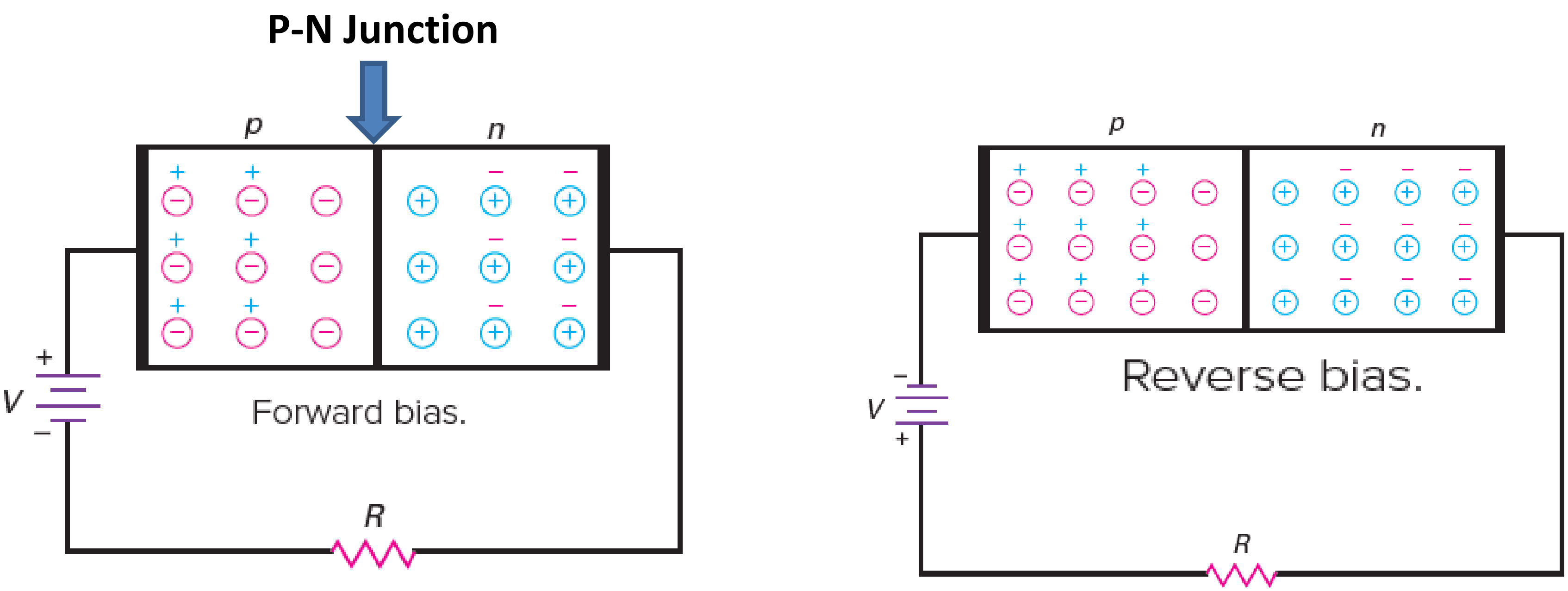




At room temperatures, valence electrons leave the orbit and their absence is marked by “ holes” (Positive charge)

Free Holes – Positively charged
Free Electrons – Negatively Charged

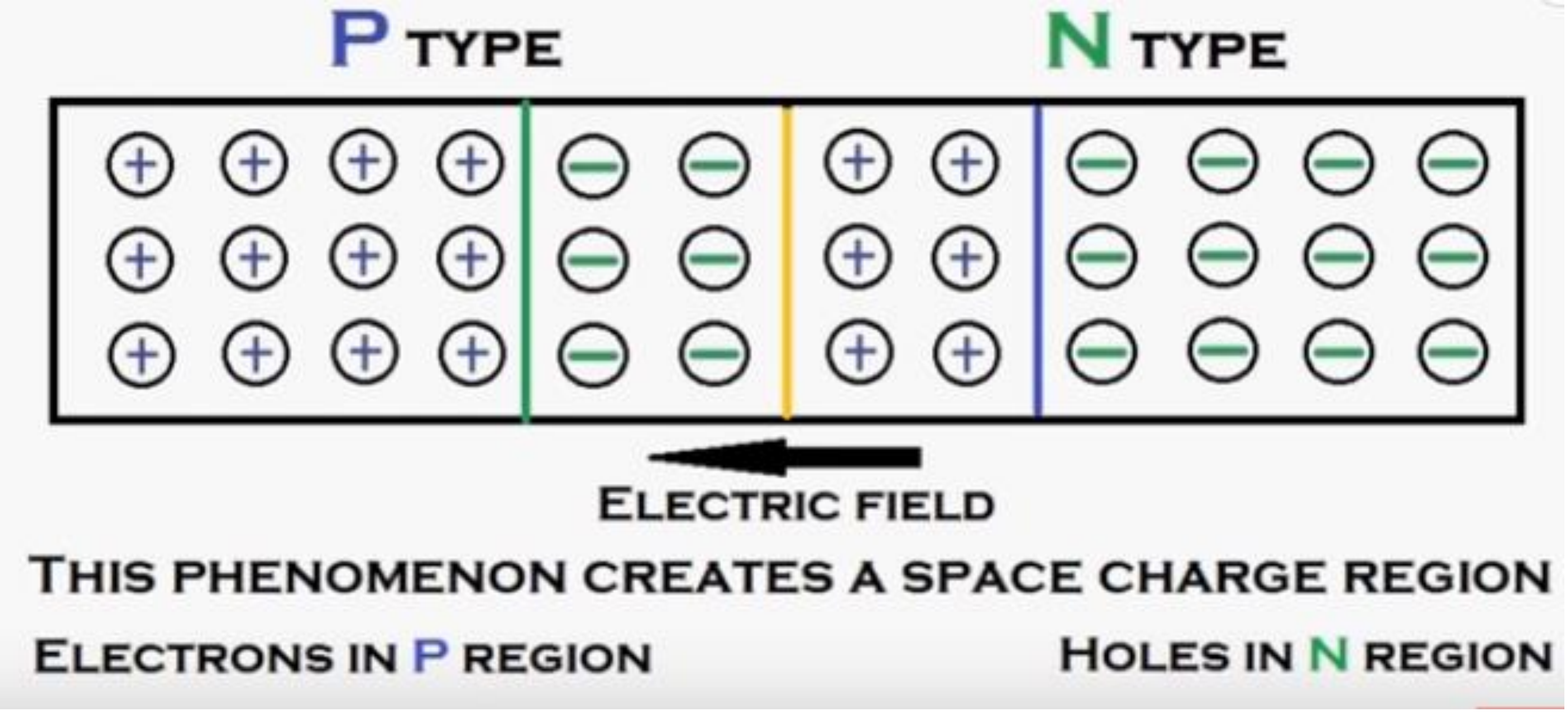
P-N Junction



Free Holes – Positively charged
Free Electrons – Negatively Charged

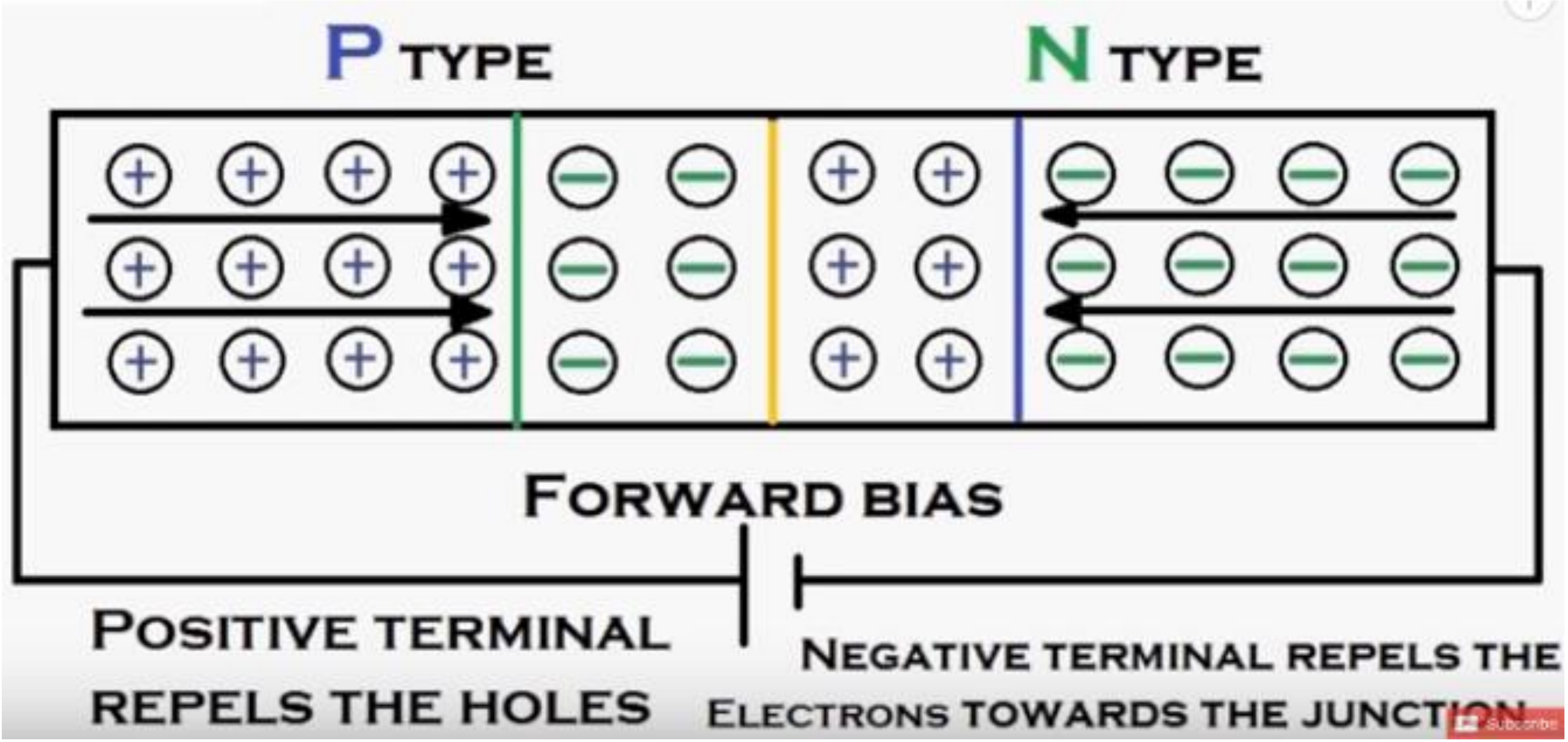
Attracts each other and creates space charge region

P-N Junction



P TYPE
N TYPE
ELECTRIC FIELD
THIS PHENOMENON CREATES A SPACE CHARGE REGION
ELECTRONS IN P REGION
HOLES IN N REGION

P-N Junction



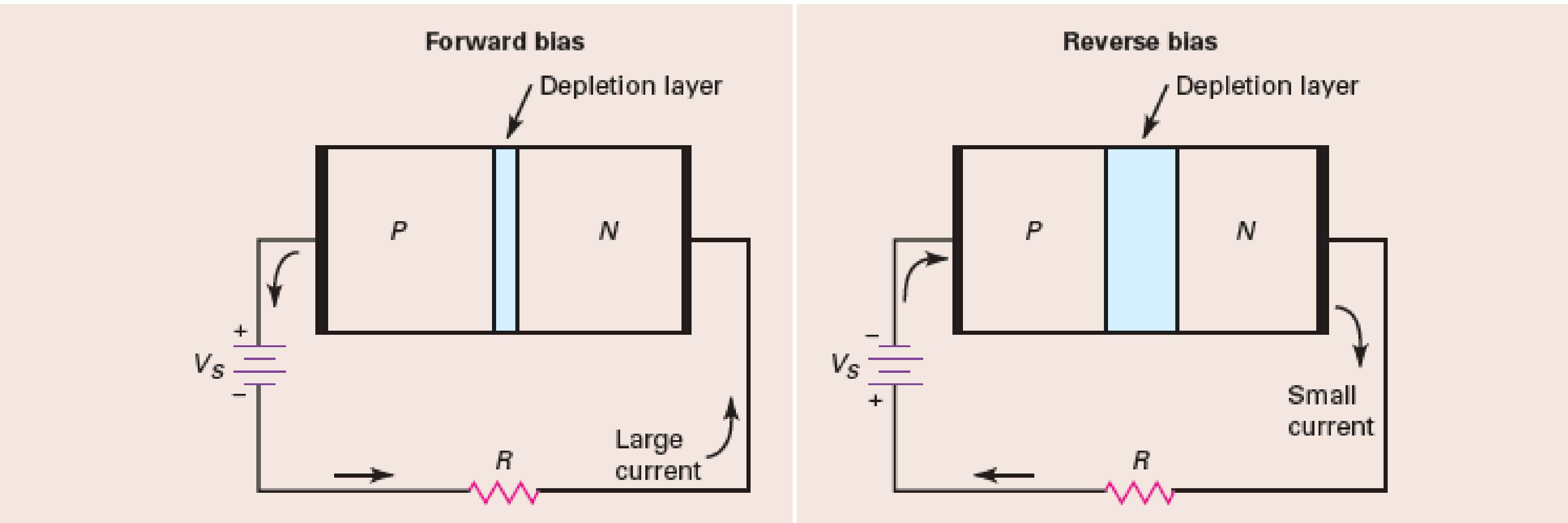
P TYPE
N TYPE
FORWARD BIAS
POSITIVE TERMINAL
REPELS THE HOLES
NEGATIVE TERMINAL REPELS THE
ELECTRONS TOWARDS THE JUNCTION

P-N Junction

P - Free Holes – Positively charged

N - Free Electrons – Negatively Charged

Attracts each other and creates Depletion space charge region

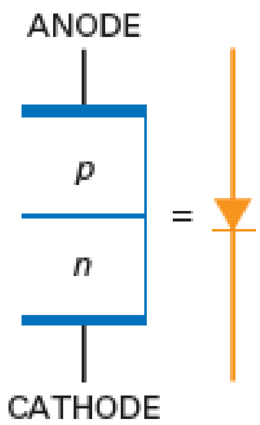


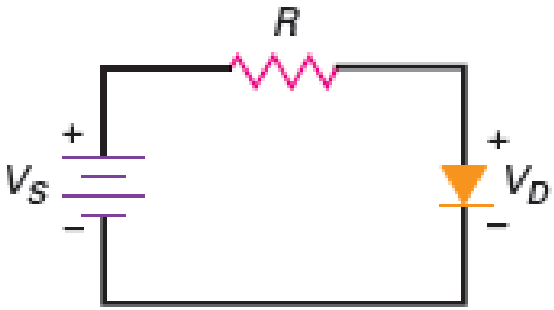
	Forward bias	Reverse bias
V_s polarity	(+) to *P* material (−) to *N* material	(−) to *P* materials (+) to *N* material
Current flow	Large forward current if $V_s > 0.7$ V	Small reverse current (saturation current and surface leakage current) if $V_s <$ breakdown voltage
Depletion layer	Narrow	Wide

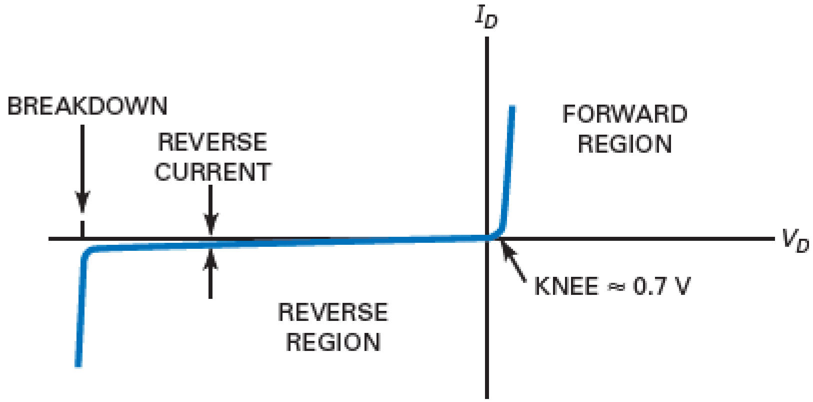
In reverse Bias –ve battery terminal attracts P and vice versa

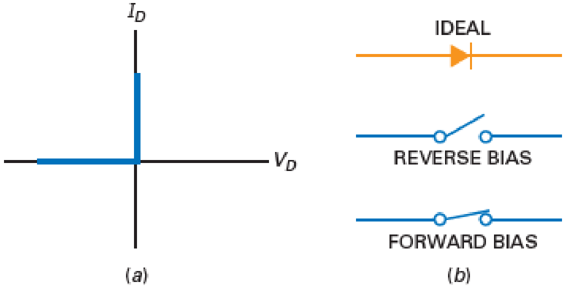
This increases Depletion space charge region

Diodes – (Electronic check valve) Unidirectional Current flow

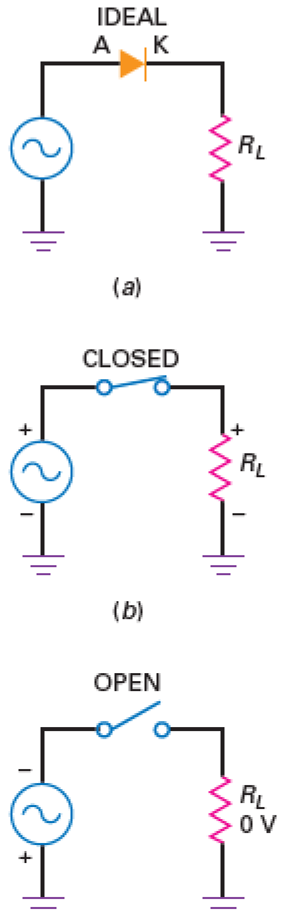


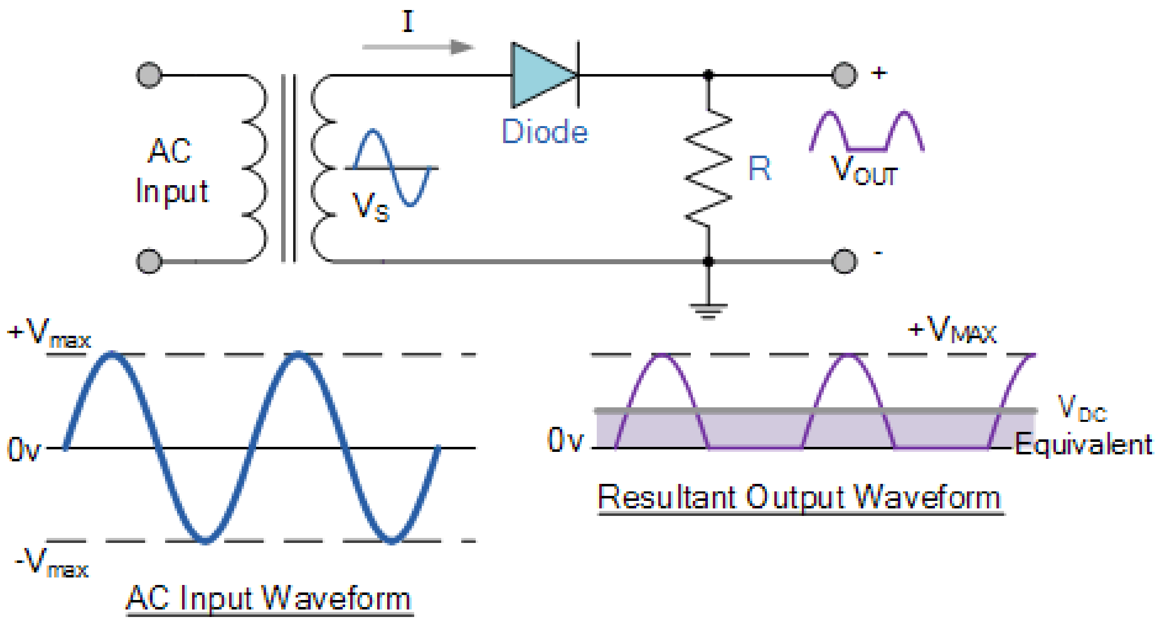






Diodes


IDEAL
A
K
R_L
(a)
CLOSED
+
−
+
R_L
−
(b)
OPEN
−
+
R_L
0 V

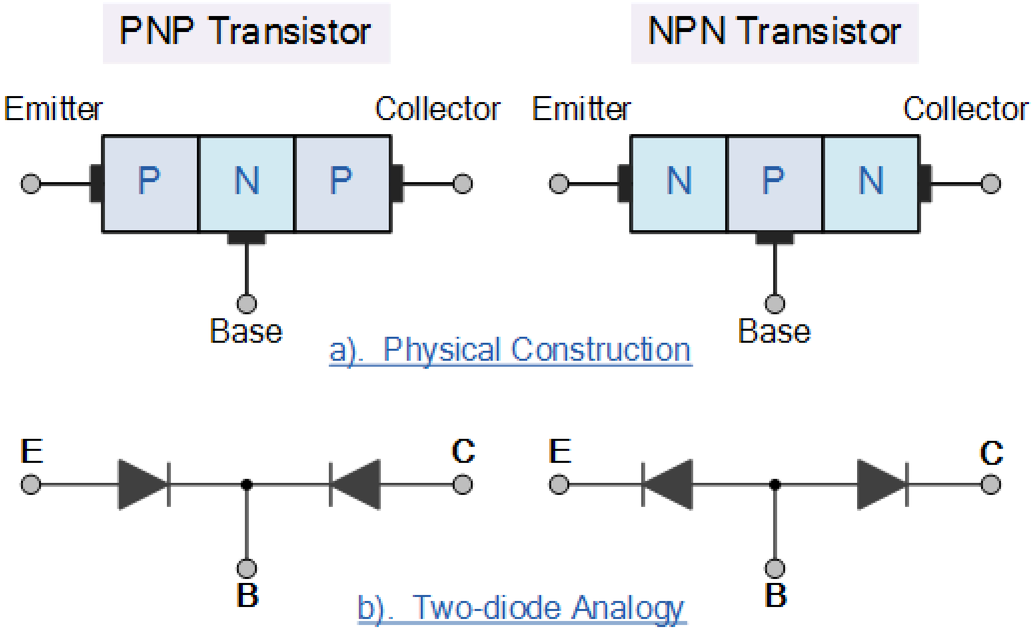

I
AC
Input
Vs
Diode
R
+
-
VOUT
+Vmax
0v
-Vmax
AC Input Waveform
+VMAX
0v
VDC
Equivalent
Resultant Output Waveform

Transistors (BJTs) – Bipolar Junction transistors

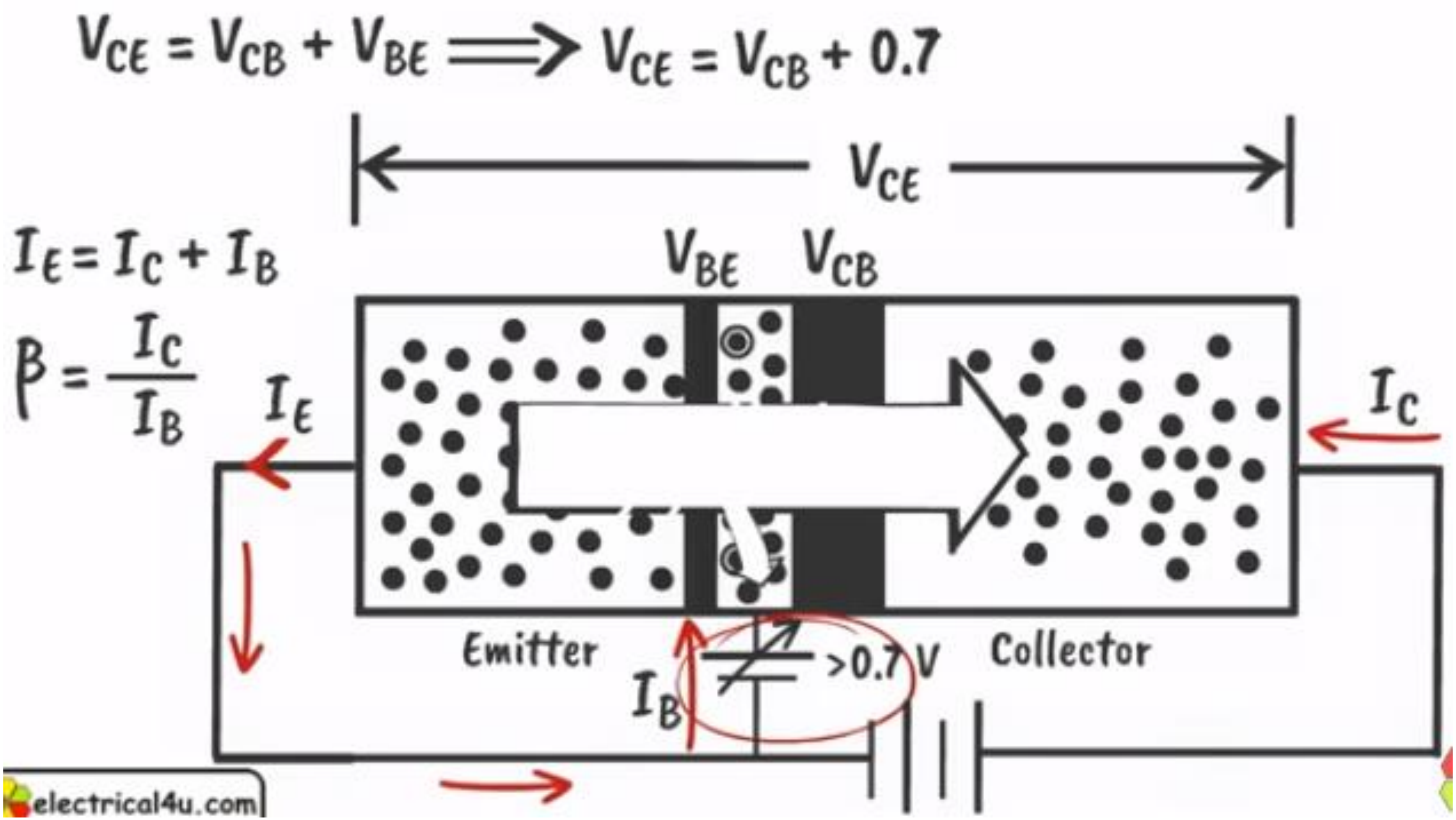
- The emitter is heavily doped.
- The base is lightly doped.
- The doping level of the collector is intermediate, between the heavy doping of the emitter and the light doping of the base.

Why called as Bipolar?

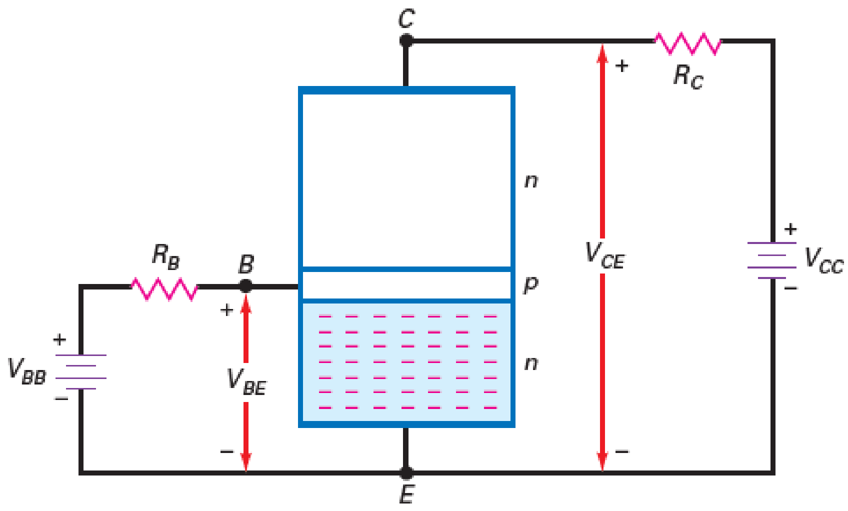
Operation depends on Free Electrons and Holes

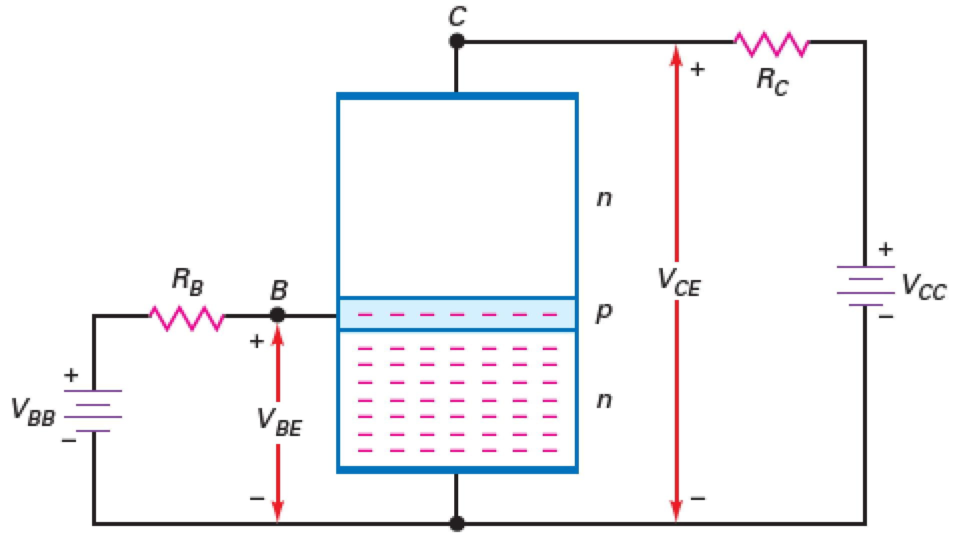


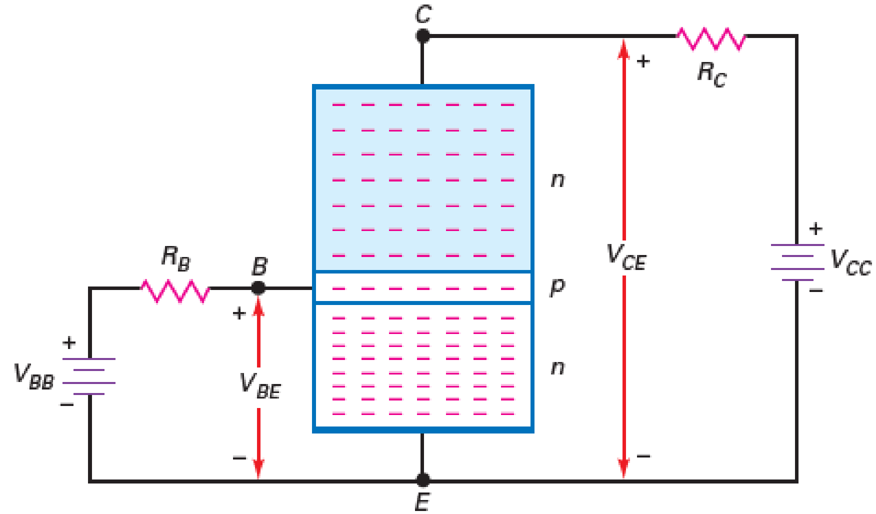
Transistors (BJTs) – Bipolar Junction transistors



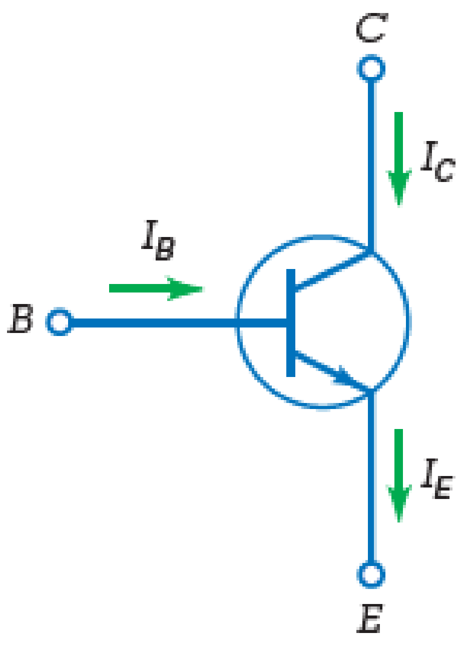
Transistors



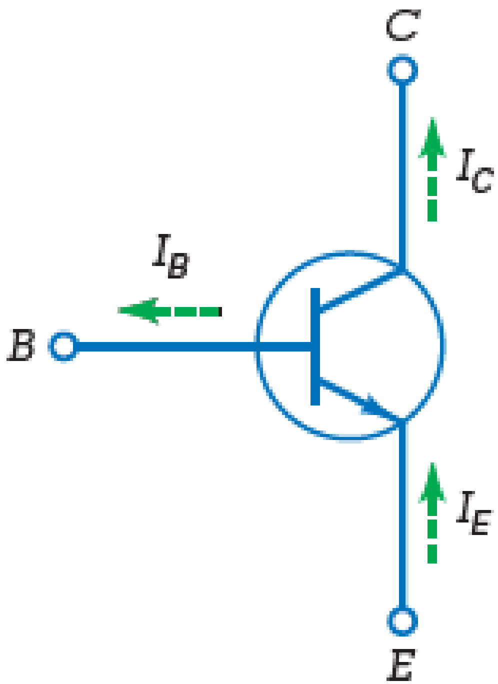




Transistors



Conventional Current



Electron Flow

$$I_E = I_C + I_B$$

$$I_C \approx I_E$$

$$\alpha_{dc} = \frac{I_C}{I_E}$$

$$\boxed{\beta_{dc} = \frac{I_C}{I_B}}$$

β_{dc} is the current gain of the transistor – A small base current controls much larger collector current

Thank you