Chapter 8
(Chapter 11 Text Book)

Transducers

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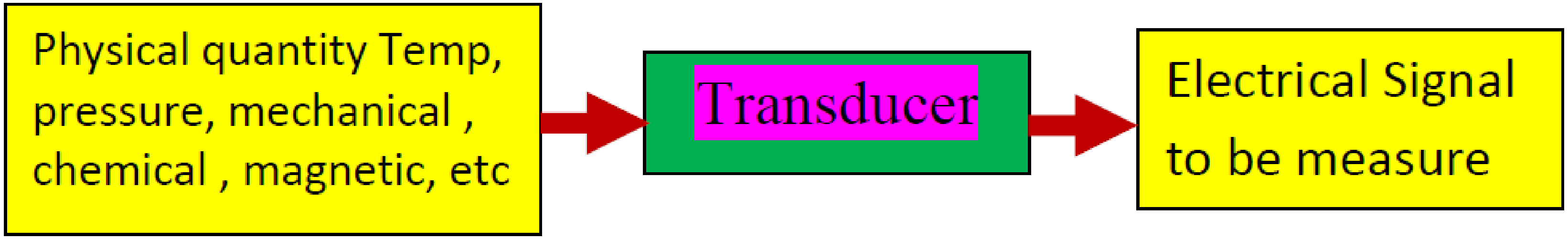
Transducer

- A device that detect and measure a physical quantity and convert into a signal that can be measured by an electronic measuring system
- requires an interface (transducer) in-between



TRANSDUCER TYPES

- 1- **Active transducer** (require an external source of energy.

  such as: potentiometer

- 2- **Passive** self generating transducer (no external source is required)

  such as: thermocouple that converts temperature difference between two wire to electric current

MEASURAND

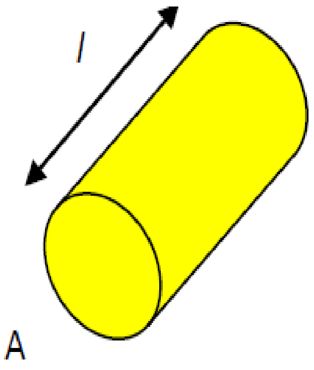
- There are several forms of energy that can be converted into an electrical signal with a transducer

Energy Source	Representative Sensors
Mechanical	Rotating van flowmeter
Thermal	Thermocouple
Nuclear Radiation	Ionization Chamber
Electromagnetic	Antenna
Magnetic	Hall-effect Sensor
Chemical	pH sensor

Transducer Principles

1- Resistive transduction

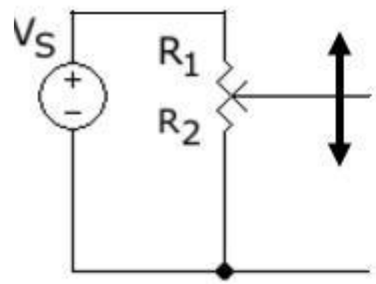
$$R = \frac{\rho l}{A}$$



l	*resistance length (m)*
A	*cross section of wire(m^2)*
ρ	*resistivity (Ω.m)*

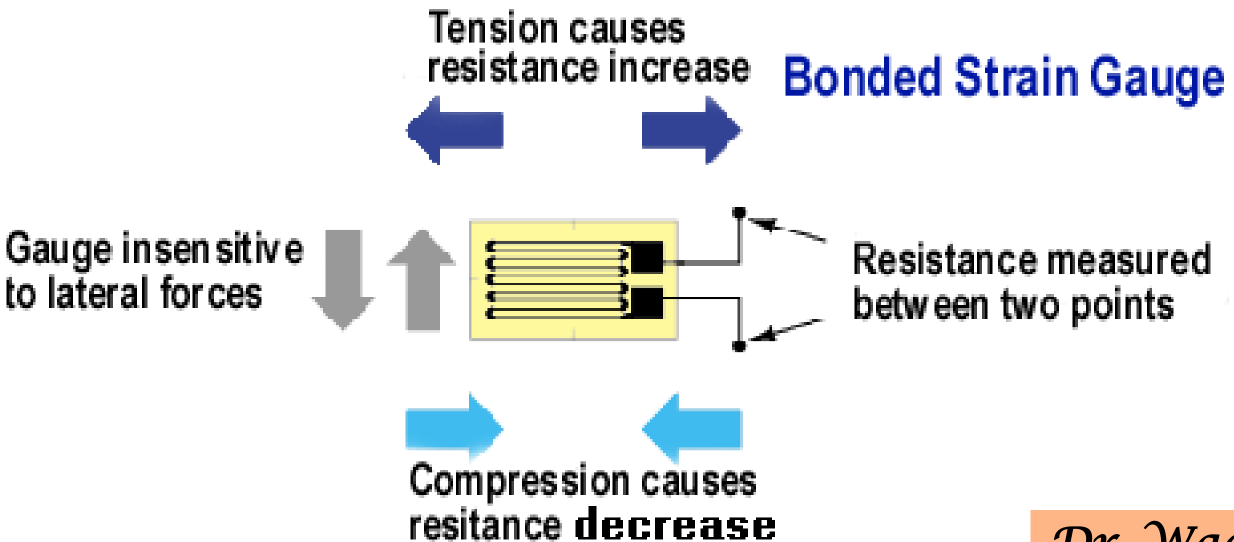
The resistance of a resistive element can be varied by several method

- a- **Sliding** a wiper along rheostat



- b- **Applying mechanical stress** (strain gauge)

It consists of a thin metallic conductor that is firmly attached to a solid object to detect strain in the object



- c- **Varying light intensity** to a photosensitive material

These sensors absorb the light which **cause resistance decrease** , like used in street light control

- **d- Changing the temperature**

Its resistance varies as the temperature varies such as that used *in car motor temperature*

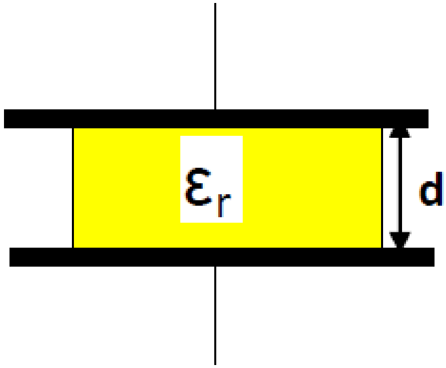
Transducer Principles

1- Resistive transduction

2- Capacitive transduction

- The capacitance of parallel plate capacitor is given by

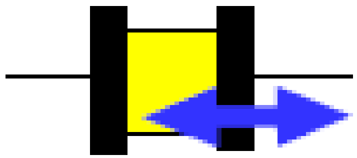
$$C = \varepsilon_o \varepsilon_r \frac{(n-1)A}{d}$$

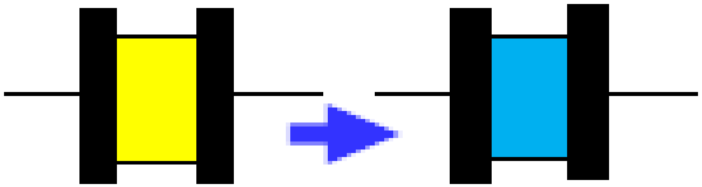


N	number of plates
A	plate area, m^2
d	plate separation, m
ε_o	air permittivity $\{(1/36\pi)*10^{-9}$ F/m$\}$
ε_r	relative dielectric constant of material between plates (dimensionless)

Capacitance transduction happed when we change

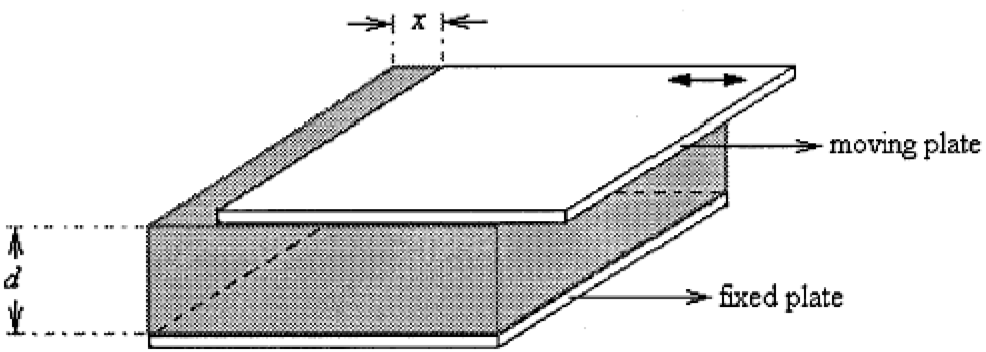
- 1- **distance** between plates
- 2- **Area** of the plate
- 3- The dielectric **material** in between





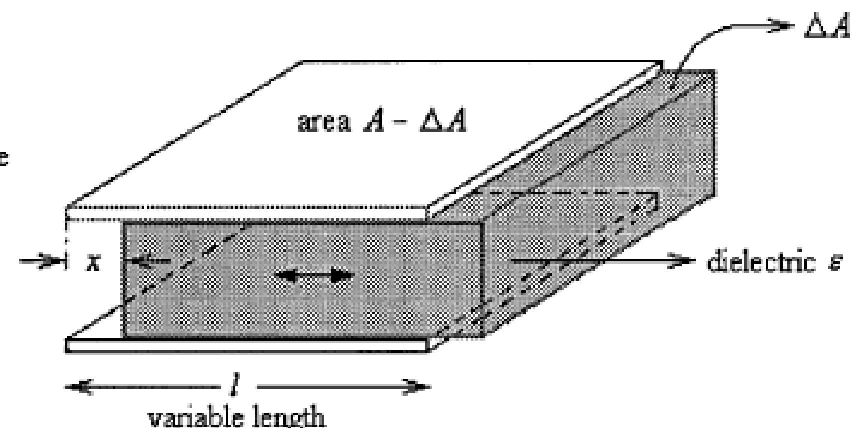
Capacitive Sensors

<u>Other Configurations</u>



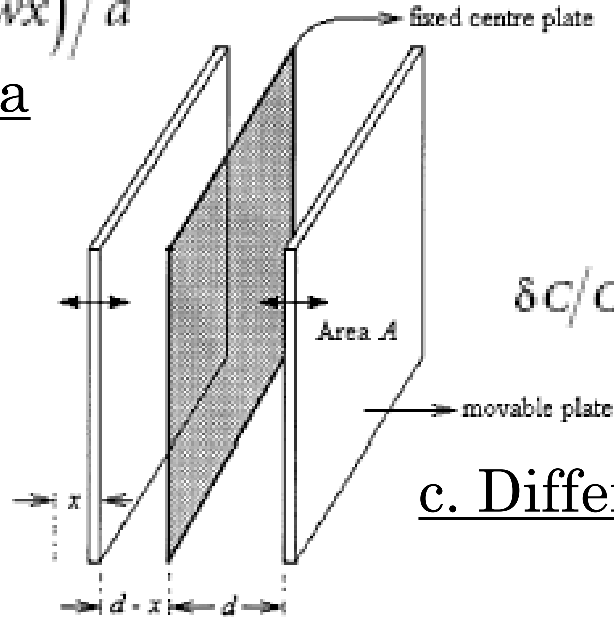
$$C = \varepsilon_r \varepsilon_0 \left(A - wx \right) / d$$

<u>a. Variable Area Mode</u>



$$C = \varepsilon_0 \; w \left[\varepsilon_2 l - \left(\varepsilon_2 - \varepsilon_1 \right) x \right]$$

<u>b. Variable Dielectric Mode</u>



$$\delta C / C = \delta d / d$$

<u>c. Differential Mode</u>

Examples for using Capacitance transduction

- *1- Capacitive* ***microphone*** *uses acoustical pressure to vary the spacing between the plates*

- *2-* ***Tuning*** *an audio signal by varying capacitance area*

TRANSDUCER PRINCIPLES

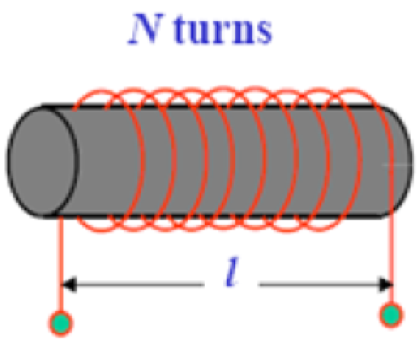
1- RESISTIVE TRANSDUCTION

2- CAPACITIVE TRANSDUCTION

3-INDUCTION TRANSDUCTION

The self inductance (L) can be changed by moving the magnetic core.

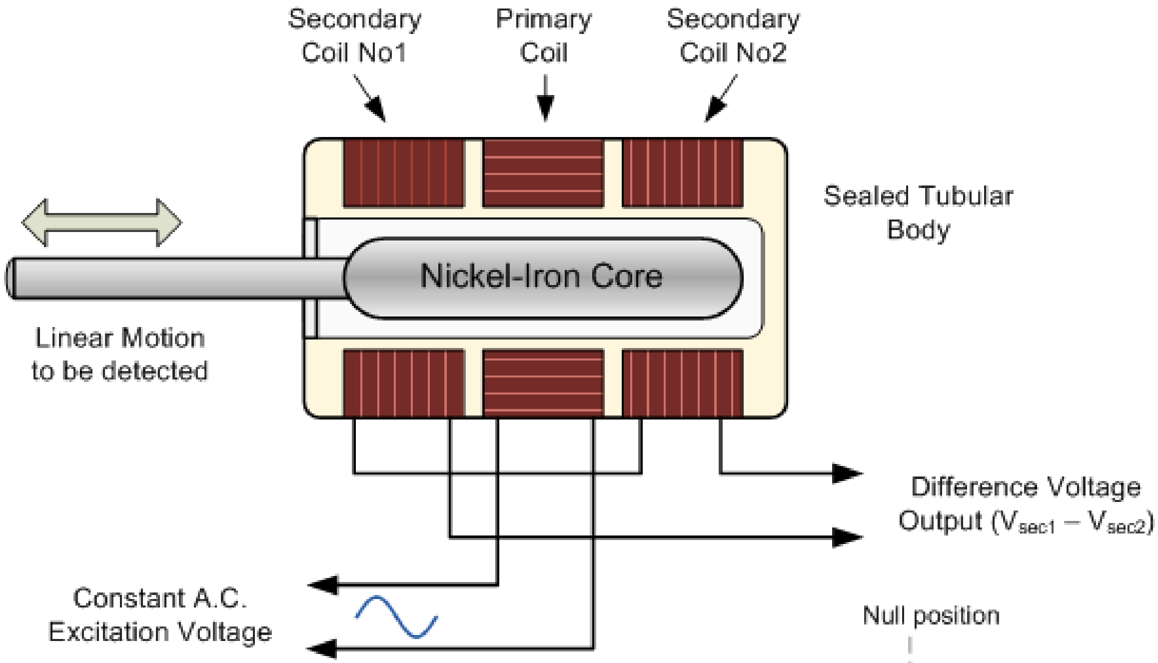
$$L = \mu_o \mu_r \frac{N^2 A}{l}$$

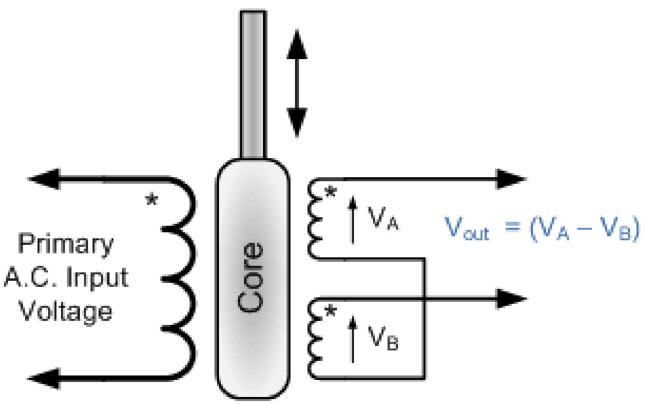


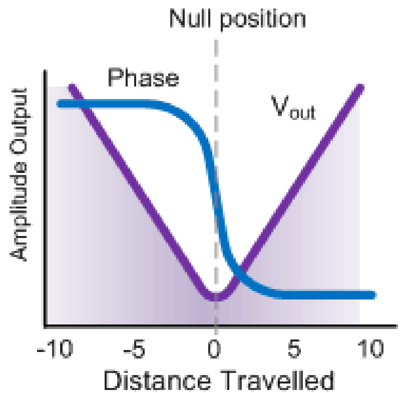
L	inductance (henry)
μ_o	air permeability ($4\pi * 10^{-7}$ H/m)
μ_r	core permeability (dimensionless)
A	core area, m^2
N	number of turns
l	coil length, m

Example

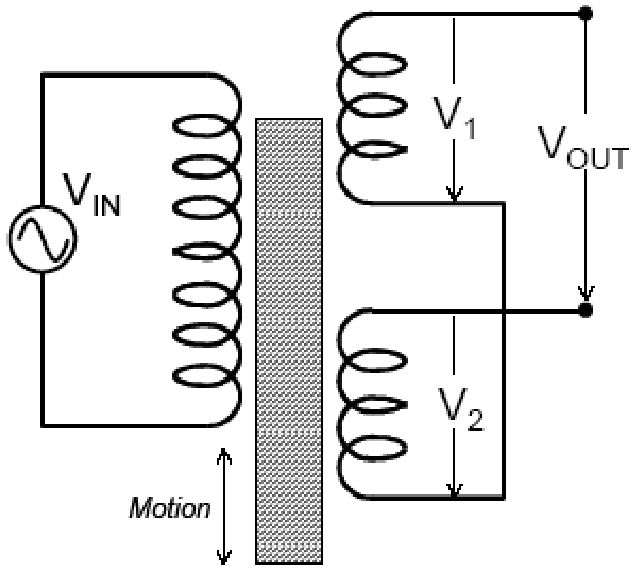
- *The **linear variable differential transformer*** (LVDT) is used for measuring linear displacement.

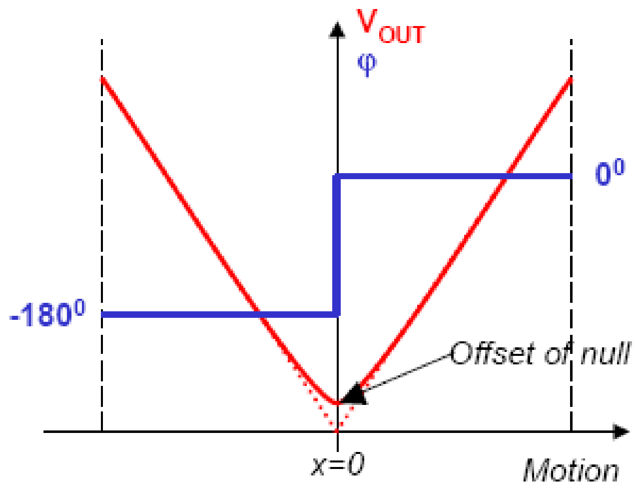






INDUCTIVE SENSORS





An inductor is basically a coil of wire over a "core" (usually ferrous)

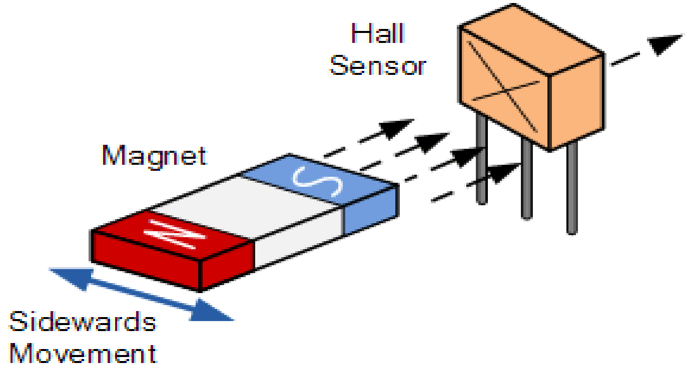
It responds to electric or magnetic fields

A transformer is made of at least two coils wound over the core: one is primary and another is secondary

Inductors and tranformers work only for ac signals

TRANSDUCER PRINCIPLES

1- RESISTIVE TRANSDUCTION
2- CAPACITIVE TRANSDUCTION
3- INDUCTION TRANSDUCTION

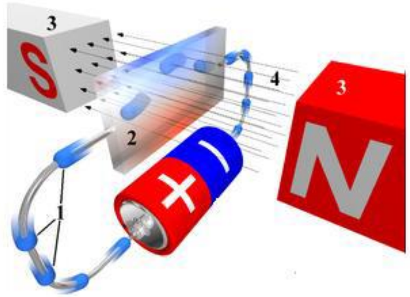


4- MAGNETIC TRANSDUCTION

- *The **Hall effect** is the production of a voltage difference (the **Hall voltage**) across an electrical conductor, cross an electric current in the conductor and **a magnetic field perpendicular to the current**. It was discovered by Edwin **Hall** in 1879.*

- The hall effect occurs when a current carrying conductor is placed in a magnetic field (such that E & H are at right angle) a voltage introduced in the conductor in direction perpendicular to both E & H

The hall effect can be used to measure magnetic field strength or measuring the current in conductor



Transducer Selection

- **1- Measurement Requirements**
- **2- Environmental considerations**

Transducer Selection

1- Measurement Requirements

- **Rang** (set of values designed to measure)
- **Input threshold** (it is the ***smallest*** detectable value of the measured quantity near the zero value
- **Dynamic behavior** (specifies how the transducer can ***respond*** to a changing in the i/p
- **Accuracy** (is the difference between measured and accepted value)
- **Repeatability** (it is max. difference between consecutive measurements of the same quantity (***Precision***)

TRANSDUCER SELECTION

2- Environmental considerations

- **Natural Hazard (**transducer must able to withstand the effect of Dust, temperature, water, humidity**)**

- **Human cause hazard** (chemical, vibration)

- **Power requirements**
- (Required supply for passive transducer)

- **Loading effect**

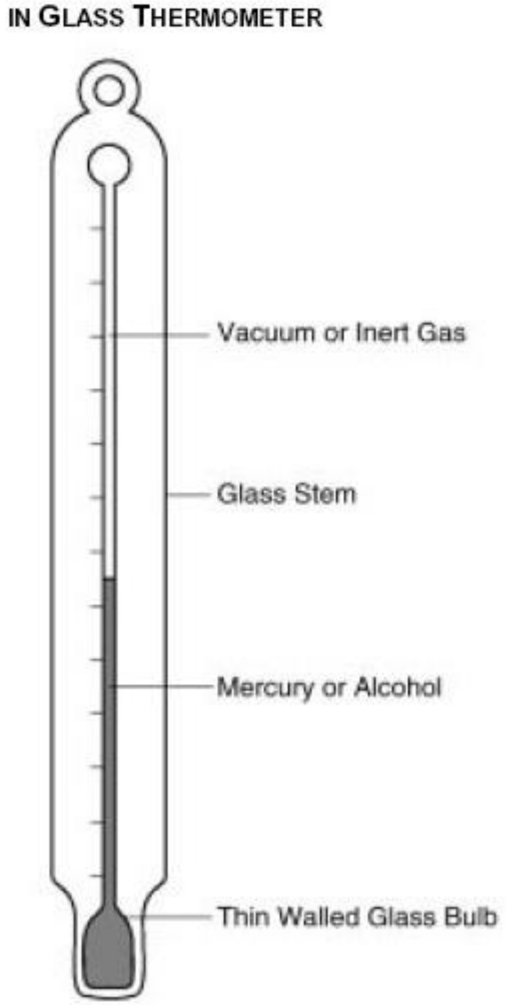
TRANSDUCERS

- **Temperature Measurements**
- Strain Gages
- Displacement Transducers
- Photosensitive Devices

Temperatures Measurement

1- Mercury Thermometer

- The first mercury thermometer was design by Gabriel Fahrenheit.
- The **Celsius scale** is more widely used worldwide than **Fahrenheit** scale (C)
- The **Kelvin** scale is an absolute scale in which all temperature are positive (it is used in most scientific work) (K)



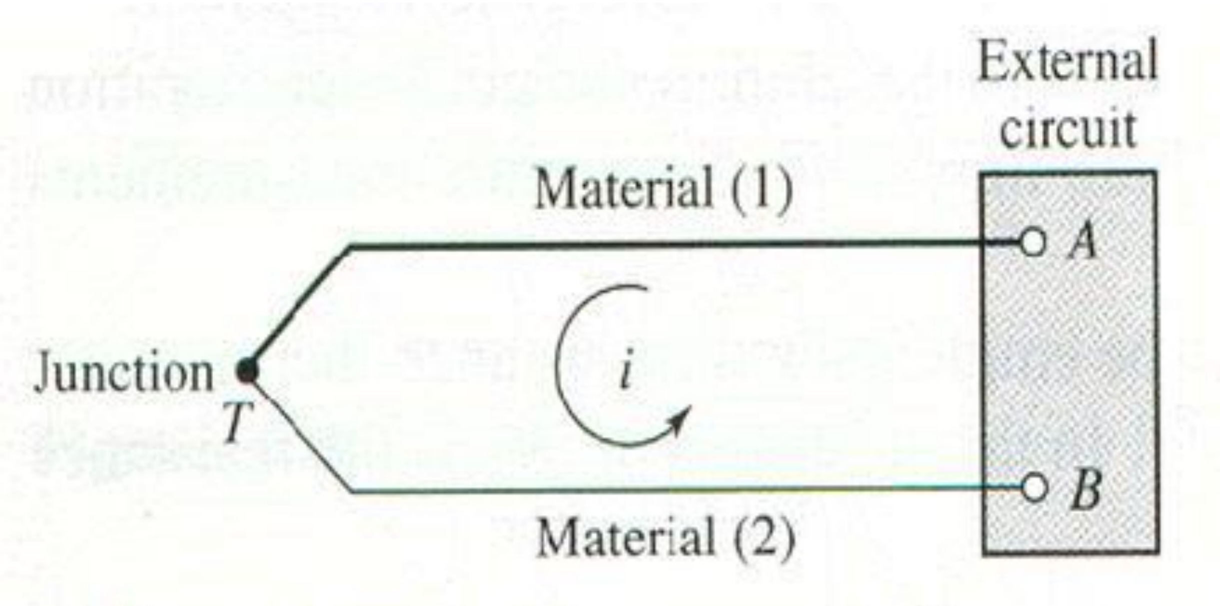
$$F = \frac{9}{5}C + 32$$

$$C = \frac{5}{9}(F - 32)$$

$$K = (C + 273.16)$$

Temperatures Measurement

2-The Thermocouple



THERMOCOUPLE

- The induced voltage depends on the wire materials and on the temperature difference between the junctions
- The induced voltage of the thermocouple is proportional to change in temperature :

$$V \cong \alpha(T_2 - T_1)$$

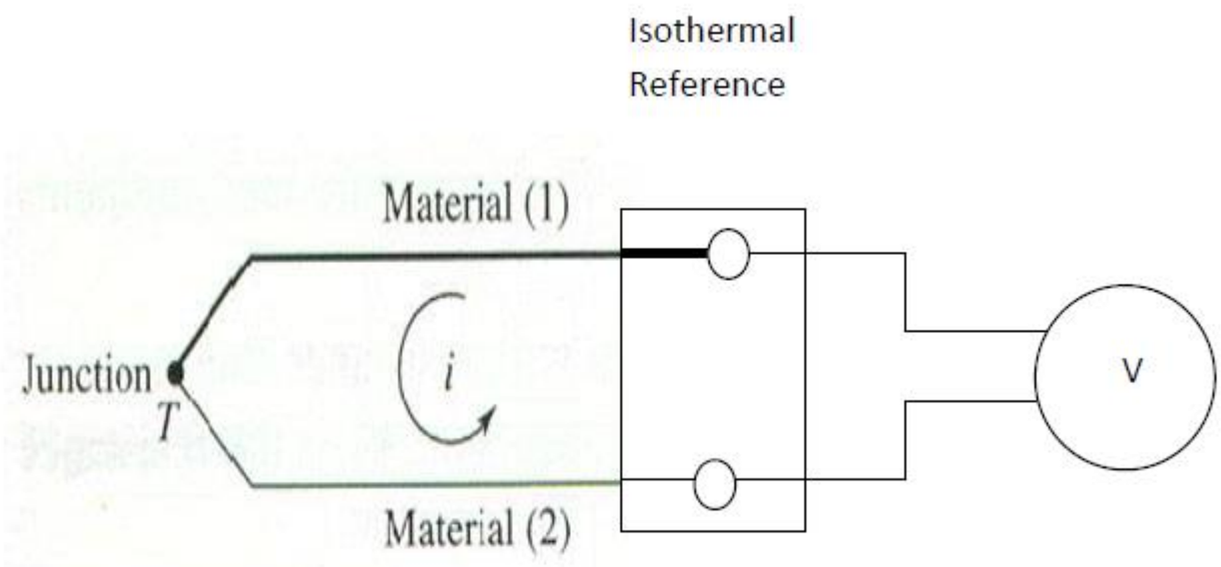
Where; $\cong \alpha($ Seebeck coefficient V/C0

(T2-T1) Temperature difference between junctions C

TEMPERATURES MEASUREMENT

THERMOCOUPLE

- To measure the voltage by voltmeter, the voltmeter lead cause a thermocouple, so to overcome this problem, we must connect the lead to **Isothermal** reference block.



TEMPERATURES MEASUREMENT

THERMOCOUPLE

- *Common commercially available thermocouples are specified by ISA (Instrument Society of America) types.*

ISA	Material (+ & -)	Temperature Range °C (°F)	Sensitivity@ 25°C (77°F) µV/°C (µV/°F)	Error*
E	Chromel & Constantan (Ni-Cr & Cu-Ni)	-270~1000 (-450~1800)	60.9 (38.3)	LT:±1.67°C(±3°F) HT:±0.5%
J	Iron & Constantan (Fe & Cu-Ni)	-210~1200 (-350~2200)	51.7 (28.7)	LT:±2.2~1.1°C (±4~2°F) HT:±0.375~0.75%
K	Chromel & Alumel (Ni-Cr & Ni-Al)	-270~1350 (-450~2500)	40.6 (22.6)	LT:±2.2~1.1°C (±4~2°F) HT:±0.375~0.75%
T	Copper & Constantan (Cu & Cu-Ni)	-270~400 (-450~750)	40.6 (22.6)	LT:±1~2% HT:±1.5% or ±0.42°C(±0.75°F)
R	Platinum & 87% Platinum/ 13% Rhodium (Pt & Pt-Rh)	-50~1750 (-60~3200)	6 (3.3)	LT:±2.8°C(±5°F) HT:±0.5%
S	Platinum & 90% Platinum/ 10% Rhodium (Pt & Pt-Rh)	-50~1750 (-60~3200)	6 (3.3)	LT:±2.8°C(±5°F) HT:±0.5%

Temperatures Measurement

Thermocouple

Thermocouple

EXAMPLE

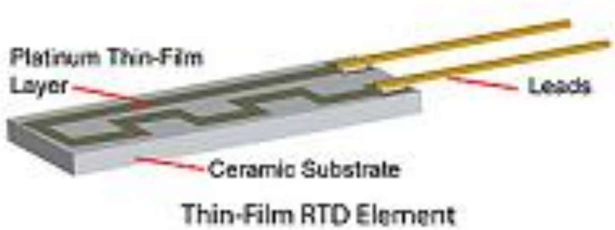
Assume a thermocouple with a seebeck coefficient of 58.5μV/oC has an output of 24mV. When the reference point is 21oC. what is the temperature of the measuring junction

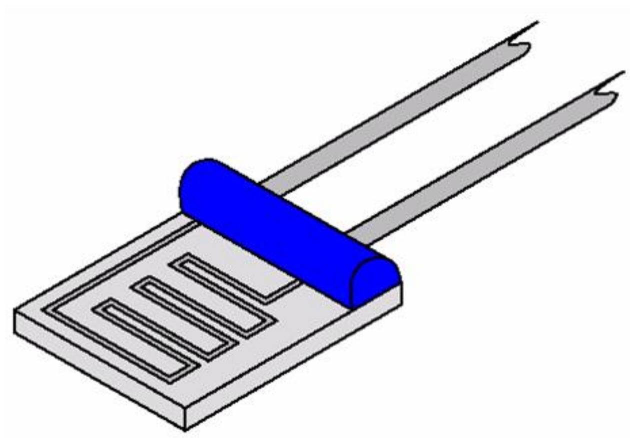
$$V \cong \alpha(T_2 - T_1)$$

Temperatures Measurement

3- Resistance Temperature Detector (RTD)

- Detectors use platinum, nickel, or resistance wire elements, whose resistance variation with temp. has a high **intrinsic** accuracy.
- They available in many configurations and sizes and as shielded and open units for both immersion and surface applications.





RTD

- The relationship between temperature and resistance of conductors is:

$$R_t = R_n(1 + \alpha t)$$

- where;

R_t resistance of RTD at certain temp (oC)

R_n resistance at 0 oC

α temperature coefficient , Ω/oC

t Temperature for which resistance is computed, oC

RTD

Example

A platinum RTD with α =0.00392Ω/ Ω/oC has a normal resistance of 100 Ω at 0oC.

(a) Compute the resistance at 450 oC

(b) At what temp is the resistance 142.6 Ω

$$R_t = R_n(1+\alpha T) = 100(1+0.00932*(450) = 276.4\Omega$$

$$t = \frac{1}{\alpha}(\frac{R_t}{R_n} - 1) = \frac{1}{0.00392}(\frac{142.6}{100} - 1) = 108.67^o C$$

4- THERMISTORS(THERMAL RESISTORS)

- A Thermistor is an electronic component that exhibits a **large change in resistance** with a change in its body temperature.
- (Thermal resistor ➔ Thermistor)

Temperatures Measurement

4- Thermistors(Thermal resistors)

- They have (**–ve**) temperature coefficient
- Thermistors are available in variety of packages.
- Manufactured from mixture of metal oxides (Nickel, Manganese, iron, cobalt, etc.)
- These oxides offer a **very large** resistance change for temperature

EXAMPLE (DATA SHEET):

The thermistor available on the IDP is a Philips 2322 640 63333.

Electrical Characteristics:

R_{25} value	33kΩ
R_{25} tolerance	+/-5%
Maximum dissipation	500mW
Dissipation factor	1.2mW/oK
Response time	1.2s
Thermal time constant	11sec

T_{amb} (oC)	R_T/R_{25}	α (%/oK)
-5	3.5881	4.64
0	2.8550	4.51
5	2.2860	4.38
10	1.8425	4.25
15	1.4941	4.13
20	1.2189	4.01
25	1.0000	3.90
30	0.8250	3.80
35	0.6841	3.69
40	0.5703	3.59
45	0.4777	3.50
50	0.4020	3.40

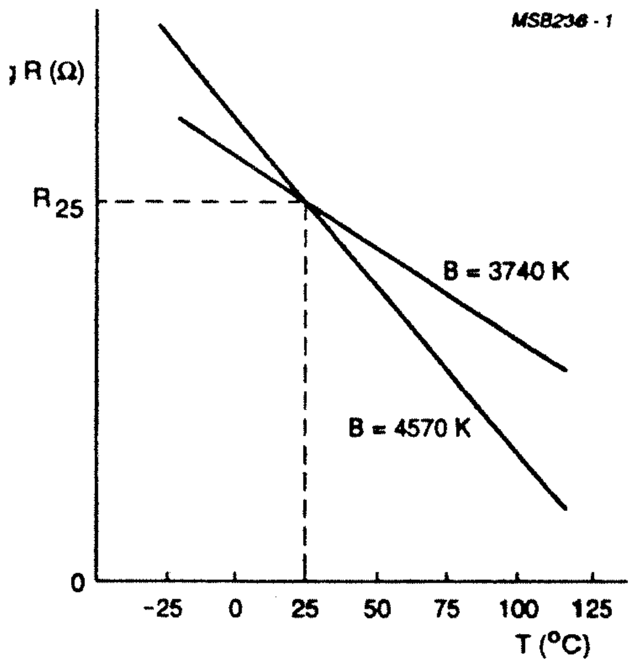


Fig.6 Typical plot of resistance as a function of temperature for an NTC temperature sensor.

CHARACTERISTICS

- High sensitivity
- Chemically stable
- Fast response times
- Physically small in size
- Have a negative temperature coefficient
- Have **limited** temperature rang 50oC-300oC

5- SEMICONDUCTOR TEMPERATURE SENSOR

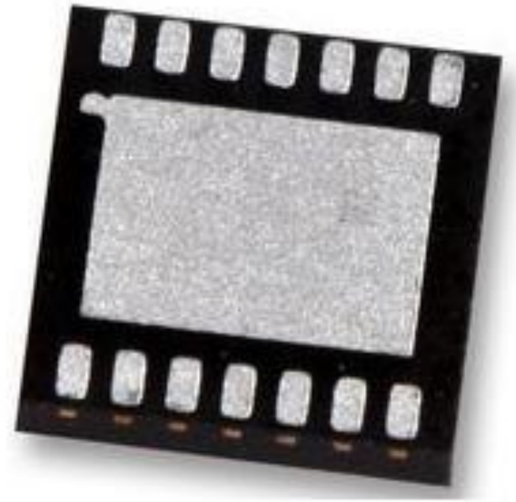
- The **semiconductor** (or IC for integrated circuit) temperature sensor is an electronic device.

Semiconductor Sensors characteristics

- 1- Linear outputs,
- 2- relatively small size,
- 3- limited temperature range (-40 to +150°C typical),
- 4- low cost,
- 5- good accuracy if calibrated

Description

- Temperature Sensor IC
- Output Type:Digital
- Sensing Accuracy Range:± 1°C
- Operating Temperature Range:-40°C to +125°C
- Supply Current:215µA
- Supply Voltage Range:3V to 5.5V



- Temperature Sensor IC
- Output Type:Digital
- Sensing Accuracy Range:± 1°C
- Operating Temperature Range:-40°C to +140°C
- Supply Current:570µA
- Supply Voltage Range:3V to 3.6V

6-Non Conducting Temperature Sensors

a- Radiation Thermometers (Pyrometers)

- are non-contact temperature sensors that can detect infrared radiation from a source
- Can used to measure hot Ovens temperatures
- Can be used to measure heat from -50oC
- The sensor converts the absorbed heat into Voltage or current
- Voltage or current can be calibrated to T

Infrared Thermometer with Laser Pointer

Measure from -54°F to 1000°F without contact

B- THERMAL IMAGE

- Infrared Thermometer with Laser Pointer
- **Measure from -54°F to 1000°F without contact**
- **Temperature Range -40 °C to 2000 °C**
- **Focusing Range of 30cm to infinity**
- **Used in airport for heat detection for some diseases (H1N1)**
- **Used in High voltage distribution Electricity station**

Strains Measurement

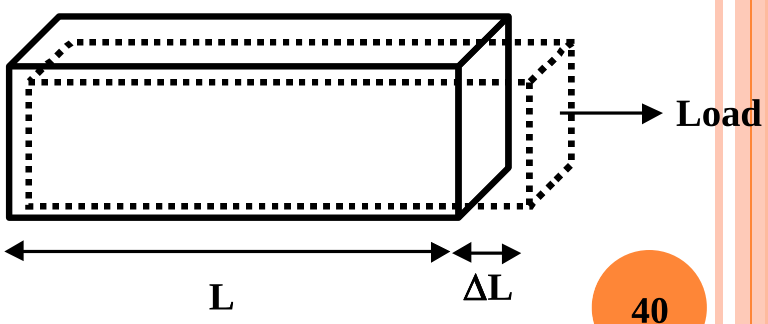
Strains Measurement

- All structural and solid objects deform to some range when subjected to external loads or forces.
- The deformation results in relative displacement that is related to the applied force.
- The effect of the applied force is referred to as a *stress* and the resulting deformation as a *strain*.

For example: the axial deformation is:

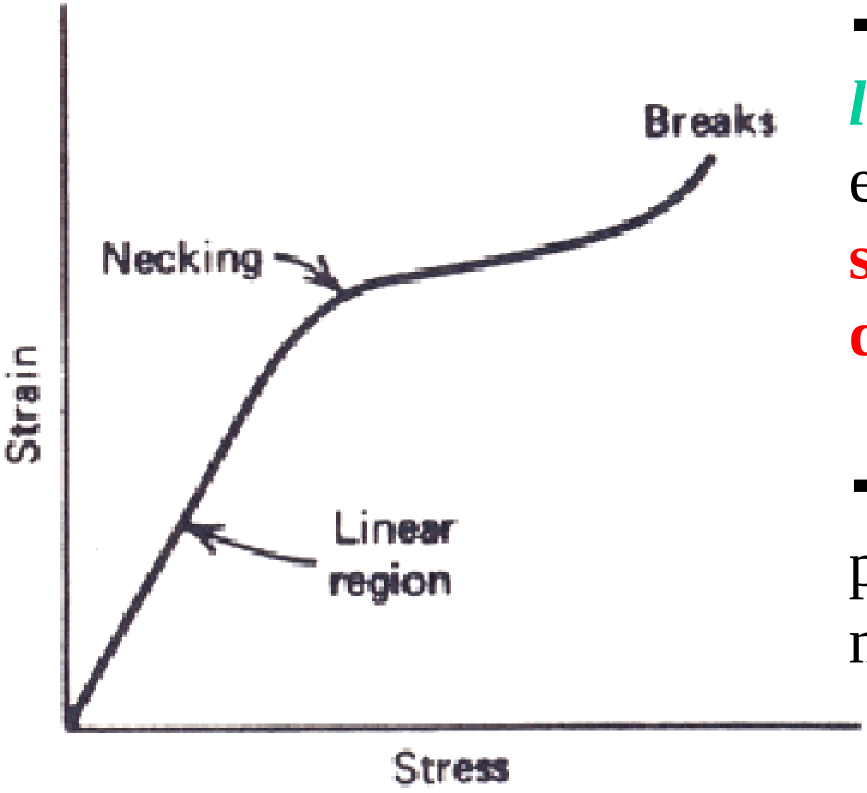
$\Rightarrow \Delta L/L = (L_2 - L_1)/L_1$

= strain (symbol: G)



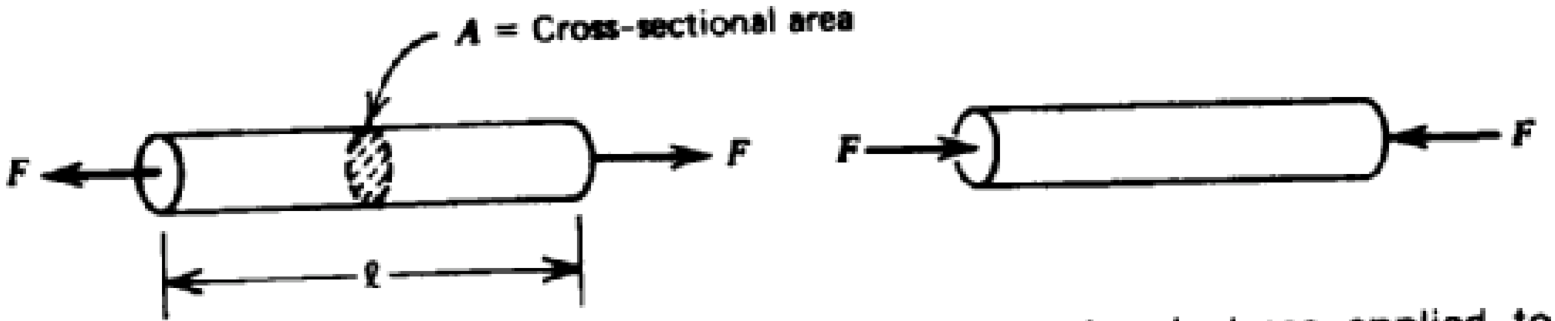
Stress – Strain Curve

IF A SPECIFIC SAMPLE IS EXPOSED TO A RANGE OF APPLIED STRESS AND THE RESULTING STRAIN IS MEASURE, A GRAPH AS BELOW RESULTS:



➔If the stress is kept within the ***linear region***, the material is essentially ***elastic*** in that if the **stress is removed, the deformation is also gone**.

➔But if the **elastic limit** is exceed, permanent deformation results. The material may be finally ***breaks***.



a) Tensile stress applied to a rod

b) Compressional stress applied to rod

(A) Stress :

- **Deformation of surface area by an applied force.**
- **Stress factor,** $S = F / A$ **(N/m²)**

(B) Strain :

- **Changes of length by either compression force or extension force**
- **Strain factor,** $G = \Delta\lambda / \lambda = \Delta L / L$
- **Tensile force,** G **= +ve**
- **Compression force,** G **= -ve**

Young's modulus of elasticity :

$$E = \text{stress} / \text{strain}$$

$$= \frac{S}{G}$$

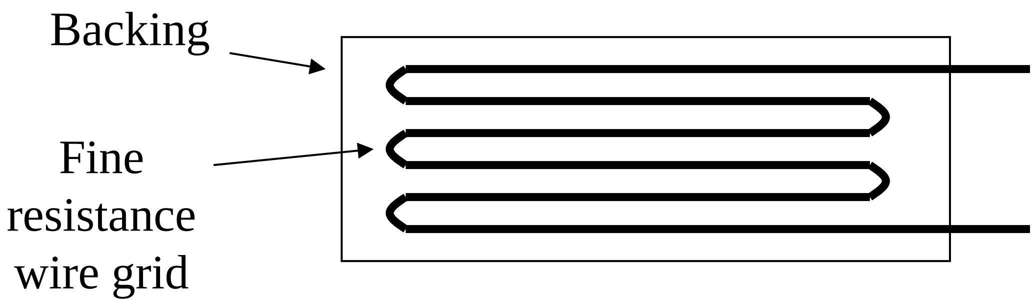
$$E = \frac{F / A}{\Delta L / L}$$

Strain Gauge

Principle of operation:

Change in strain
Change in resistance

The Construction of Strain Gauge



- The **strain gauge** is an example of a transducer that uses **electrical resistance variation in wires to sense the strain** produced by a force on the wires.
- It is **used for measuring** weight, pressure, mechanical force, or displacement.
- It is a thin plastic base supports thin ribbon of metal, joined in a zig-zag to form one long electrically conductive strip.
- It is usually cemented to the object undergoing stress.
- The entire device is typically 10mm long, with 16 or more parallel metal bonds.

When the plastic is stress, a tensile stress **tends to elongate the wire and increases its length**, ***l*** , and decrease its cross-sectional area ***A***.

=>The consequences is an increases in R.

For every materials, its resistance is always relate by the equation:

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

ρ : resistivity of the material

L : length of the conductor in m ***(L)***

A : area of the conductor in m^2

GF - Gauge factor (K),

$$K = (\Delta R / R) / (\Delta L / L)$$

$$= (\Delta R / R) / G$$

R = resistance without strain.

L = length in meter without strain.

ΔR **=** change in the resistance when strain is applied.

Δl **=** change in the ***length*** when ***strain*** is applied.

- The strain gauge's **resistance varies** as a function of the strain:

$$\Delta R = K.R.G$$

where

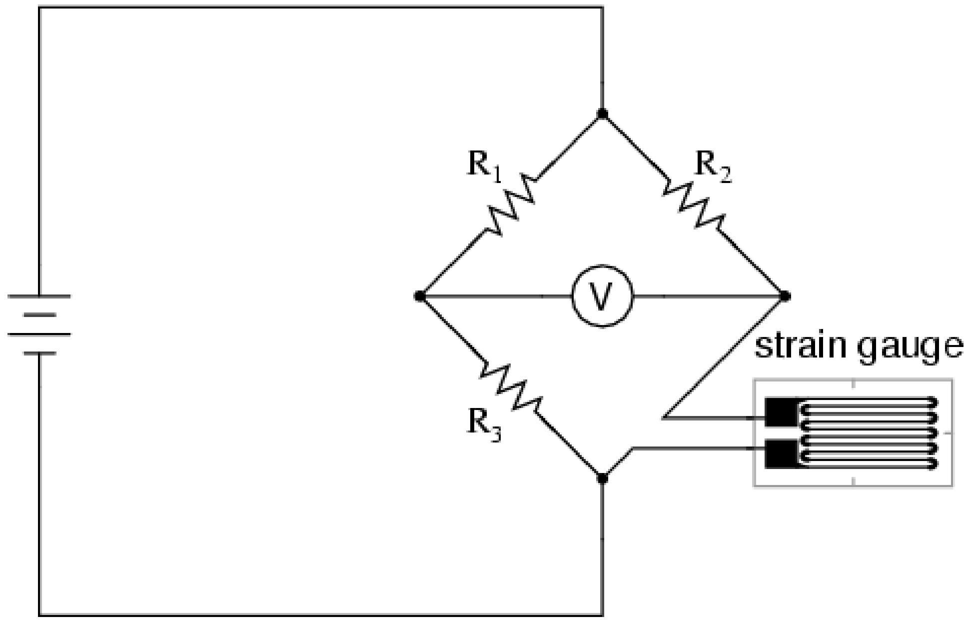
G is the **strain**, **($\Delta\lambda / \lambda$)**

R is the nominal resistance,

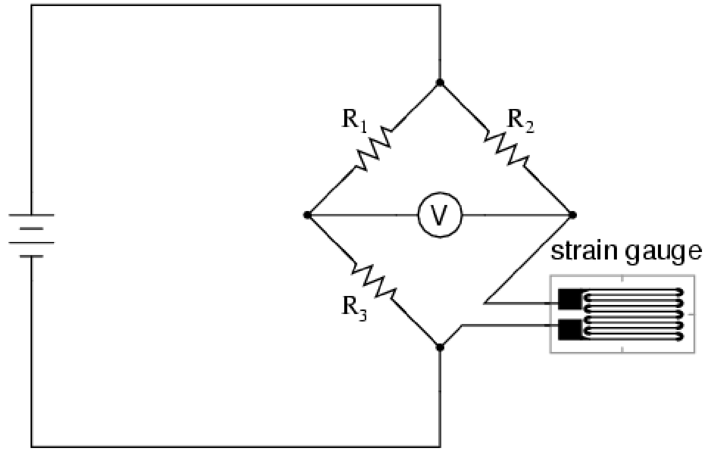
K is the **Gauge Factor (GF)**

MEASUREMENT USING STAIN GAUGE

- Thus, in order to use the strain gauge as a practical instrument, we must measure **extremely small changes in resistance** with high **accuracy**.
- To measure very small resistance with strain gauge, we use **Wheatstone Bridges**



- R2 in the diagram is set at a value equal to the strain gauge resistance with no force applied.
- The two ratio arms of the bridge (R1 and R3) are set equal to each other.
- With **no force applied** to the strain gauge, the bridge will be **symmetrically balanced** and the voltmeter will indicate zero volts, representing zero force on the strain gauge.
- As the strain gauge is either compressed or tensed, its resistance will ***decrease*** **or** ***increase*****, respectively. The** unbalancing of the bridge produce an indication at the **voltmeter**.



- The strain (ε) is found by

$$\varepsilon = \frac{4V_r}{GF(1+2V_r)}$$

Where

$$V_r = \left(\frac{V_{out}}{V_{in}}\right)_{strained} - \left(\frac{V_{out}}{V_{in}}\right)_{unstrained}$$

V_{out} o/p voltage from the unloaded bridge

V_{in} excitation voltage

Substitute these equations and neglect error due to nonlinearity, we get the strain to be :

$$\varepsilon = \frac{4V_{out}}{GF\,V_{in}}$$

Example

A stain gauge with normal resistance of 350Ω and GF=2.00 is connected into quarter bridge. The excitation voltage to bridge is set to 15V. the other bridge resistors, including the dummy gauge are 350 Ω. Assume the bridge is initially balanced with no strain and has an output of 45μV under strain

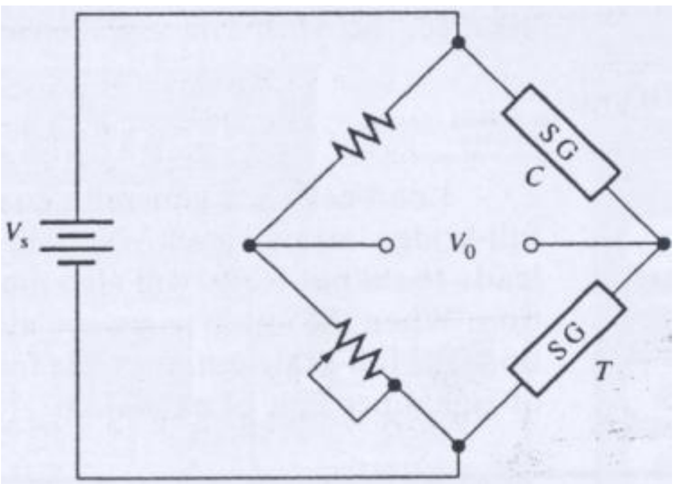
- (a) Compute the exact applied strain
- (b) Compute the applied strain assuming the bridge is linear

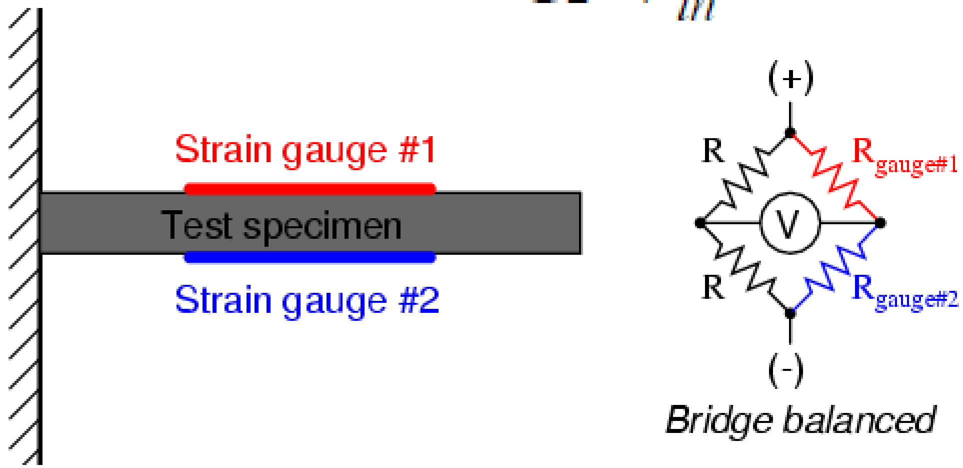
$$V_r = \left(\frac{V_{out}}{V_{in}}\right)_{strained} - \left(\frac{V_{out}}{V_{in}}\right)_{unstrained} = \left(\frac{45*10^{-6}}{15}\right) - \left(\frac{0}{15}\right) = 3*10^{-6}$$

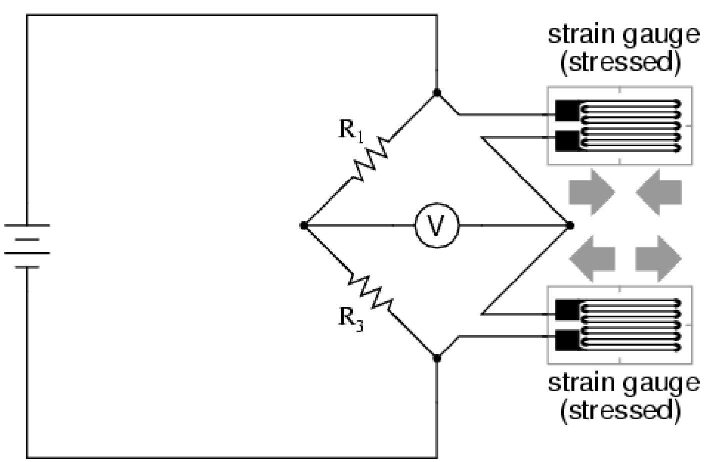
$$\varepsilon = \frac{4V_r}{GF(1+2V_r)} = \frac{4*3*10^{-6}}{2(1+2*3*10^{-6})} = 5.9996*10^{-6} = 5.9996\mu\varepsilon$$

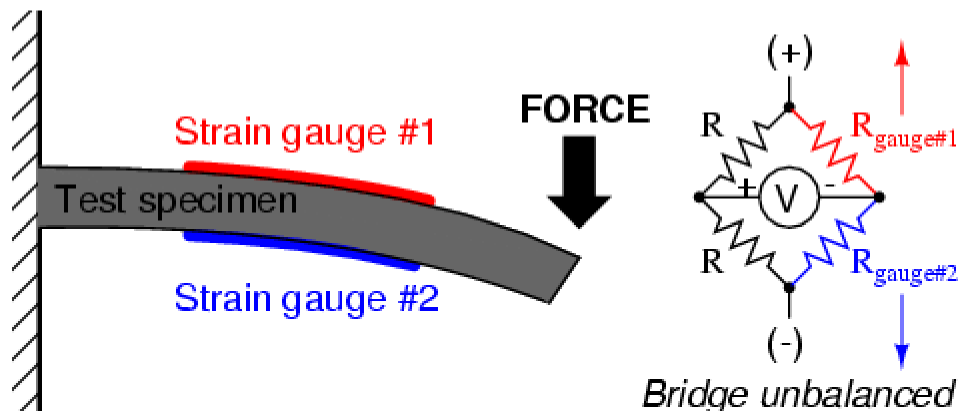
$$\varepsilon = \frac{4V_{out}}{GF\,V_{in}} = \frac{4*45*10^{-6}}{2*15} = 6*10^{-6} = 6\mu\varepsilon$$

- **2-half -bridge arrangements** $\varepsilon = \dfrac{2V_{out}}{GF\, V_{in}}$



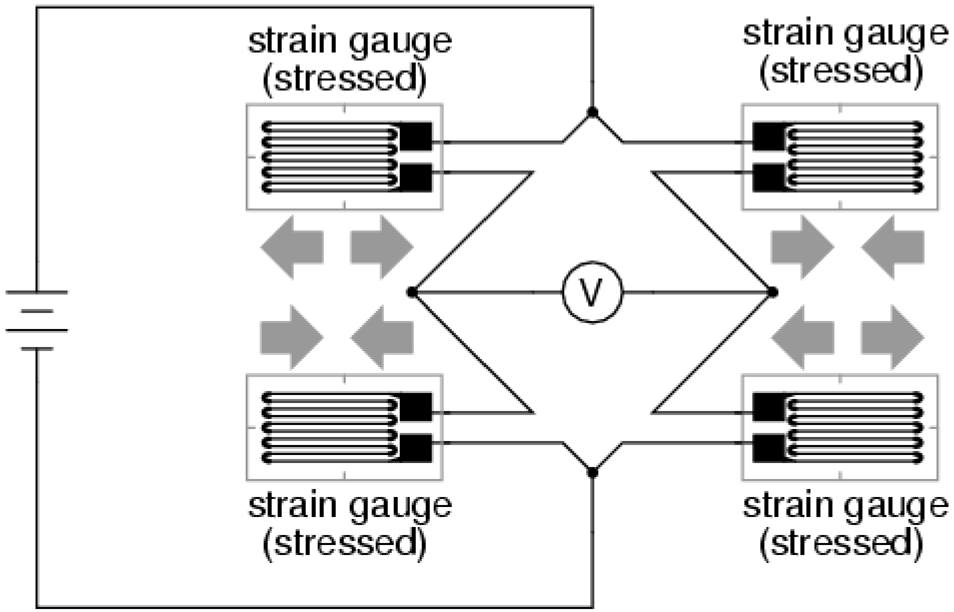






- **3-full -bridge arrangements**

$$\varepsilon = \frac{V_{out}}{GF\, V_{in}}$$



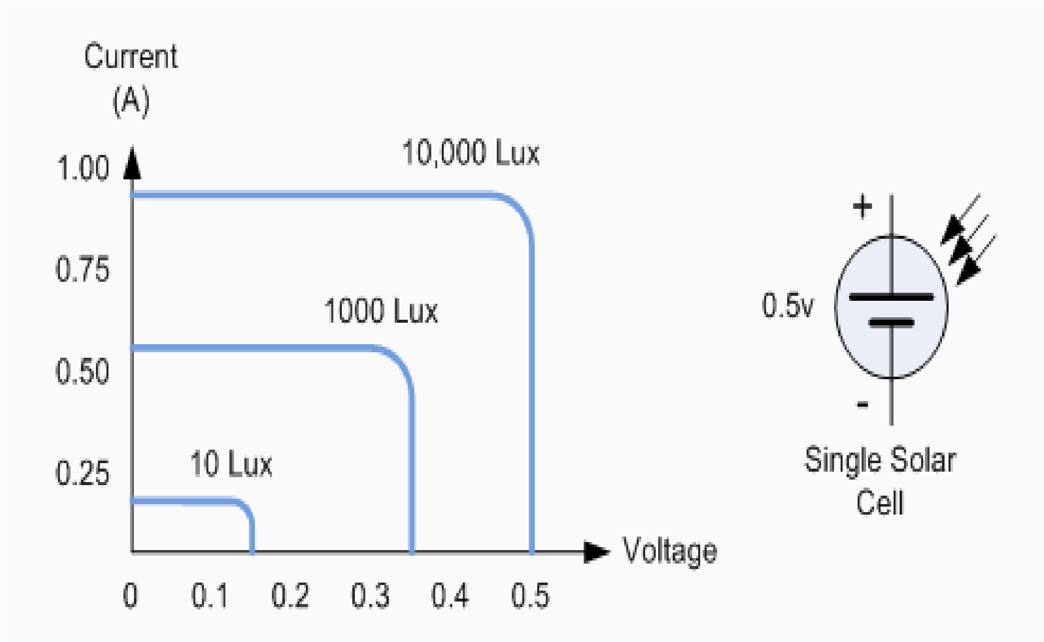
Metal Strain Gauges

- **Metal** strain gauges are formed from thin resistance wire or from thin sheets of ***metal foil***.
- They can be used under conditions of **extreme temperature**

Measurement of Light
Optical Transducer

1- Photo-voltaic Cells –

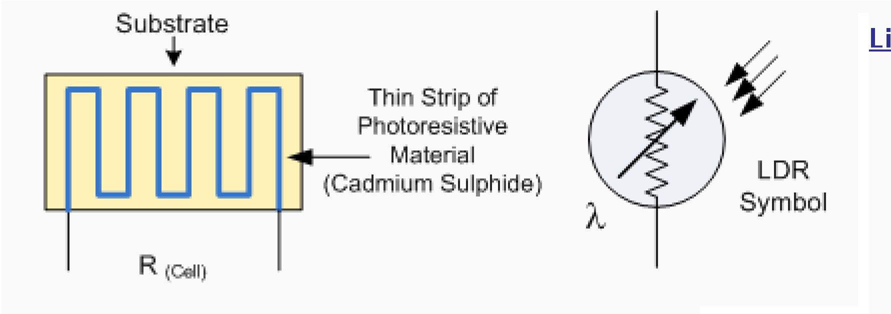
- These photo devices generate an **emf** in proportion to the **radiant light** energy received.
- The most common photovoltaic material is Selenium

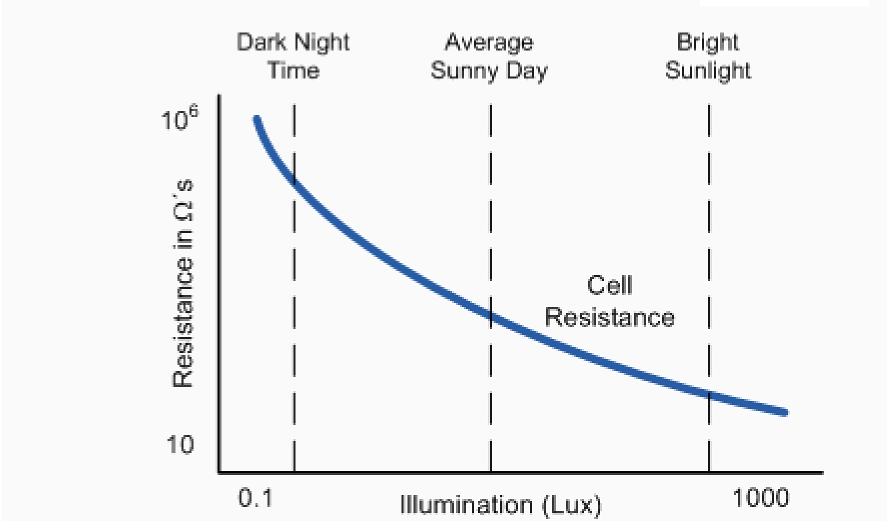


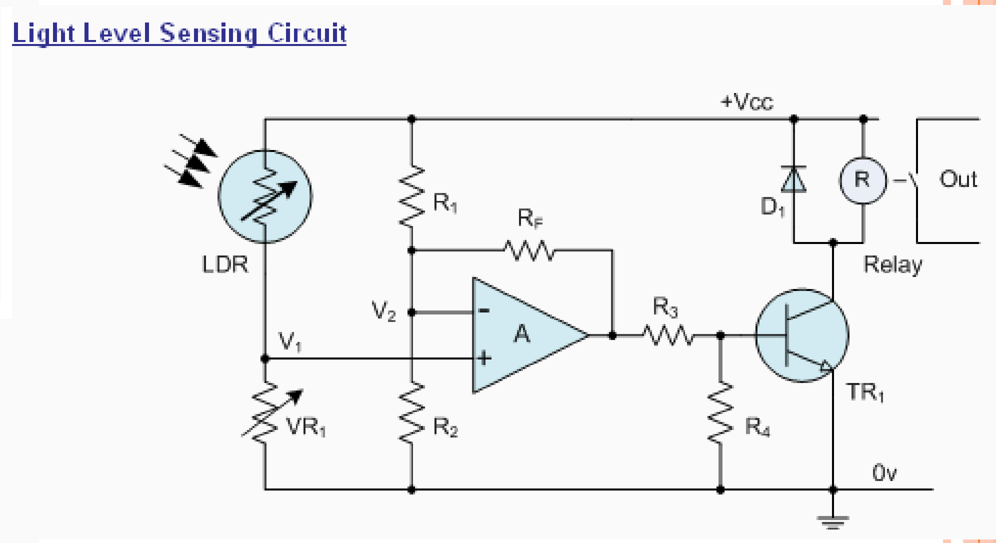
Optical Transducer

2- Photo-conductive Cells -

- These photo devices vary their electrical resistance when subjected to light.
- The most common photoconductive material is Cadmium Sulphide







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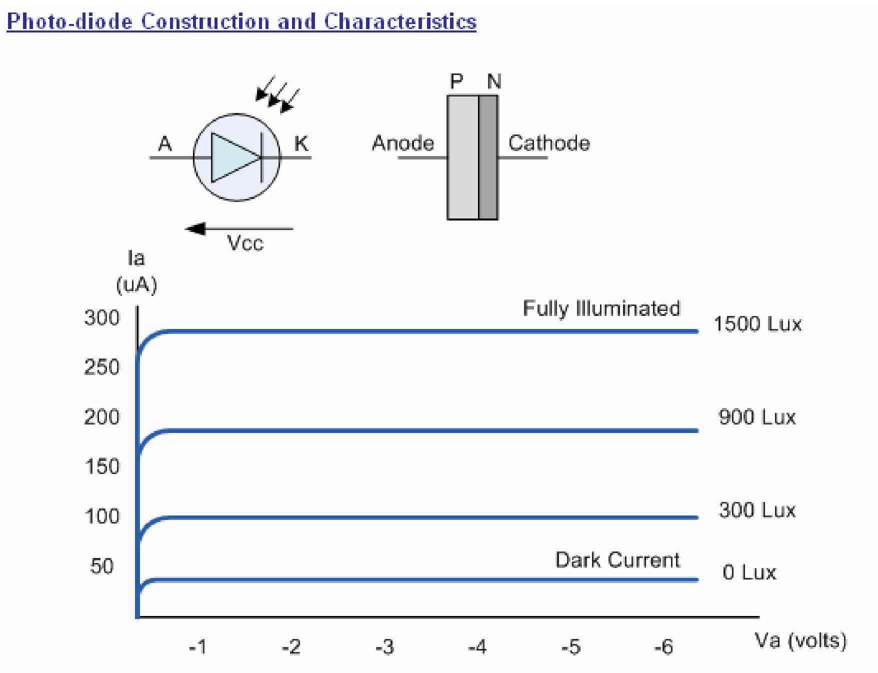
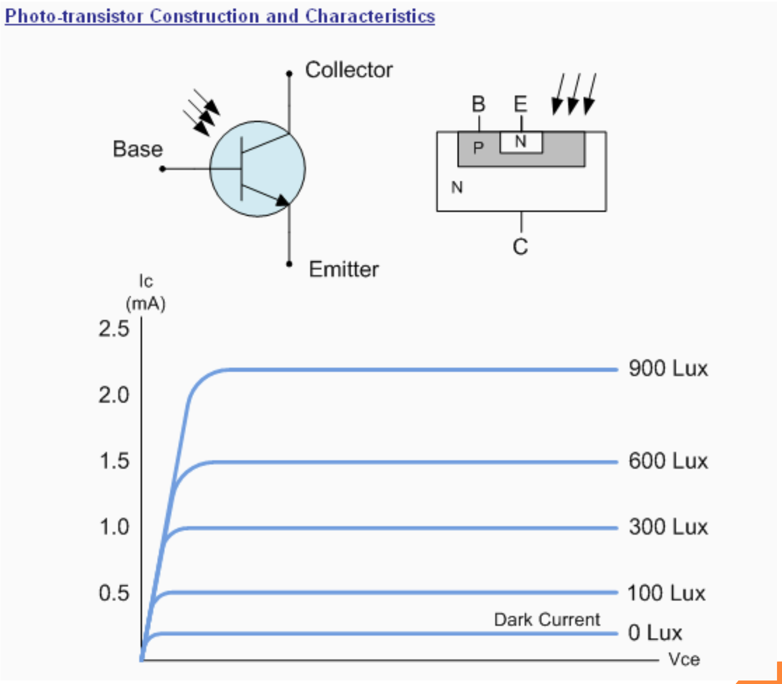
Optical Transducer

3- Photo-junction Devices –

- These photo devices are mainly semiconductor devices such as the **photodiode** or **phototransistor** which use light to control the flow of electrons and holes across their **PN-junction**.

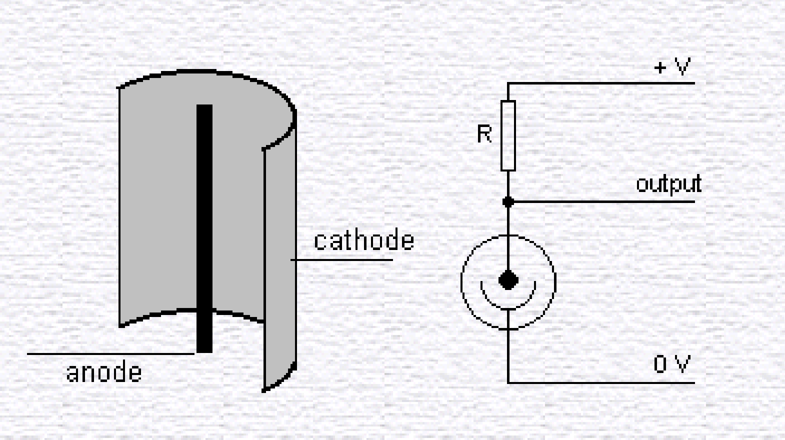


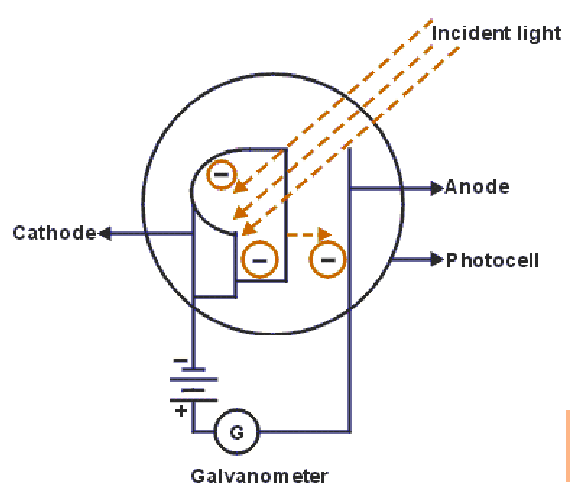


4- Photo-emissive Cells –

- These are photo devices which **release** free electrons from a light sensitive material such as caesium when **struck by light**

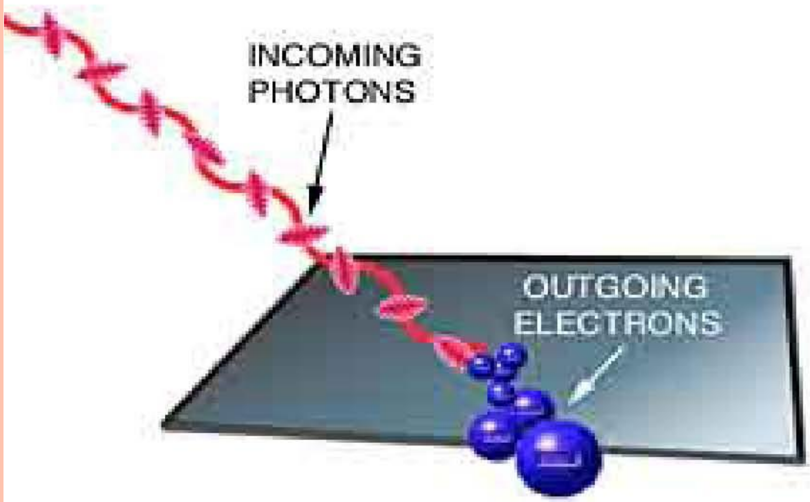
- The photo emissive cell consists of a glass envelope with a vacuum inside.
- The envelope also contains a light sensitive cathode and an anode.
- When light strikes the cathode negative electrons are emitted and are attracted by the positive anode.
- The value of this current is proportional to the intensity of light falling on the cathode.
- The PEC can be used as part of a potential divider circuit

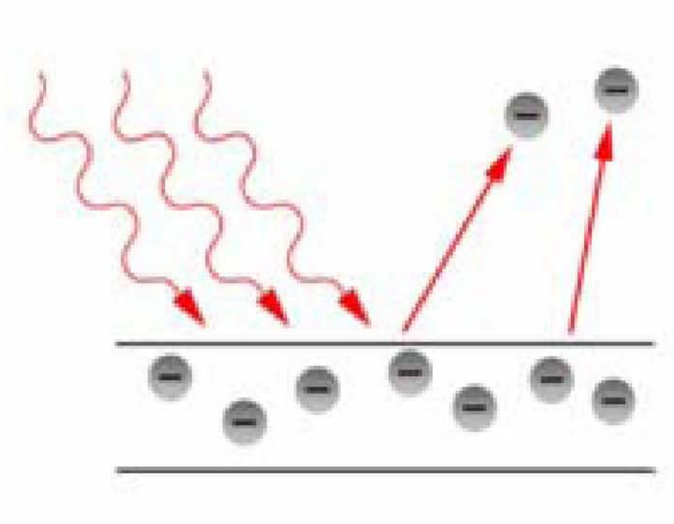




- **Photoelectric Effect**

  Is the emission of electrons from matter upon the absorption of electromagnetic radiation, such as ultraviolet radiation or x-rays.-refers to the emission, or ejection, of electrons from the surface of, generally, a metal in response to incident light.





Photoelectric Transducer

Can be categorized as: photoemissive, photoconductive, or photovoltaic.

No.	Types	Characteristics
1.	Photoemmisive	radiation falling into a cathode causes electrons to be emitted from cathode surface.
2.	Photoconductive	the resistance of a material is change when it's illuminated.
3.	Photovoltaic	Generate an output voltage proportional to radiation intensity

Measurement of Motion

- Motion can be along straight line or can be circular.
- • The measurement of motion includes:
  1- Displacement -
  2- Velocity –
  Tachometer (revolution-counter or RPM gauge)
  3- Acceleration -