

**IPE 301**

**Instrumentation and Control**

**Chapter 2**

***Instrumentation System Elements***

# Introduction

- **Sensor:** Produces a signal relating to the quantity being measured
- **Signal Processor:** Takes the output from the sensor and converts it into a form which is suitable for data presentation
- **Data Presentation:** The data is displayed, recorded or transmitted to some control system

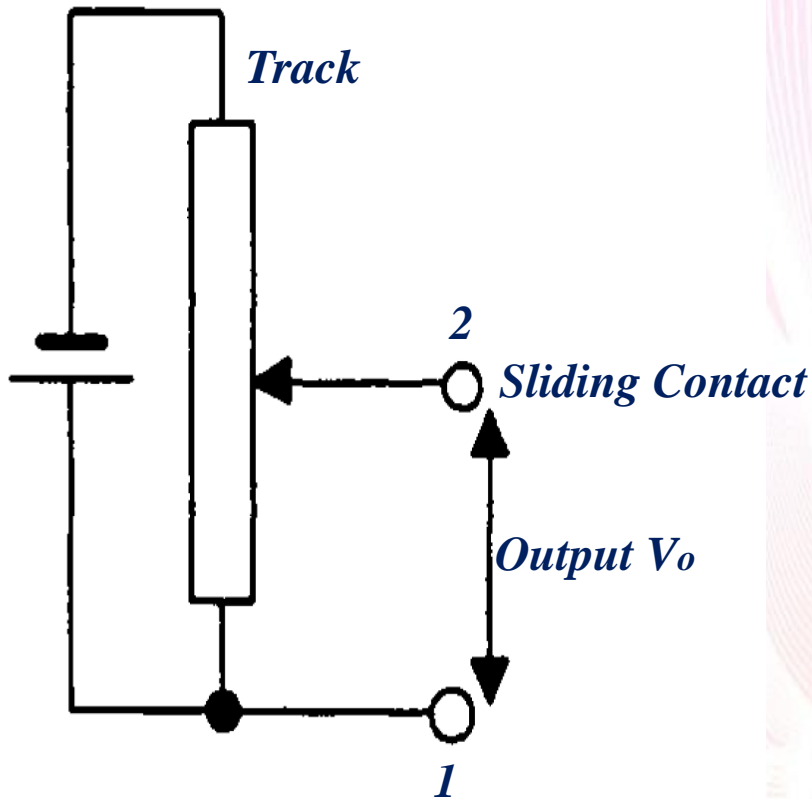
# Displacement Sensors

## Uses:

- Measure a linear displacement
- Measure an angular displacement
- Detect motion (within the ‘view’ of the sensor)
- Detect the presence of some object (also called ‘proximity sensors’)

# Displacement Sensors

## Potentiometer:



$$\frac{V_o}{V_s} = \frac{R_{1,2}}{R}$$

$V_o$  = Output Voltage

$V_s$  = Supply Voltage

$R_{1,2}$  = Resistance between terminal 1 and 2

$R$  = Total resistance

**Tracks can be:**

- ✓ Wire wound track
- ✓ Plastic track
- ✓ Cermet track

# Displacement Sensors

## Strain Gauge:

$$\frac{\Delta R}{R} = G \varepsilon$$

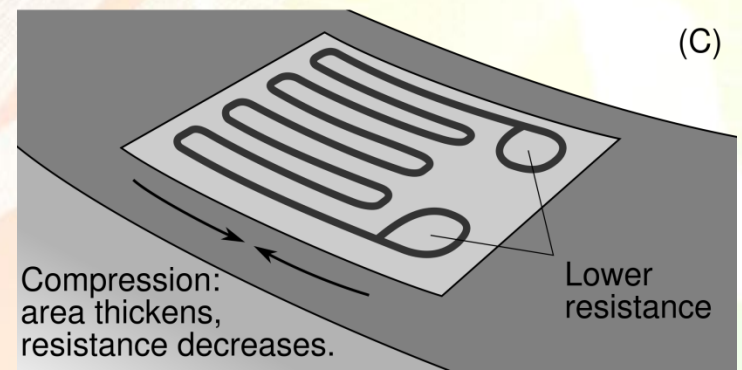
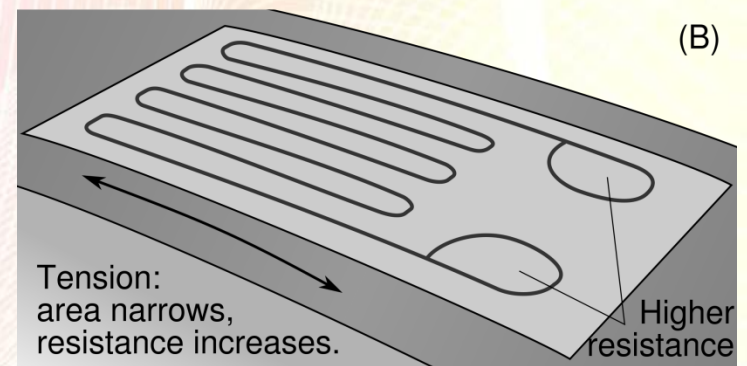
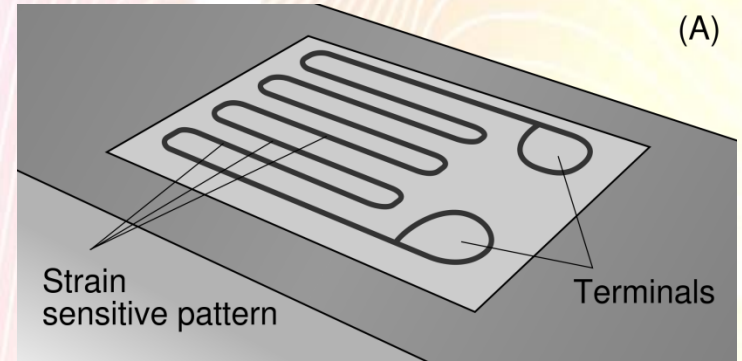
$\Delta R$  = Change in resistance due to strain

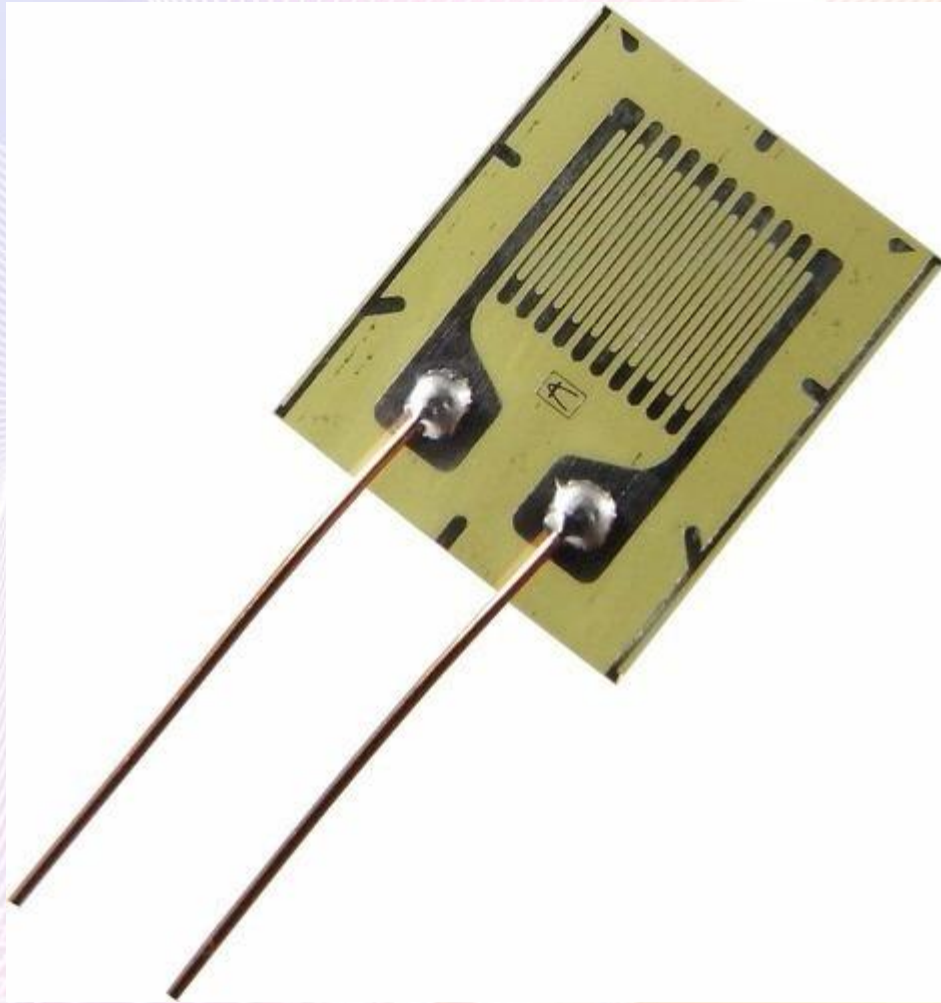
$R$  = Original resistance

$G$  = Gauge factor

$\varepsilon$  = Strain (mm/ mm)

❖ A displacement sensor might be constructed by attaching strain gauges to a cantilever, the free end of the cantilever being moved as a result of the linear displacement being monitored.





# Displacement Sensors

## Capacitive Element:

$$C = \frac{\epsilon_r \epsilon_0 A}{d}$$

$\epsilon_r$  = the relative permittivity of the dielectric between the plate

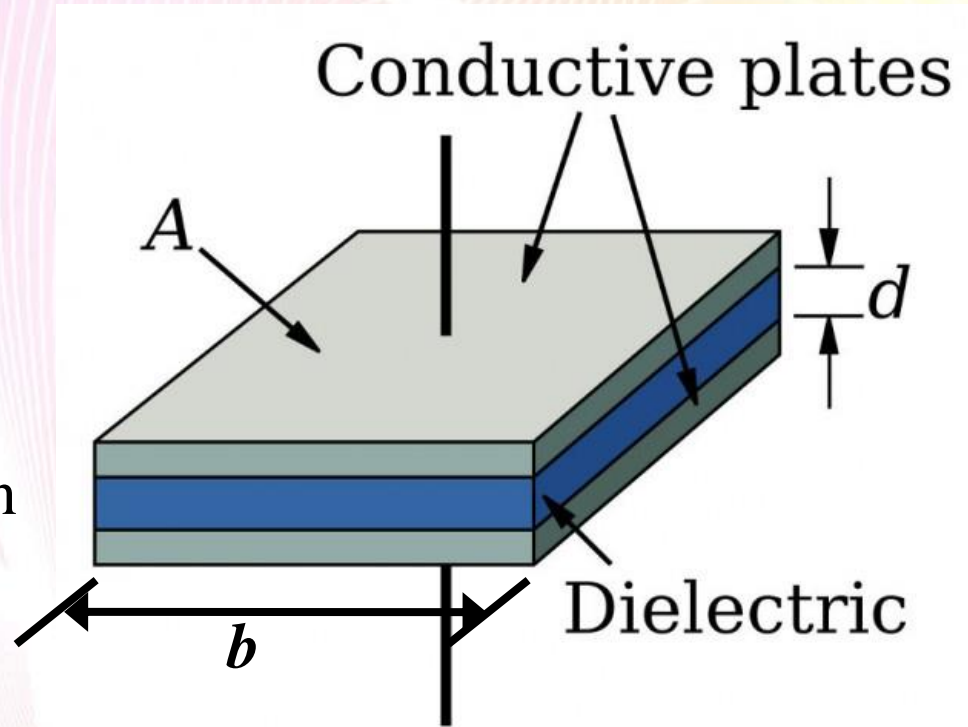
$\epsilon_0$  = permittivity of free space

$A$  = the area of overlap between the two plates

$d$  = the plate separation

$b$  = the width of plate

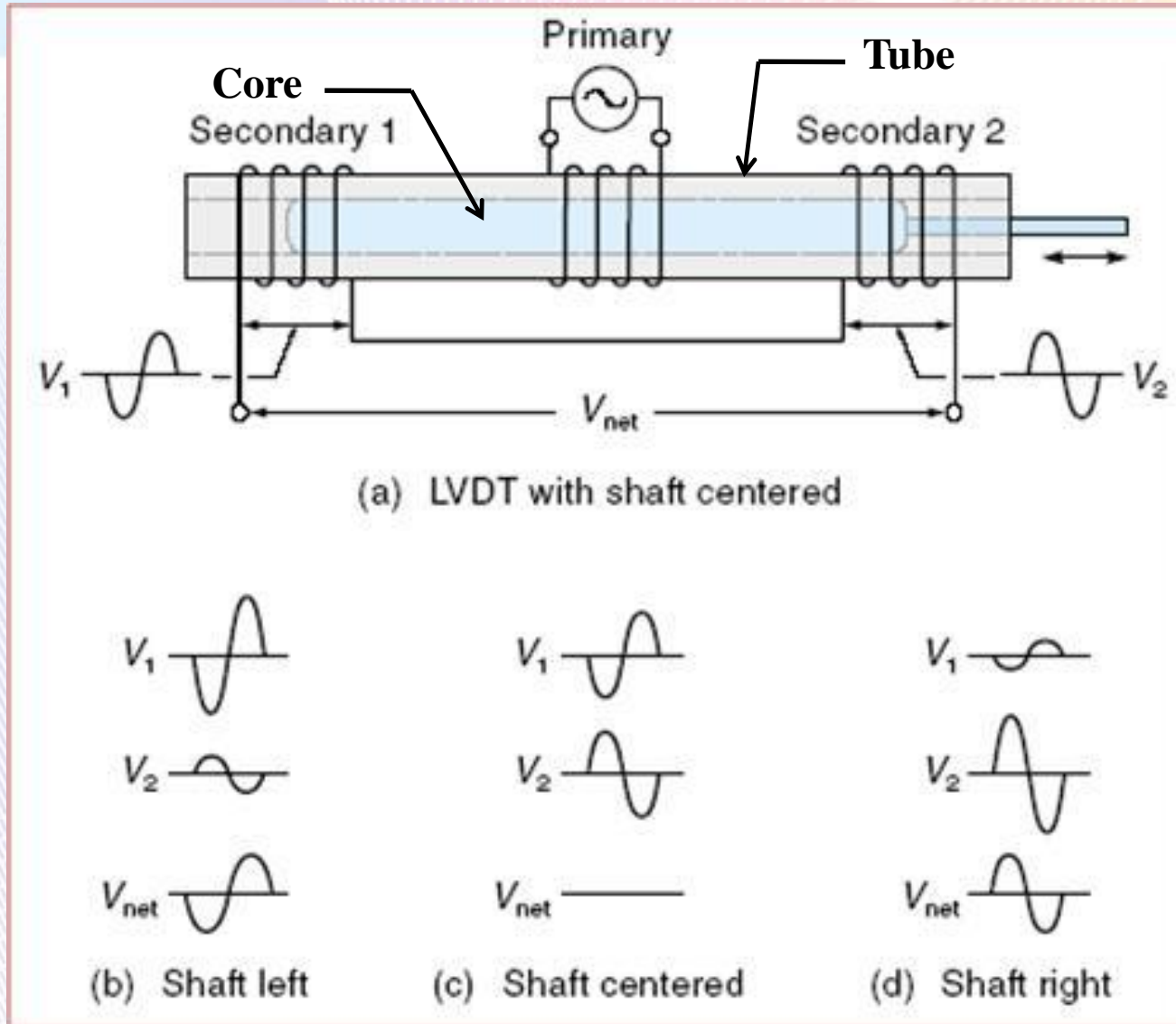
## Example: Push-pull displacement sensor



❖ The capacitance will change if the plate separation changes, the area of overlap of the plates changes, or a slab of dielectric is moved into or out of the plates.

# Displacement Sensors

## Linear Variable Differential Transformer (LVDT):

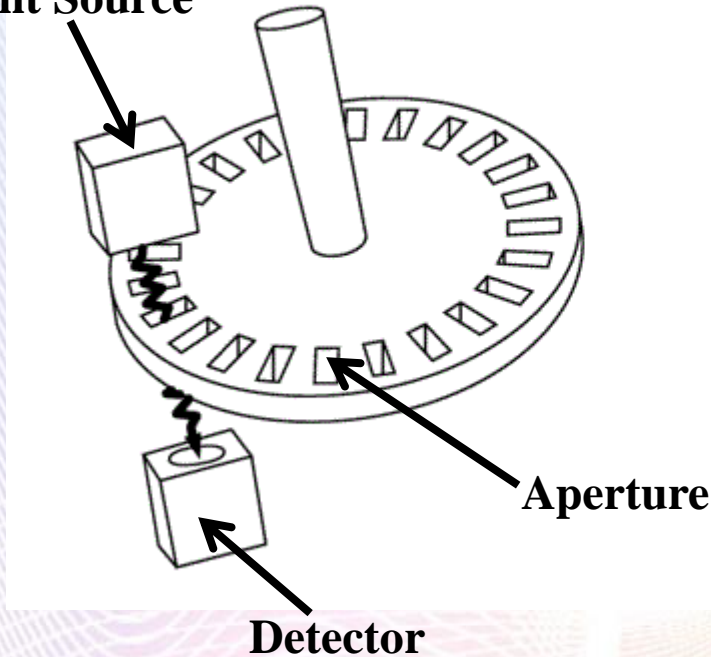


# Displacement Sensors

## Optical Encoders:

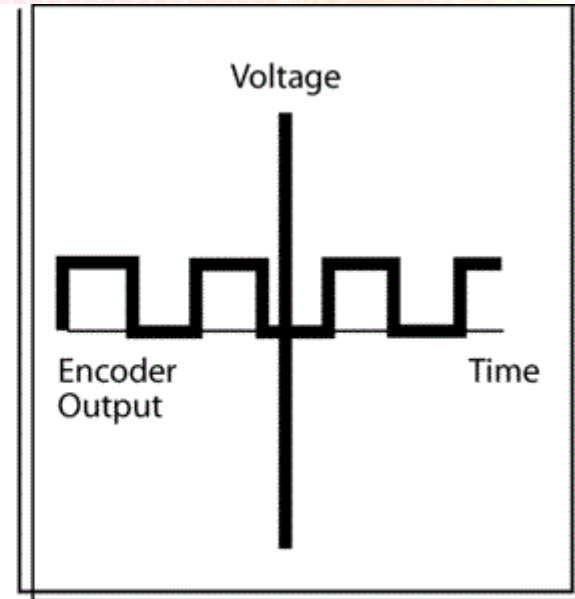
- Provides a digital output as a result of an angular or linear displacement
- Two categories: (i) incremental (ii) absolute

Light Source



Aperture

Detector



**Fig: Incremental optical encoder**

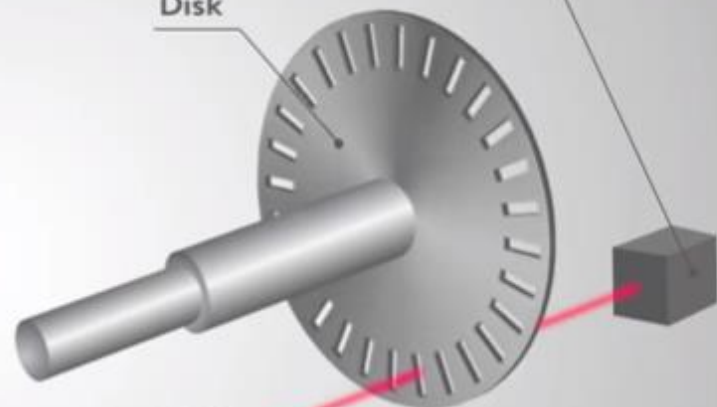


Light Source

Disk

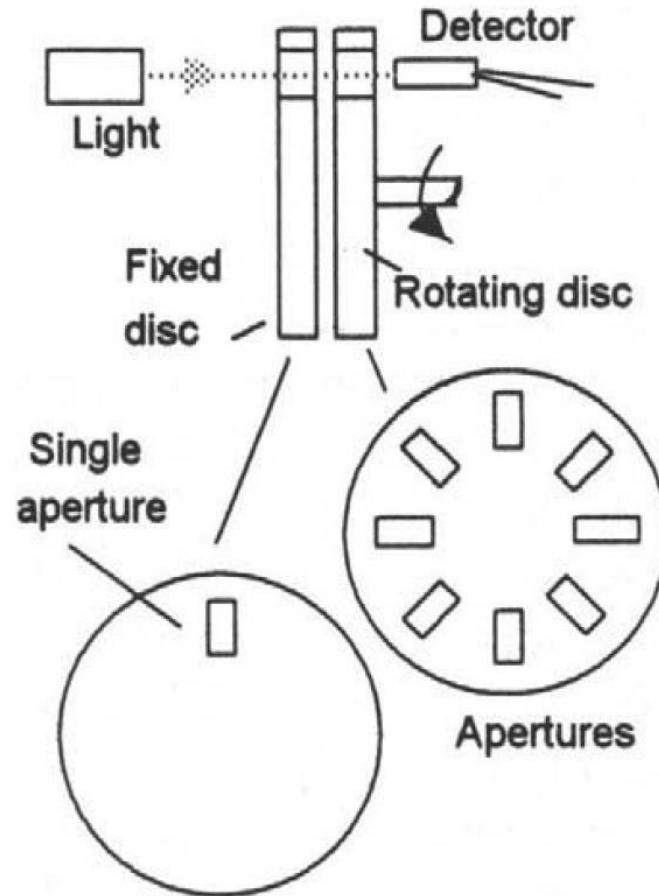


Light Detector



# Displacement Sensors

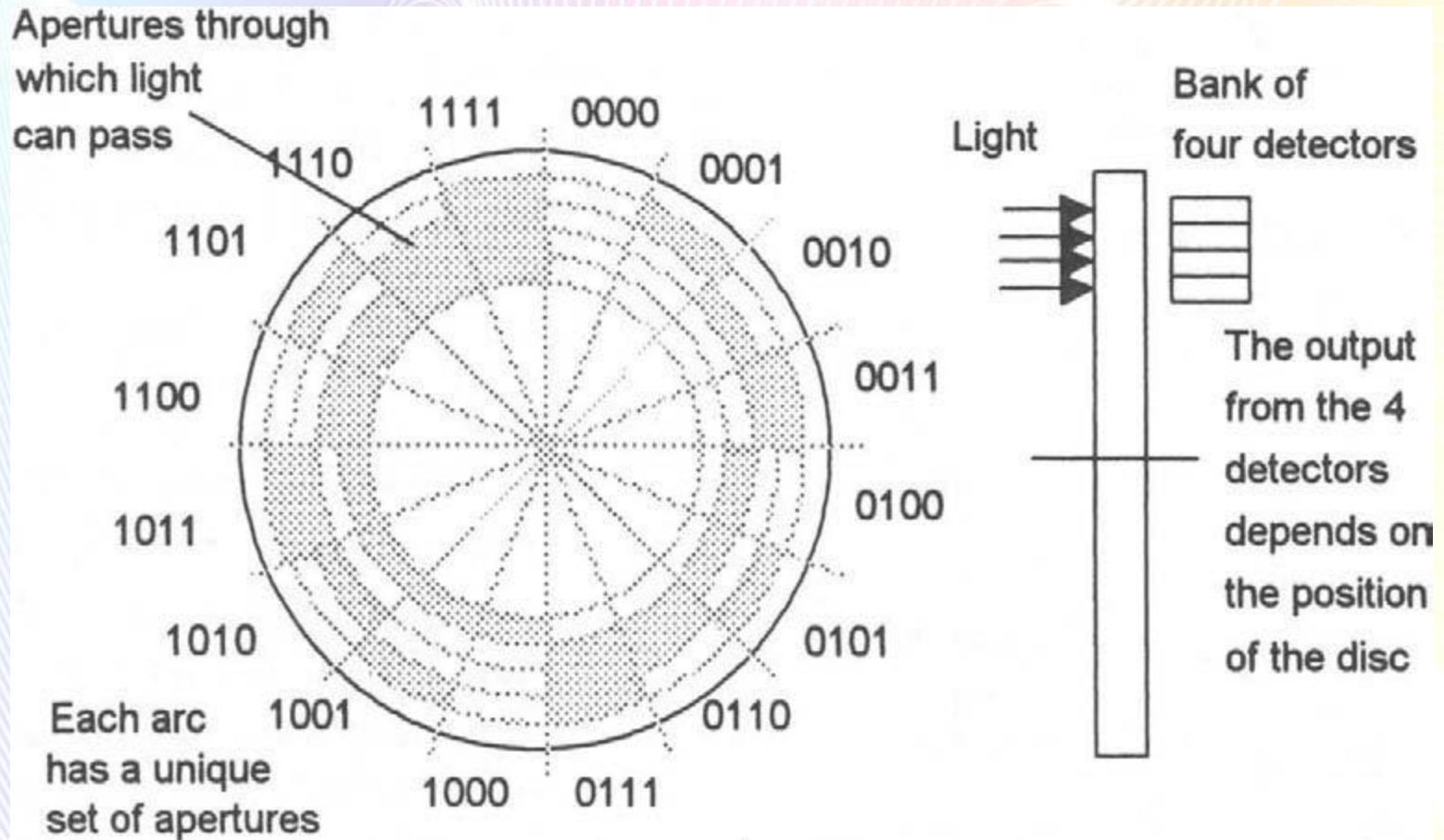
## Optical Encoders:



**Fig: Incremental optical encoder**

# Displacement Sensors

## Optical Encoders:



❖ Gray code is generally used

Fig: Absolute optical encoder

# Displacement Sensors

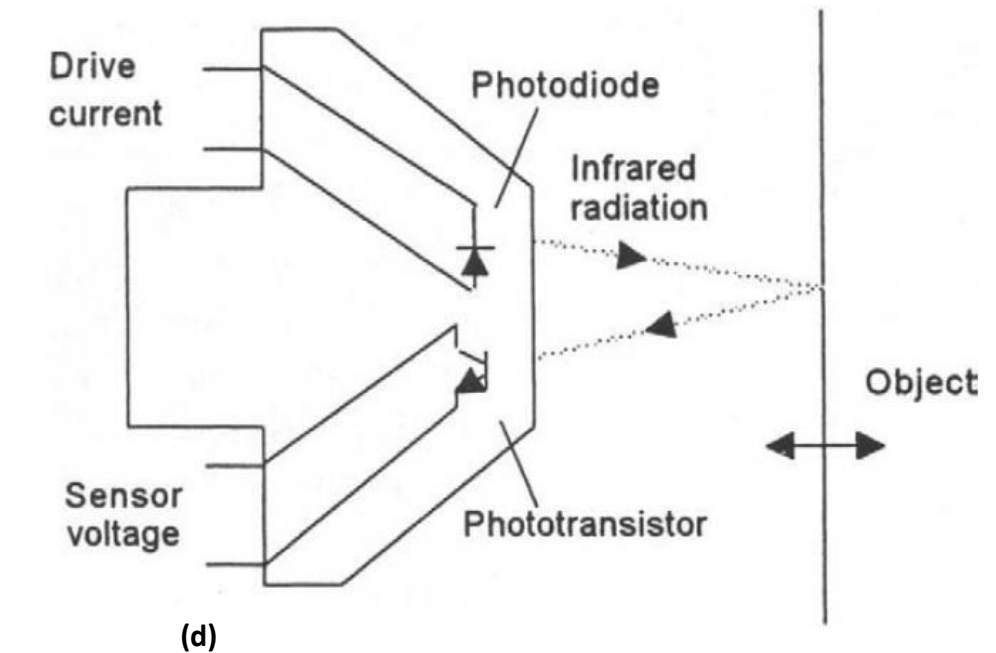
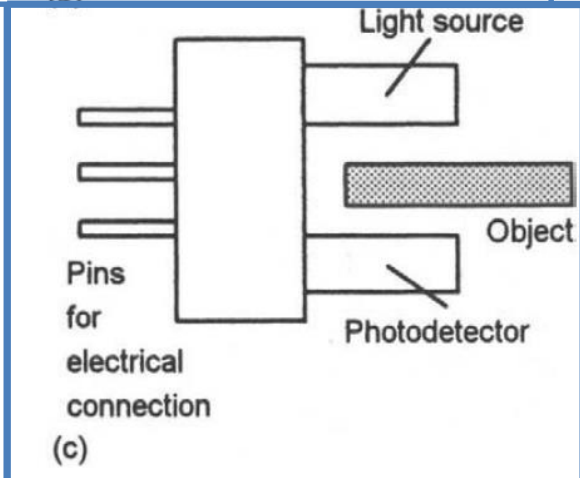
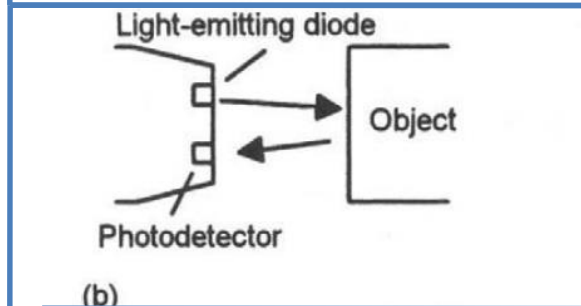
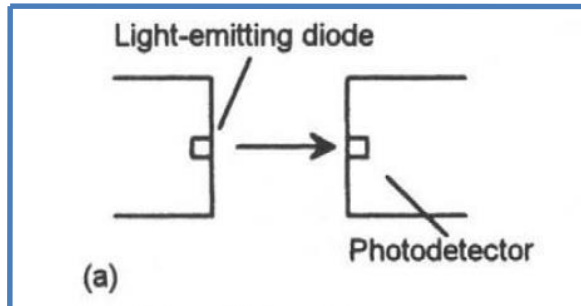
## Resolution of Incremental Optical Encoders:

- ❑ The number of windows on the disc varies from 60 to over a thousand with multi-tracks having slightly offset slots in each track.
- ❑ With 60 slots occurring with 1 revolution then, since 1 revolution is a rotation of  $360^\circ$ , the minimum angular displacement, i.e. the resolution, that can be detected is  $360/60 = 6^\circ$

**What about resolution of absolute optical encoders?**

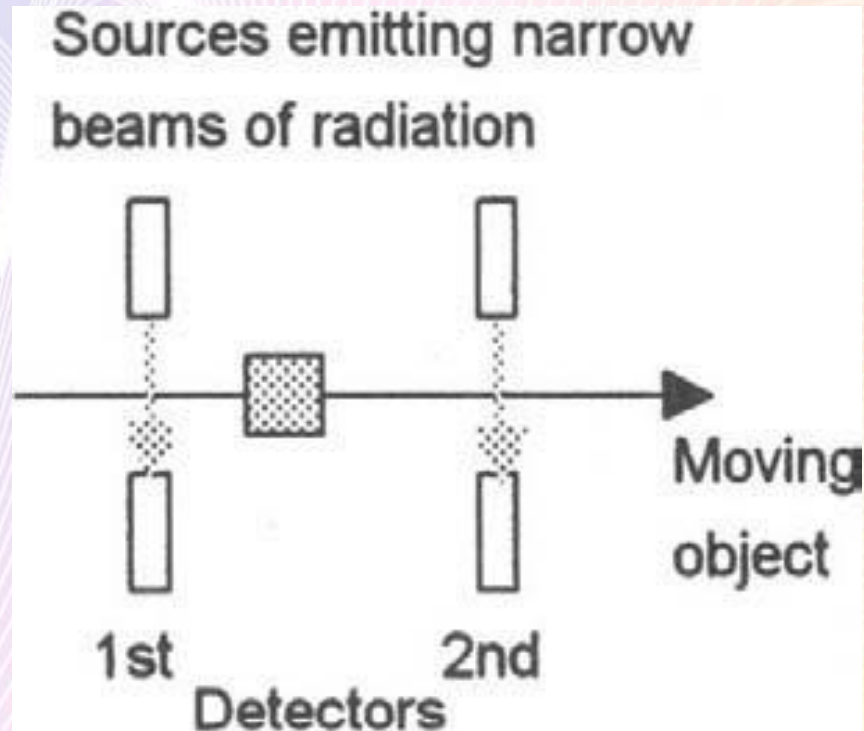
# Displacement Sensors

## Proximity Sensors:



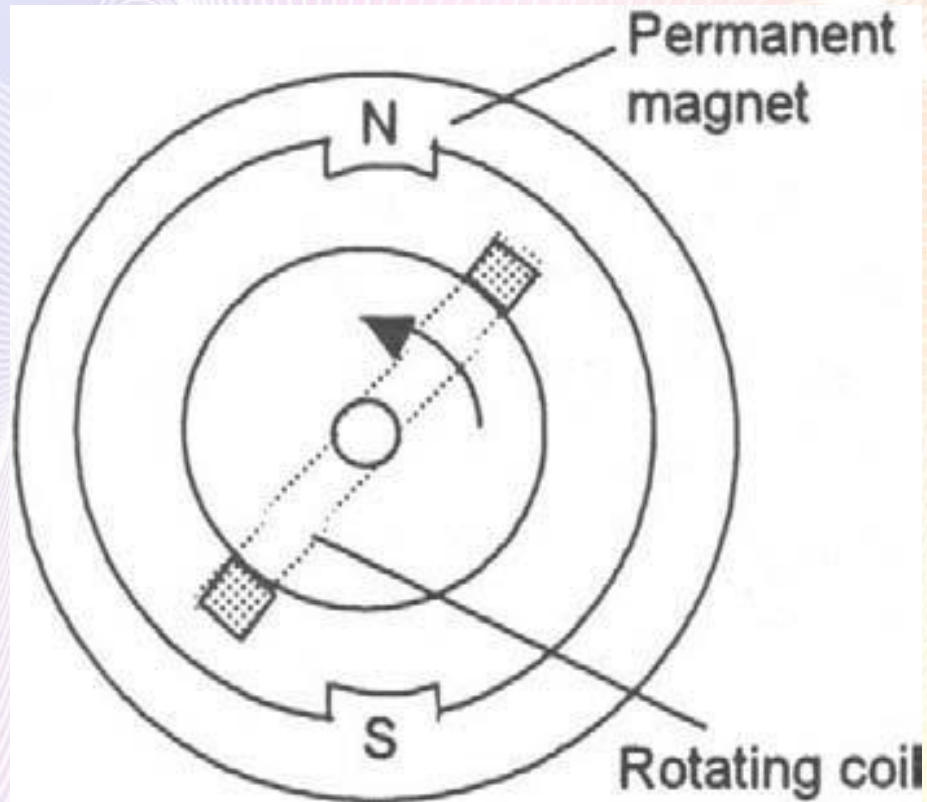
# Speed Sensors

**Optical Method: Measurement of linear speed is possible**



# Speed Sensors

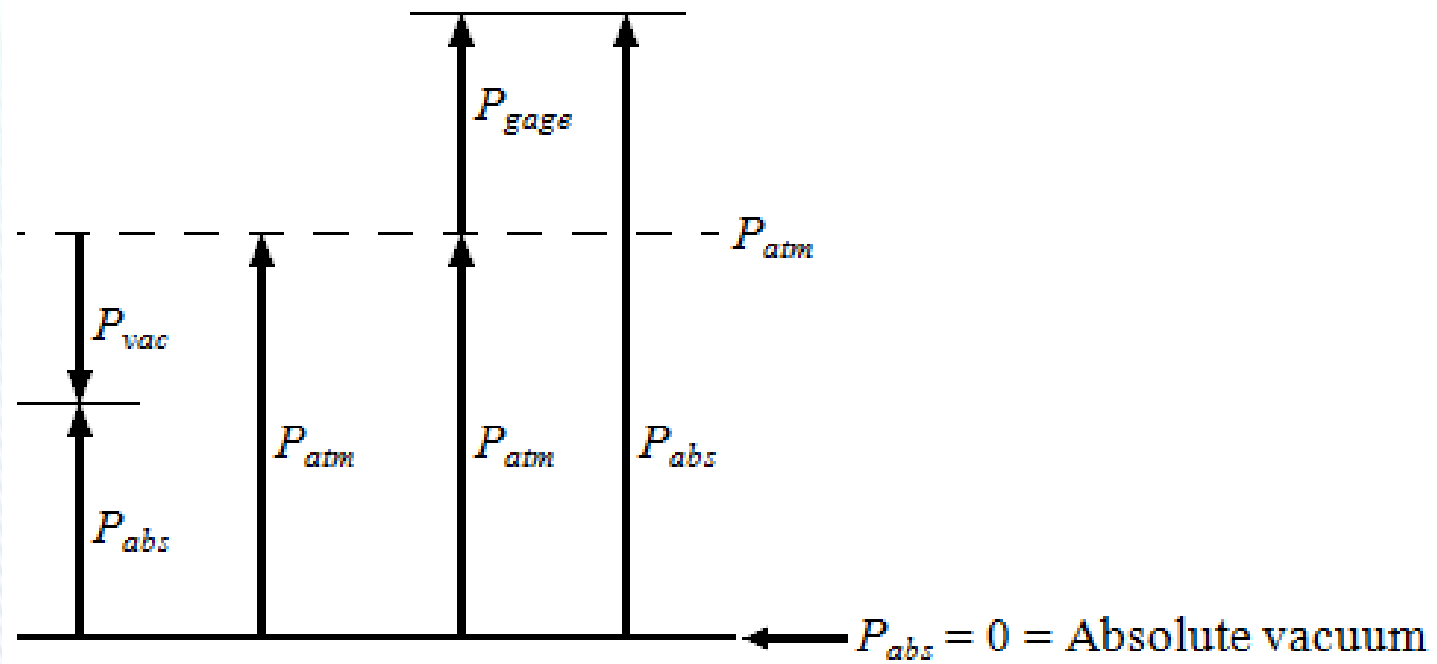
**Tachogenerator:** Measurement of angular/ rotational speed is possible



❖ *Incremental Encoders* can also be used for measuring angular/ rotational speed

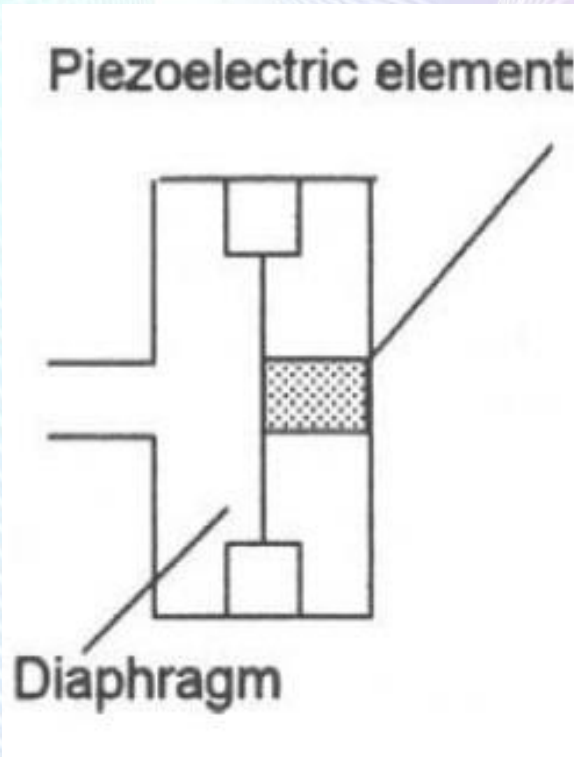
# Fluid Pressure Sensors

- **Absolute pressure** - The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure).
- **Gage pressure** - Gage pressure is the pressure relative to the atmospheric pressure. In other words, how much above or below is the pressure with respect to the atmospheric pressure.
- **Vacuum pressure** - Pressures below atmospheric pressure are called vacuum pressures and are measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure.



# Fluid Pressure Sensors

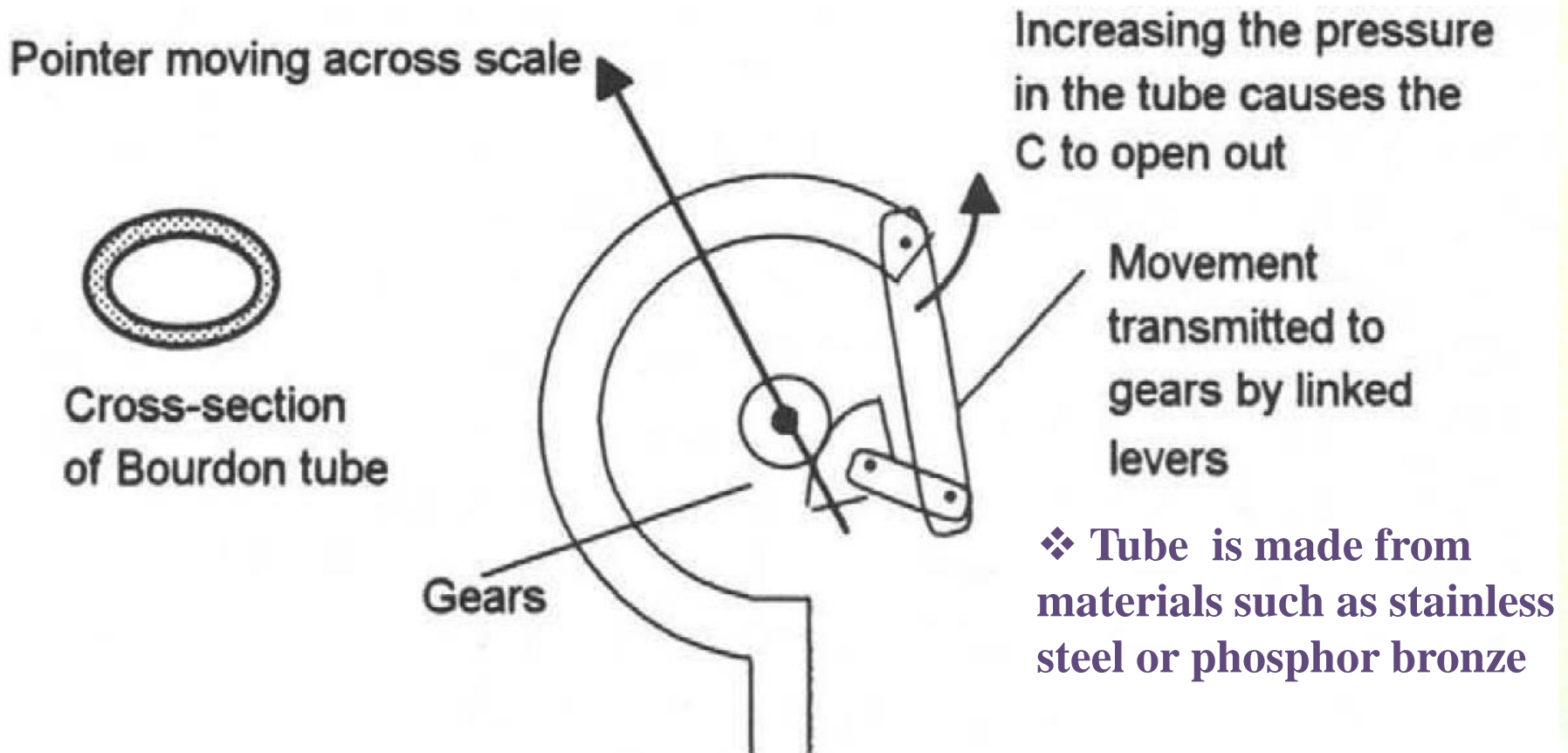
## Piezoelectric Sensor:



- **Piezoelectricity:** When certain crystals (Quartz, Tourmaline, Zirconate-Titanate) are stretched or compressed, charges appear on their surfaces.
- The amount of charge produced and hence the potential difference depends on the extent to which the crystal is compressed and hence is a measure of the pressure difference between the two sides of the diaphragm.
- The sensor is not suitable for static pressure measurements.

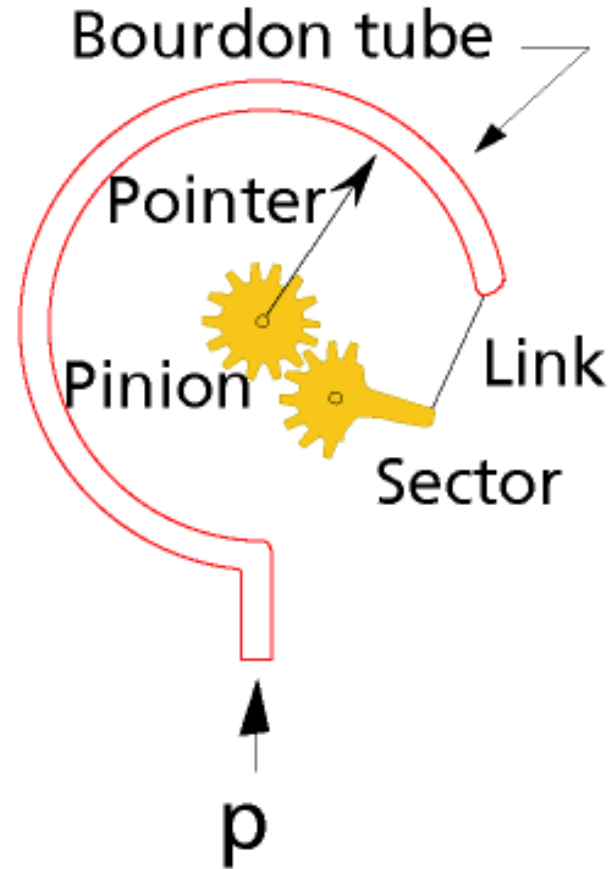
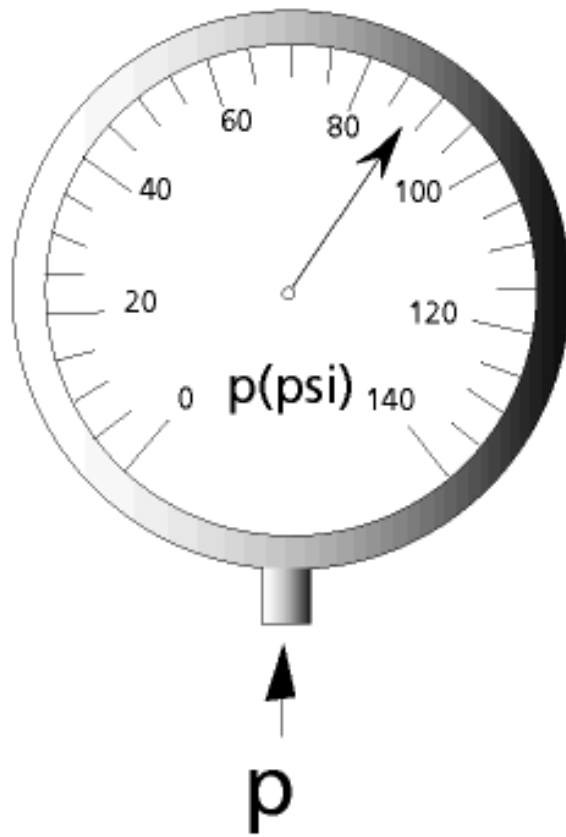
# Fluid Pressure Sensors

## Bourdon Tube:



# Fluid Pressure Sensors

## Bourdon Tube:



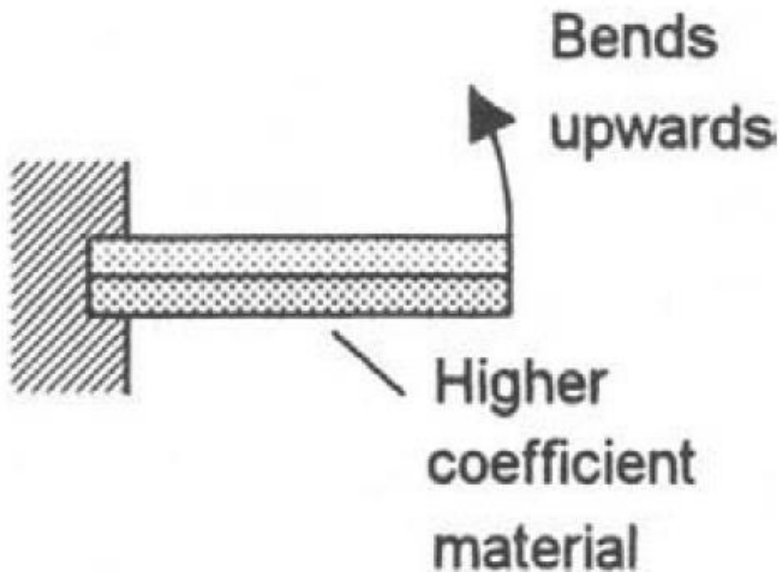
# Temperature Sensors

**Bimetallic Strips:** It consists of two different metal strips of the same length bonded together.

➤ The amount by which the strip curves depends on the two metals used, the length of the composite strip and the change in temperature.

➤ If one end of a bimetallic strip is fixed, the amount by which the free end moves is a measure of the temperature.

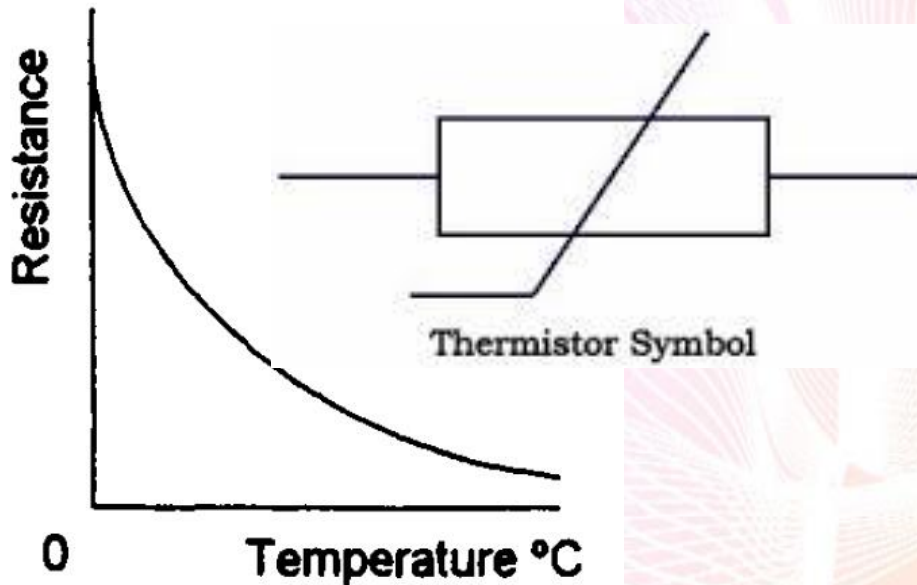
➤ Bimetallic strip devices are robust, relatively cheap, have an accuracy of the order of  $\pm 1\%$  and are fairly slow reacting to changes in temperature.



# Temperature Sensors

## Thermistors:

- Thermistors are semiconductor temperature sensors made from mixtures of metal oxides, such as those of chromium, cobalt, iron, manganese and nickel.
- The resistance of thermistors decreases in a very non-linear manner with an increase in temperature



- Because of their small size they have small thermal capacity and so respond very rapidly to changes in temperature.
- They give very large changes in resistance per degree change in temperature. So range is small.
- Their main disadvantage is their non-linearity.

# Temperature Sensors

Thermocouples:

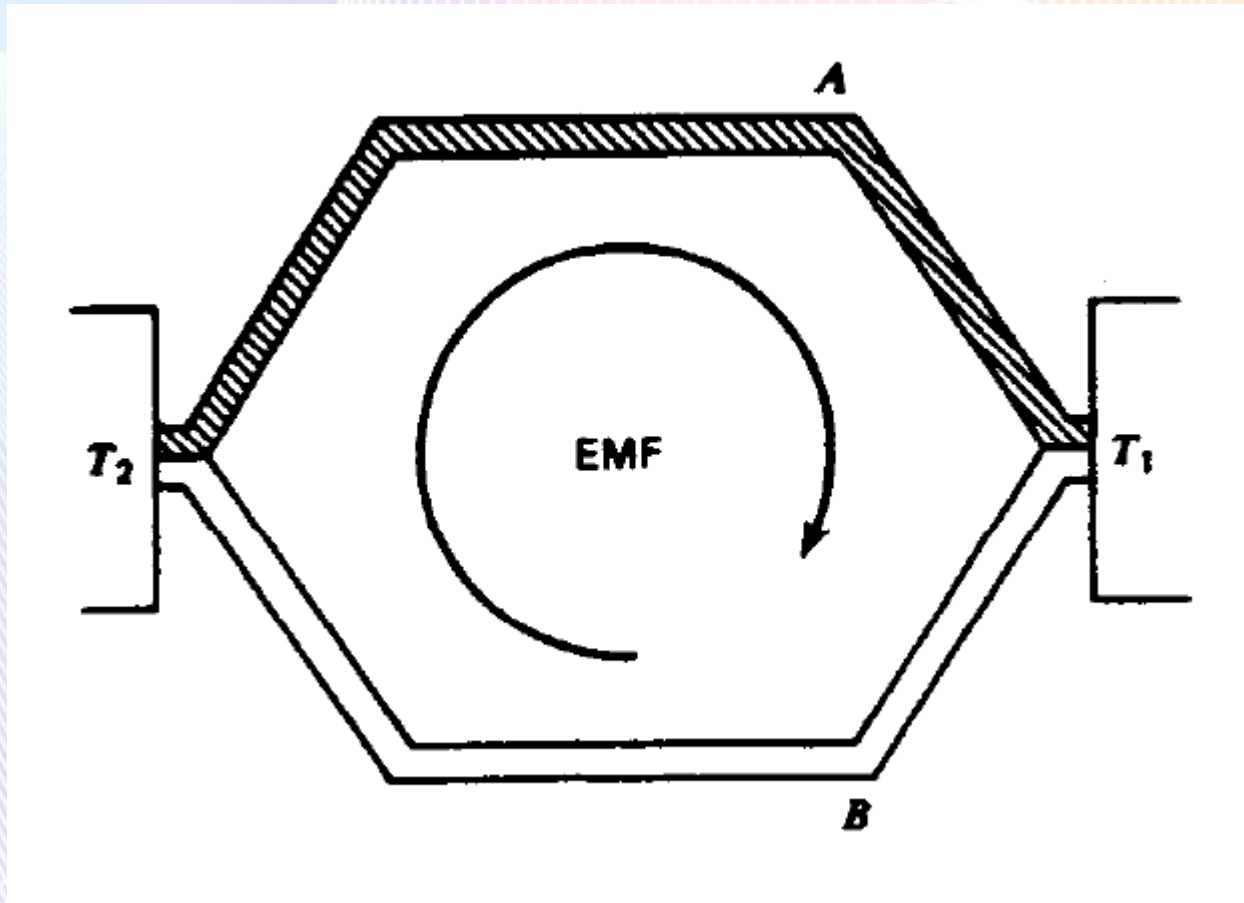


Fig: Seebeck Effect

# Temperature Sensors

**Thermocouples:**

**EMF Produced:** 
$$E = \int_{T_1}^{T_2} (Q_A - Q_B) dT$$

$E$  = emf produced in volts

$T_1$  &  $T_2$  = junction temperatures in K

$Q_A$  &  $Q_B$  = thermal conductivity

**Approximate Linear Relation:**

$$E = \alpha(T_2 - T_1)$$

$\alpha$  = constant in V/K

**Approximate Non-Linear Relation:** If one junction is at 0 °C, then

$$E = at + bt^2$$

# Temperature Sensors

Thermocouples:

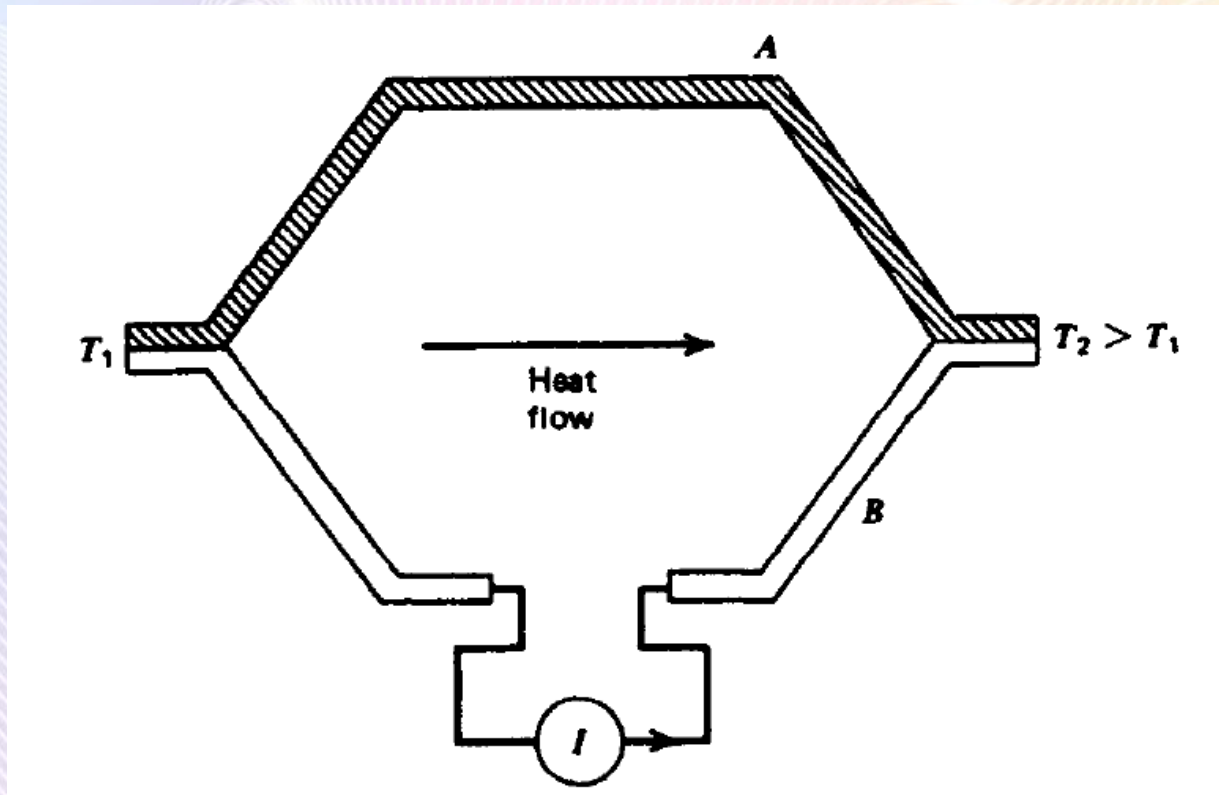


Fig: Peltier Effect

# Temperature Sensors

## Thermocouple Types:

Type	Materials	Range (°C)	Sensitivity (mV/°C)
E	Chromel-constantan	0 to 980	63
J	Iron- Constantan	-180 to 760	53
K	Chromel- Alumel	-180 to 1260	41
R	Platinum- 13% platinum/ rhodium	0 to 1750	8
T	Copper- constantan	-180 to 370	43

❖ The base-metal thermocouples, E, J, K and T, are relatively cheap but deteriorate with age. They have accuracies which are typically about  $\pm 1$  to 3%. Noble-metal thermocouples, e.g. R, are more expensive but are more stable with longer life. They have accuracies of the order of  $\pm 1\%$  or better.

# Temperature Sensors

## Thermocouples

### Law of intermediate temperatures:

$$E_{T,0} = E_{T,I} + E_{I,0}$$

**Problem:** Consider a type E thermocouple. The following is data from standard tables.

Temperature (°C)	0	20	180	200
EMF (mV)	0	1.192	11.949	13.419

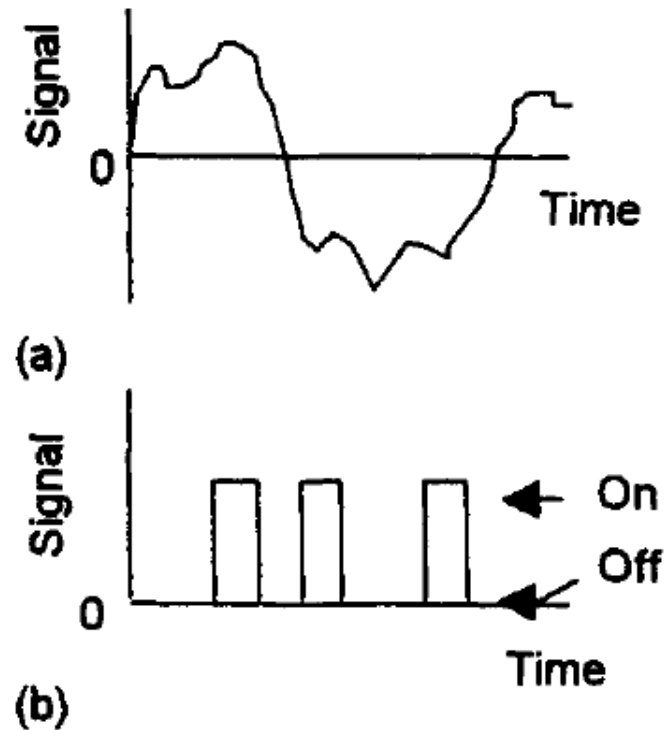
What is the thermoelectric EMF at 200° C with the cold junction at 20°C?

# Signal Processing

- The **output signal from the sensor** of a measurement system has generally to be **processed in some way to make it suitable for display** or use in some control system.
- **For example,**
  - ✓ the signal may be too small and have to be amplified,
  - ✓ be analogue and have to be made digital,
  - ✓ be digital and have to be made analogue,
  - ✓ be a resistance change and have to be made into a current change, etc.
- All these changes can be referred to as *signal processing*.

# Analog Signal and Digital Signal

- An *analog signal* is one that is continuously variable, changing smoothly over a range of values.
- A *digital signal* increases in jumps, being a sequence of pulses, often just on-off signals. The value of the quantity instead of being represented by the height of the signal, as with analogue, is represented by the sequence of on-off signals.



**Figure Signals:**  
*(a) analogue, (b) digital*

# Analog to Digital Converter (ADC)

- The electrical output from sensors such as thermocouples, resistance elements used for temperature measurement, strain gauges, diaphragm pressure gauges, LVDTs, etc. is in analog form.
- Microprocessors require digital inputs.
- Thus, where a microprocessor is used it has to be converted into a digital form before it can be used as an input to the microprocessor.
- Thus there is a need for analog-to-digital converters (ADC).

# Analog to Digital Conversion

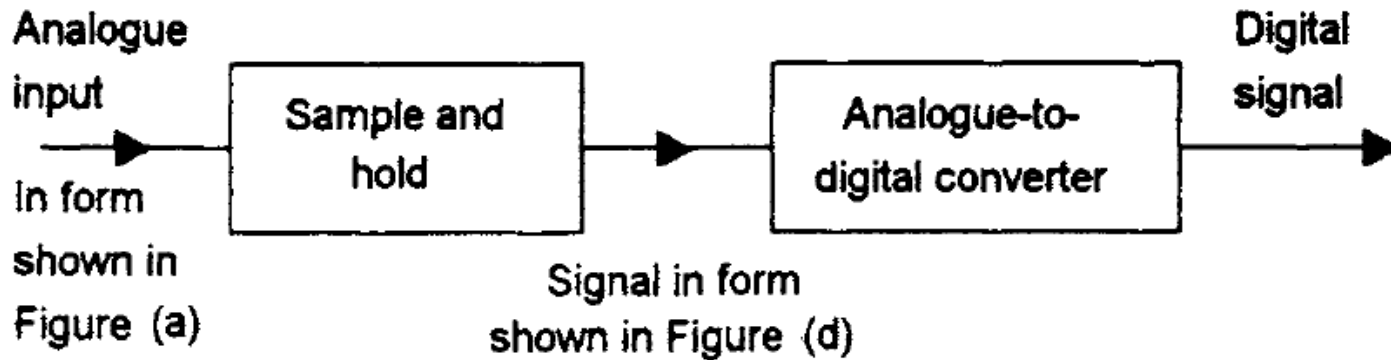
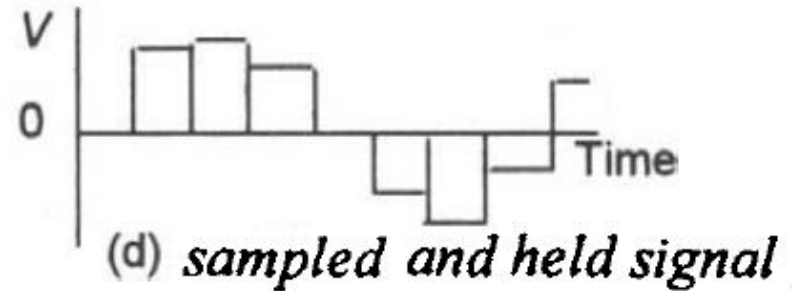
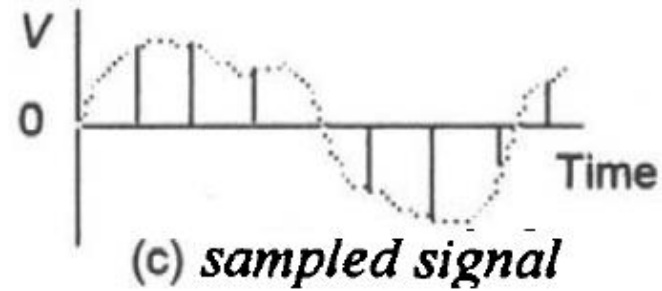
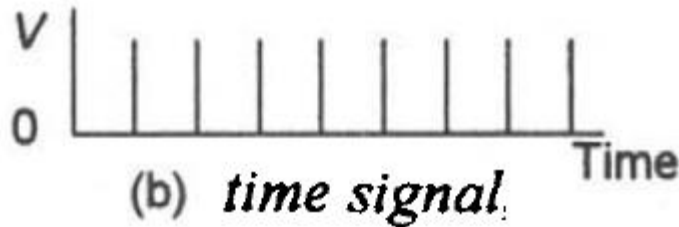
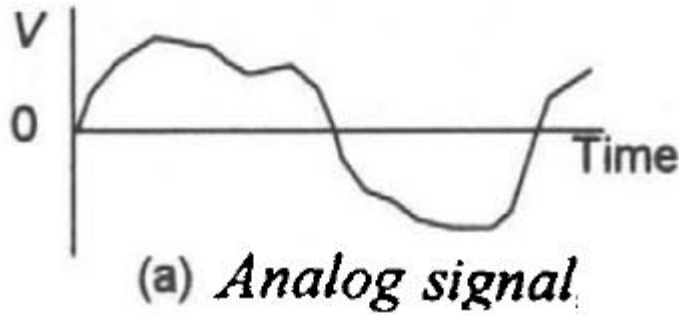


Figure *Analogue-to-digital conversion*

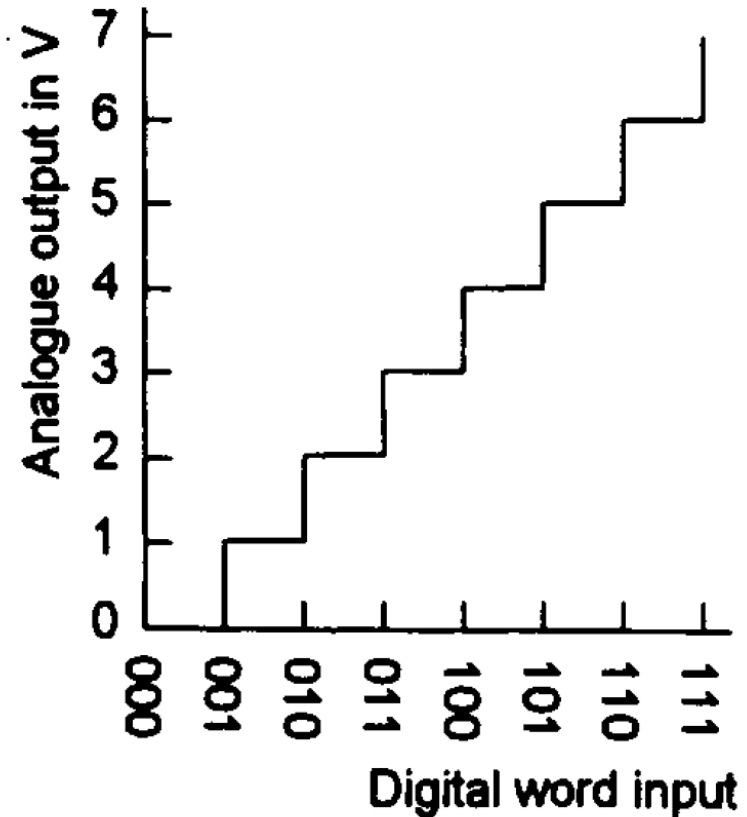
# Analog to Digital Converter (ADC)

**Problem:** A thermocouple gives an output of 0.4 mV for each degree change in temperature. Temperatures from 0 to 200 °C can be measured using this thermocouple.

- a. What is the full scale output from the thermocouple?
- b. What will be the word length required when its output passes through an analogue-to-digital (ADC) converter if resolution of the ADC is 0.5 °C?
- c. What is the actual resolution?
- d. For a resolution of 0.5 °C, what should be the minimum value of analog voltage signal from the thermocouple so that the ADC can detect the signal? How does this value change for the new resolution?

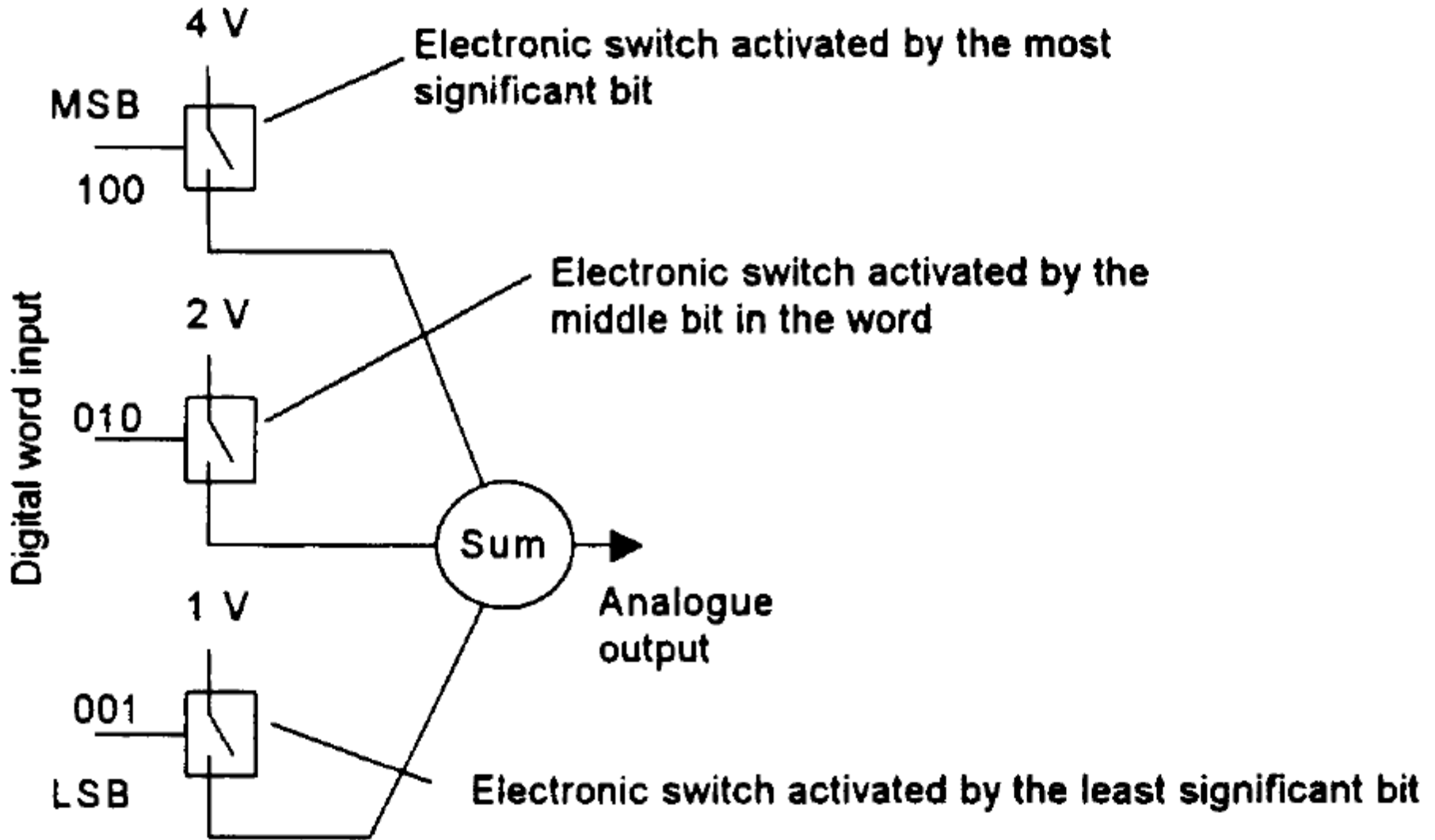
# Digital to Analog Converter (DAC)

- The output from a micro-processor is digital.
- Most control elements require an analogue input and so the digital output from a microprocessor has to be converted into an analogue form before it can be used by them.
- Thus there is a need for digital-to-analogue converters (DAC).



**Fig: Digital to analog conversion**

# Digital to Analog Converter (DAC)



**Figure: Principle of a 3-bit DAC**

# Digital to Analog Converter (DAC)

**Problem:** A microprocessor gives an output of an 8-bit word. This is fed through an 8-bit digital-to-analogue converter to a control valve which requires 6.0 V to be fully open. What will be the change in output to the valve when there is a change of 1 bit?