Prepared by: Dr. Archana Sharma

Module 5

Physics of Sensors for IoT applications

(As per Revised syllabus SVU 2023)

1. Introduction to Sensors

Measurement is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processor(s) for controlling the whole system. For an electronic circuit or system to perform any useful task or function it needs to be able to communicate with the “real world” whether this is by reading an input signal from an “ON/OFF” switch or by activating some form of output device to illuminate a single light. In other words, an Electronic System or circuit must be able or capable to “do” something and Sensors and Transducers are the perfect components for doing this.

A sensor is a device that receives and responds to a signal. This signal must be produced by some type of energy, such as heat, light, motion or chemical reaction. Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal. Devices which perform an “Input” function are commonly called Sensors because they “sense” a physical change in some characteristic that changes in response to some excitation, for example heat or force and covert that into an electrical signal. Devices which perform an “Output” function are generally called Actuators and are used to control some external device, for example movement or sound. Actuators can be used to switch voltages or currents. An actuator is something that actuates or moves something. More specifically, an actuator is a device that converts energy into motion or mechanical energy. Therefore, an actuator is a specific type of a transducer.

There are many variables which affect our everyday lives: the speed of a car, the velocity of the wind, and the temperature in a home. In most of the situations these variables are continuously monitored.

The elements that sense these variables and convert them to a usable output are transducers. The word “Transducer” is the collective term used for both Sensors which can be used to sense a wide range of different energy forms such as movement, electrical signals, radiant energy, thermal or magnetic energy etc. Electrical Transducers are used to convert energy of one kind into energy of another kind, so for example, a microphone (input device) converts sound waves into electrical signals for the amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves

2. Selection Criteria:

A number of static and dynamic factors must be considered in selecting a suitable sensor to measure the desired physical parameter. Following is a list of typical factors:

(i) Range—Difference between the maximum and minimum value of the sensed parameter
(ii) Resolution—The smallest change the sensor can differentiate
(iii) Accuracy—Difference between the measured value and the true value
(iv) Precision—Ability to reproduce repeatedly with a given accuracy
(v) Sensitivity—Ratio of change in output to a unit change of the input
(vi) Resonance—The frequency at which the output magnitude peak occurs
(vii) Operating temperature—The range in which the sensor performs as specified
(viii) Deadband—The range of input for which there is no output
(ix) Signal-to-noise ratio—Ratio between the magnitudes of the signal and the noise at the output
(x) Response time-- It describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.

3. Characterization of Sensors

Generally, sensors can be classified into many types based upon the applications, input signal, and conversion mechanism, material used in sensor, production technologies or sensor characteristics such as cost, accuracy or range. Sensors are characterized depending on the values of some of the important parameters. The characteristics of sensors are described here in this section.

Types	Properties
Thermal sensor	Temperature, heat, flow of heat etc
Electrical sensor	Resistance, current, voltage, inductance, et
Magnetic sensor	Magnetic flux density, magnetic moment, e
Optical sensor	Intensity of light, wavelength, polarization,
Chemical sensor	Composition, pH, concentration, etc
Pressure sensor	Pressure, force etc
Vibration sensor	Displacement, acceleration, velocity, etc
Rain/moisture sensor	Water, moisture, etc
Tilt sensors	Angle of inclination, etc
Speed sensor	Velocity, distance etc

4. **Review of different types of sensors used in IoT**

The Internet of Things (IoT) is a network of physical devices, interfaces, and other items embedded with sensors, actuators, electronics, and connectivity. These devices collect data from their environment through IoT sensors and communicate it to systems. Data from **IoT**

sensors can be used better to understand a system or process for further actions. It can also prevent tragedies, decrease usage costs, and simplify your everyday life. They are one of the key components in IoT devices that collect data from surroundings and transmit them over networks. IoT Sensors are electronic chipsets or modules that sense the ambient or system conditions and transmit that data to the Internet through a gateway. These different sensors can function through physical contact, radiation, or magnetic fields.

IoT sensors measure the physical environment to collect data about things like temperature or air quality; they can then transmit the information via a network to gateways and the cloud. Once in the database, it can be analyzed further for the next course of action. IoT sensors are often combined with other technologies, such as AI and cloud computing.

There are two main types of sensors used in IoT applications:

- **Passive sensors:** detect changes in their environment without any dedicated power supply (e.g., temperature)
- **Active sensors:** require some form of power source to function (e.g., battery)

Passive sensor	Active sensor
Does not require external power	It requires power
It can only be used to detect energy when the naturally occurring energy is available	Provides its own energy source for illumination
No interference problem in the environment	Less interference problem
Can operate in the same environment condition	Can operate in different environment conditions
Sensitive to weather condition	Not sensitive
Not well suited for darkness conditions	Works well in darkness conditions
Difficulties in interpreting the output signals	Easy to interpret
Less control of noise	Better control of noise
Low price	High price
Examples: camera, Sonar	Examples: LASER, Radar etc

A wide variety of IoT sensors are available in the market for different use cases and applications. Here is the breakdown of popular types of IoT sensors and how they are used in IoT:

i. Temperature Sensors: Temperature sensors or thermal sensors can detect the temperature of an object, surface, or environment. A temperature sensor measures and sends the temperature of something or someone to a cloud or other devices via a network. For example, a device like a thermostat is temperature-controlled using temperature sensors.

ii. Humidity Sensing: Humidity sensor detects changes in moisture levels in different mediums like air, liquids, or solids. Humidity sensors detect the layer's response to electronic signals through an electronic circuit that converts electrical signals into digital ones.

iii. Fire Detection Sensors: They are used to detect smoke and heat. Such detection can be helpful in industrial operations and smart buildings. For example, fire detection can detect smoke and heat from combustion processes within combustion chambers like furnaces.

iv. **Light Sensors:** Light sensors are photodetectors that are designed to detect visible light. These sensors are used for smart street light automation to measure luminance from various light sources, such as sunlight. Light sensors can be useful to turn on lights when sunlight is low or unavailable automatically.

v. **Proximity Sensors:** Proximity sensors can help identify if there are nearby objects, animals, or humans passing by. Such sensors detect the presence and take further necessary actions such as turning on lights, recording camera footage for safety, or even helping with car parking. Infrared sensors, ultrasonic sensors, optical sensors, and LiDAR can help with such proximity detection.

vi. **Gas Detection Sensors:** Gas leak detectors can be used to identify a particular gas in the surroundings. It can help detect potentially dangerous gasses to avoid any harmful accident or effects on a particular user. An example of such detection can be detecting hydrogen sulphide, a gas found in natural gas pipelines that cause explosions if not detected in any leaks.

vii. **Soil moisture sensors:** These sensors are used in agriculture to monitor soil moisture levels, helping farmers make more informed irrigation and fertilizer application decisions.

viii. **Smart parking sensors:** Sensors in parking lots can detect when a parking spot is occupied and help drivers find empty spots quickly, reducing congestion.

ix. **Flood detection sensors:** Sensors placed in areas prone to flooding can monitor water levels and send alerts to residents and emergency responders.

x. **Health monitoring sensors:** Wearable sensors can be used to track a patient’s vital signs, allowing healthcare providers to monitor their condition remotely.

xi. **IR sensors:** Infrared (IR) sensors have become increasingly popular in IoT projects developed by IoT companies due to their ability to emit and detect infrared radiation to sense the surrounding characteristics. They are particularly useful in healthcare, as they simplify monitoring blood pressure and blood flow. They are also commonly used in everyday smart devices such as smartphones and smartwatches. Given their wide range of applications, IR sensors are poised to play an important role in the smart home industry.

xii. **Chemical sensors:** Those essential components are used in various industries to detect liquids or air composition changes. For example, in the industrial sector, chemical sensors can be used for environmental monitoring and process control to ensure that the production process is safe and efficient. In medicine, chemical sensors can detect glucose levels in a diabetic patient’s blood or analyze breath samples for disease diagnosis. In bigger cities, chemical sensors can monitor air quality and detect harmful chemicals to protect the population.

These are just a few examples of how sensors are being used in IoT to improve our daily lives. As technology continues to evolve, we can expect even more innovative sensor data applications in the future. Other than these, there are many IoT sensors available in the market to detect pressure sensors, acceleration detectors, air quality detectors, and many such IoT devices.

5. Mechanical Sensors

Mechanical sensors form a class of sensors that are sensitive to changes in mechanical properties. In combination with the micromachining technology, mechanical sensors such as cantilevers and acoustic sensors play an important role in molecular detection and many other biomedical applications. Mechanical sensors are used to measure variables such as position, velocity, acceleration, force, pressure, levels (such as a liquid in a tank), and also flow of a liquid.

5.1: Pressure Sensors: Pressure sensors work by measuring a physical change that happens, as a reaction to pressure differences. After measuring these physical changes, the information is converted into electric signals. These signals can then be displayed as usable data that the team can then interpret.

- **Piezoelectric pressure sensors:** The main working principle of the **piezoelectric pressure sensor** is the **piezoelectric effect**. The piezoelectric materials mainly used in **piezoelectric sensors** include quartz, potassium sodium tartrate, and dihydrogen phosphate. Among them, quartz/silica is a natural crystal. Piezoelectric sensors are mainly used in the measurement of acceleration, pressure, and force. The piezoelectric acceleration sensor is a commonly used accelerometer. It has the characteristics of simple structure, small size, light weight, and long service life. Piezoelectric acceleration sensors have been widely used in the measurement of vibration and shock in airplanes, automobiles, ships, bridges, and buildings, especially in the aviation and aerospace fields.

  Piezoelectric effect: When certain dielectrics are deformed by external forces in a specific direction, polarization will occur inside them. **Positive and negative charges** will appear on their two opposing surfaces. When the external force is removed, it will return to the uncharged state. This phenomenon is called a positive piezoelectric effect. With the change in the direction of the applied force the polarity of the charge also changes accordingly. Conversely, when an electric field is applied in the polarization direction of the dielectric, these dielectrics will also deform. After the electric field is removed, the deformation of the dielectric will disappear. This phenomenon is called the inverse piezoelectric effect. The type of sensor developed based on the dielectric piezoelectric effect is called a piezoelectric sensor.

- **Strain gauge pressure sensors**

  The working principle of the **metal resistance strain gauge** is that the resistance of the strain resistance adsorbed on the base material changes with the mechanical deformation. This effect is commonly known as the resistance strain effect. The resistance strain gauge is a sensitive device that converts the strain change on the test piece into an electrical signal. It is one of the main components of the piezoresistive strain sensor.

5.2: Motion Sensors: A motion sensor, or motion detector, is an electronic device that uses a sensor to detect nearby people or objects. Motion sensors are an important component of any security system. When a sensor detects motion, it will send an alert to your security system, and with newer systems, right to your mobile phone. If you have subscribed to an alarm monitoring service, motion sensors can even be configured to send an alert to your monitoring team.

- **Passive Infrared (PIR) Sensor:** Passive infrared sensors include a thin Pyroelectric film material, that responds to IR radiation by emitting electricity. This sensor will activate burglar alarm whenever this influx of electricity takes place. These sensors are commonly used in indoor alarms.

- **Ultrasonic Sensor:** Active ultrasonic sensors emit ultrasonic sound waves at a frequency above the range of human hearing. These waves bounce off objects in the immediate vicinity and return to the motion sensor. A transducer within the sensor acts as a waypoint for the signal—it sends the pulse and receives the echo. The sensor determines the distance between itself and the target by measuring the time between sending and receiving the signal. If the signal received is within specified parameters, the motion sensor will trigger, alerting you that someone or something is near the sensor.

- **Microwave Sensor:** These sensors emit microwave pulses. Much like an active ultrasonic sensor, the microwaves bounce off objects and return to the sensor. They actually cover a larger area than PIR sensors, but are more susceptible to electronic interference.
- **Tomographic Sensor:** These systems sense disturbances to radio waves as they pass from node to node of a mesh network. They have the ability to detect over large areas completely because they can sense through walls and other obstructions.

6: Environmental Sensors

Water, air, and soil pollution, food contamination, chemical exposures, ultraviolet radiation, and climate change are all factors that lead to a variety of diseases and health problems around the world. Toxic gases, heavy metal ions, pesticides, and fertilizers, among other contaminants, play a significant role in environmental concerns. Careful monitoring and control of these environmental hazards are urgently needed, which necessitates the use of cutting-edge techniques of environmental sensors to detect distinct environmental contaminants in a highly sensitive manner. Environmental sensors are connected objects capable of providing various types of information: location, position, the individual's movements, and contextual elements which can be compared to data collected via sensors embedded on or implanted in the individual, including the validation of alarms, like in the case of falls.

6.1: Temperature sensor: It is used to measure the amount of energy in the form of heat and cold produced by an object and system. It allows one to sense or detect any physical change to that energy and gives the output as analog or digital. Temperature sensors are used in various applications such as notification of environmental temperature, medical instruments, automobiles etc. According to application and its characteristics, many different types of temperature sensors are available.

- ***Thermostat:*** The thermostat is a kind of contact temperature sensor employing an electro-mechanical component and using two thermally different kinds of metals, nickel, copper, tungsten or aluminium etc, which are stuck together to form a Bi-metallic strip. When it is cold, one of the strips is contracted and its contacts are closed and current passes through the thermostat. When it is hot, one metal strip is expanded and opens the contacts to stop the flow of current.
- ***Thermistor***: The thermistor is another type of temperature sensitive device or resistance whose electrical resistance changes as the object temperature changes. This is made up of semiconductor materials. When temperature of the object or surroundings increases or decreases, resistance will also increase or decrease. How much the resistance will increase or decrease depends on the properties of the semiconductor material. Thermistors are used for precise temperature measurement, control and compensation.
- ***Thermocouple:*** The thermocouple is a device which is used for the measurement of the temperature variation in a measurement of sensors. The thermocouples are coupled with two metals joined together forming a junction. Thus, there are two junctions in the metals, one is called hot junction and other is called cold junction, also referred as measuring junction and reference junction, respectively. When the two junctions are at different temperatures, a voltage is developed across the junction, which is used to measure by the temperature sensor. The thermocouple is based on three main effects: Thomson effect, Seebeck and Peltier effect. It has broadest range of temperatures of all the temperature sensors, covering from −200 °C to 2000 °C.

6. 2: Humidity sensor: Humidity is the amount of water present in the surrounding air and a hygrometer is the device which measures humidity directly. Humidity is a non-electrical quantity that is converted into electrical quantity by using resistance, capacitance and impedance properties. There are various parameters that change due to humidity. There are five basic types of humidity sensor which are discussed below.

- **Resistive hygrometer**: In a resistive hygrometer, the main element is a material whose resistance changes with the change in humidity or relative humidity. A wire or electrode coated with hydroscopic salt (lithium chloride) can be used for measurement of the humidity.
- **Capacitive hygrometer**: In a capacitive hygrometer, the changes in humidity are caused by the changes in the capacitance. Dielectric medium is used in the capacitor and the capacitor consists of two electrodes or plates and a dielectric medium is there between the plates. There is also some hydroscopic material which exhibits the change in dielectric constant with the change in the humidity. Therefore, such hydroscopic material or salt can also be used for construction of a capacitive hygrometer.

- **Microwave refractometer**: A microwave refractometer consists of two cavities, each coupled with Klystron, a material which produces microwaves in which one cavity is filled with dry air and another cavity is filled with a mixture whose humidity is to be measured.
- **Aluminium oxide hygrometer**: In an aluminium oxide hygrometer, aluminium oxide is coated on anodized aluminium and this aluminium oxide exhibits a change in the dielectric constant with respect to changes in humidity. This change can be measured to measure the humidity by bridge or electric method.
- **Crystal Hygrometer**: In a crystal hygrometer, crystals are coated with hydroscopic materials (hydroscopic polymers). These crystals are used as frequency determination elements in the oscillator, and therefore just like with the capacitive hygrometer, if there is change in humidity then frequency also changes. Frequency changes due to the humidity as the mass of the crystal changes with amount of water absorbed by the coating. This change in frequency is measured.

Humidity sensors are used in industry, agriculture, the medical field, environment monitoring etc.

The sensor technologies have changed a lot in the last decade in terms of compactness, smartness and sensitivity. The traditional sensors such as photo-sensors, optical sensors, capacitive sensors and almost all sensors have been replaced by their integrated circuit forms such as MEMS (microelectromechanical system).

The sensors are embedded in all modern computing and navigation devices in compact forms and this is why an ordinary smartphone carries around 22 sensors for various purposes. The technologies of sensors have further advanced and become intelligent as smart sensors and available in wearable forms. This may be seen in smart watches, smart gadgets or a large application such as self-driving cars where hundreds of smart sensors are involved for seamless and smooth driving without assistance of a driver. The same can also be seen in robotics, medical diagnosis, brain–computer interface (BCI) and many more, where AI (artificial intelligence) has empowered the sensors with intelligence and smartness for emerging and modern applications such as industry, healthcare and sophisticated automation. The sensor technologies have become advanced now and cognitive and smart sensors are being used in all modern applications.

Module 5: SENSORS

1. Introduction about Sensors

For an electronic circuit or system to perform any useful task or function it needs to be able to communicate with the “real world” whether this is by reading an input signal from an “ON/OFF” switch or by activating some form of output device to illuminate a single light. In other words, an Electronic System or circuit must be able or capable to “do” something and **Sensors and Transducers** are the perfect components for doing this.

A sensor is a device that receives and responds to a signal. This signal must be produced by some type of energy, such as heat, light, motion or chemical reaction. Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal.

Devices which perform an “Input” function are commonly called **Sensors** because they “sense” a physical change in some characteristic that changes in response to some excitation, for example heat or force and covert that into an electrical signal. Devices which perform an “Output” function are generally called **Actuators** and are used to control some external device, for example movement or sound. **Actuators** can be used to switch voltages or currents. An actuator is something that actuates or moves something. More specifically, an actuator is a device that converts energy into motion or mechanical energy. Therefore, an actuator is a specific type of a transducer.

There are many variables which affect our everyday lives: the speed of a car, the velocity of the wind, and the temperature in a home. In most of the situations these variables are continuously monitored. The elements that sense these variables and convert them to a usable output are transducers. The word “Transducer” is the collective term used for both **Sensors** which can be used to sense a wide range of different energy forms such as movement, electrical signals, radiant energy, thermal or magnetic energy etc. There are many different types of sensors and transducers, both analogue and digital and input and output available to choose from. The type of input or output transducer being used, really depends upon the type of signal or process being “Sensed” or “Controlled” but we can define a sensor and transducers as devices that converts one physical quantity into another. Electrical **Transducers** are used to convert energy of one kind into energy of another kind, so for example, a microphone (input device) converts sound waves into electrical signals for the amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves and an example of this type of simple Input/Output (I/O) system is given below in Figure 1.

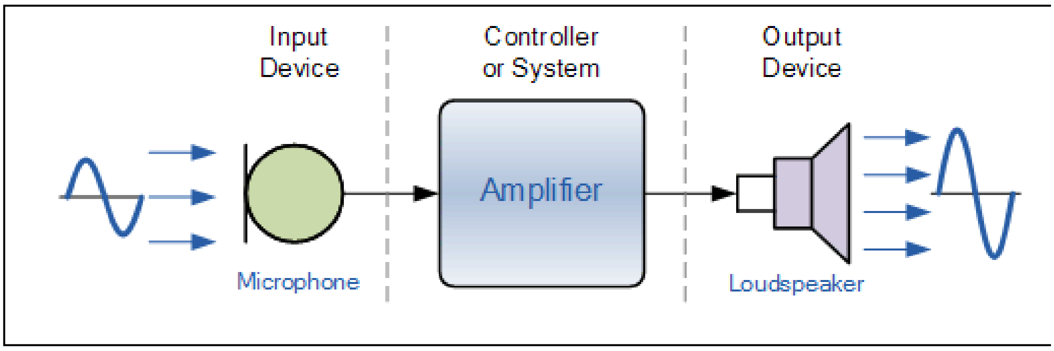


Figure 1: Electrical transducer

Because of the broad definition transducers come in many varieties converting many different types of energy.

2. Effects used in SENSORS Technology

Generally, sensors can be classified into many types based upon the applications, input signal, and conversion mechanism, material used in sensor, production technologies or sensor characteristics such as cost, accuracy or range.
The physical principles or the effects on which a sensor works is grouped in the following **Table 1**:

Domain	**Examples**
Mechanical	Length, Area, Volume, Torque, Pressure etc.
Electrical	Voltage, Current, Inductance, Resistance etc.
Magnetic	Field Intensity, Flux density etc.
Chemical	Electrochemical effect, spectroscopy etc.
Thermal	Temperature, Entropy, Heat flow etc.
Radiant	Intensity, Phase, Wavelength etc.

Based on the above principles we will be discussing about the following main effects that are being used in the sensors:

2.1. Piezoelectric effect:

Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for “push”. One of the unique characteristics of the piezoelectric effect is that it is reversible, meaning that materials exhibiting the **direct piezoelectric effect** (the generation of electricity when stress is applied) also exhibit the **inverse piezoelectric effect** (the generation of stress when an electric field is applied). When piezoelectric material is placed under mechanical stress, a shifting of the positive and negative charge centers in the material takes place, which then results in an external electrical field. When reversed, an outer electrical field either stretches or compresses the piezoelectric material. The piezoelectric effect is very useful within many applications that involve the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultrafine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, such as scanning probe microscopes (STM, AFM, etc).

2.1.1. Use in Sensors

The principle of operation of a piezoelectric sensor is that a physical dimension, transformed into a force, acts on two opposing faces of the sensing element. The detection of pressure variations in the form of sound is the most common sensor application, which is seen in piezoelectric microphones and piezoelectric pickups for electrically amplified guitars. Piezoelectric sensors in particular are used with high frequency sound in ultrasonic transducers for medical imaging and industrial nondestructive testing.

2.1.2. Piezoelectric Motors

Because very high voltages correspond to only tiny changes in the width of the crystal, this crystal width can be manipulated with better-than-micrometer precision, making piezo crystals an important tool for positioning objects with extreme accuracy, making them perfect for use in motors. In piezoelectric motors, the piezoelectric element receives an electrical pulse, and then applies directional force to an opposing ceramic plate, causing it to move in the desired direction. Motion is generated when the piezoelectric element moves against a static platform (such as ceramic strips).

2.1.3. Piezoelectric crystals

In a quartz crystal, if an electric voltage is applied in the direction of the electrical axis; mechanical stress is produced in the direction of Y-axis. Conversely, if mechanical stress is applied along the Y- axis, electric charges appear on the faces of the crystal along the X- axis. Consider an X-axis crystal plane of thickness ’t’ and length ‘l’ (along the optic axis). When an alternating voltage is applied across the faces of this plate along electrical axis, then alternating stresses and strains are set up both in its thickness and length. If the frequency of alternating voltage is equal to the natural frequency of vibration of the plate, then resonance occurs resulting in large amplitude of oscillation.

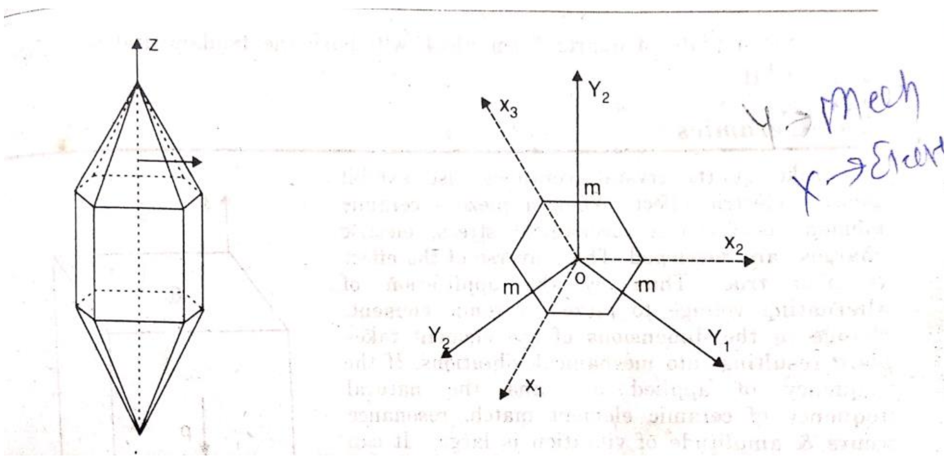


Figure 2 (a) Quartz crystal in natural form (b) shows the section of quartz crystal perpendicular to z- axis

The frequency of the thickness vibration of the crystal can be given as (along X-axis): $f = \frac{1}{2t}\sqrt{\frac{Y}{\rho}}$ where, Y is the young’s modulus; ρ is the density of the crystal and t is the thickness of the crystal.

2.2. Magnetostriction effect

Magnetostriction is a phenomenon observed in all ferromagnetic materials. It couples elastic, electric, magnetic and in some situations also thermal fields and is of great industrial interest for use in sensors, actuators, adaptive or functional structures, robotics, transducers and MEMS.

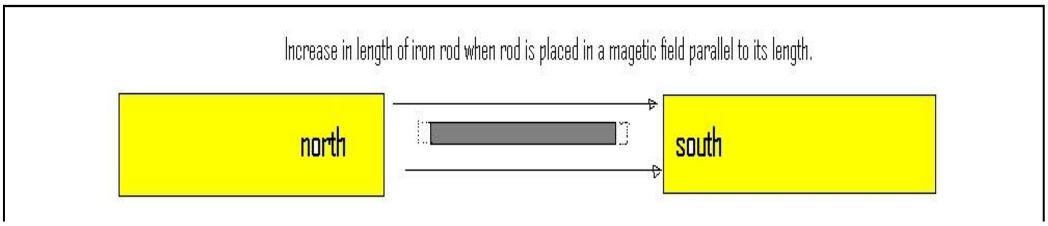


Figure 3: Magnetostriction effect

Magnetostriction is property of ferromagnetic materials that causes them to change their shape or dimension during the process of magnetization (as shown in Figure 3). The variation of materials magnetization due to the applied magnetic field changes the magnetostrictive strain until reaching its saturation value. The effect causes energy loss due to frictional heating in susceptible ferromagnetic cores.

Explanation: A magnetostrictive material develops large mechanical deformations when subjected to an external magnetic field. This phenomenon is attributed to the rotations of small magnetic domains in the material, which are randomly oriented when the material is not exposed to a magnetic field. The orientation of these small domains by the imposition of the magnetic field creates a strain field. As the intensity of the magnetic field is increased, more and more magnetic domains orientate themselves so that their principal axes of anisotropy are collinear with the magnetic field in each region and finally saturation is achieved. Material showing negative magnetostriction contract when the magnetic field increases in strength and expand when it decreases. The converse is true for materials showing positive values of magnetostriction. The magnetostriction coefficient is given as the ratio of change in length to the original length. Magnetostriction coefficient $\lambda = \frac{\delta L}{L}$.

The frequency of the oscillation is given as $f = \frac{1}{2L}\sqrt{\frac{Y}{\rho}}$ where, Y is the young's modulus; ρ is the density of the crystal and L is the length of the rod.

2.2.1. Magnetostriction Transducers:

A magnetostriction transducer is a device that is used to convert mechanical energy into magnetic energy and vice versa. Such a device can be used as a sensor and also for actuation as the **transducer** characteristics is very high due to the bi-directional coupling between mechanical and magnetic states of the material. This device can also be called as an electro-magneto mechanical device as the electrical conversion to its appropriate mechanical energy is done by the device itself. In other devices, this operation is carried out by passing a current into a wire conductor so as to produce a magnetic field or measuring current induced by a magnetic field to sense the magnetic field strength.

2.3. Magnetoresistance

The resistance of some of the metal and the semiconductor material varies in the presence of the magnetic field, which is called the magnetoresistance. The materials showing this property are known as the magnetoresistor. The magnetoresistor is used for determining the presence of a magnetic field their strength and the direction of the force. It is made of the indium antimonide or indium arsenide semiconductor material. The resistance of the magneto resistor is directly proportional to the magnetic field, i.e., their resistance increases with the increase in the intensity of magnetic field. The variation in resistance occurs because of the magneto effect. The magnetoresistor operates without physical contacts which is their major advantage. It has various applications like it is used in the hard disk of the computer, an electronic compass, for measuring the current etc.

Explanation: The working principle of a magneto resistor works on the concept which relates the direction of current and that of magnetic force. The magnetic field strength is highest, when the current is in same direction as that of the magnetic force, while weakest when it is 90^0 to the magnetic force. So how does it affect the resistance of the material? The answer is simple. What is current? Current is nothing but flow of free electrons. When a material is placed in the absence of any magnetic force, these electrons move in an orderly fashion, mostly in straight lines. As soon as it is subjected to magnetic force, the free electrons get excited and start moving in an indirect motion creating collision among them. These collisions restrict the flow of free electrons such that only few can flow freely. This means the flow of current is restricted, that means the electrical resistance has increased with increase in magnetic field strength. Thus, to put in short terms, the resistance of a magneto resistor increases with increase in magnetic field strength and decreases with a decrease in magnetic field strength.

2.4. Seebeck effect

Consider two wires of different metals (say copper and iron) joined at their ends to form two junctions A (Hot junction) and B (Cold junction) as shown in Figure 4. Such an arrangement is called a thermocouple. If one junction is kept hot and other cold, it is observed that the galvanometer shows deflection. This means an e.m.f. is generated in the circuit. The e.m.f. thus produced is called thermo e.m.f. and the resulting current is known as thermoelectric current. Hence, the phenomenon of generation of e.m.f. in a thermocouple when its two junctions are at different temperature is known as Seebeck Effect.

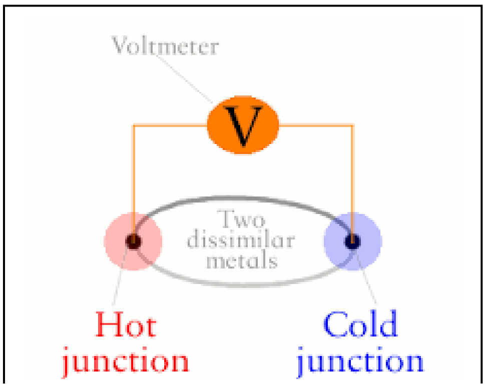


Figure 4: Seebeck effect

Explanation: Seebeck effect is a manifestation of the fact that if two points in a conductor (or a semiconductor) are maintained at different temperatures, the charged carriers (electrons or holes) in the hotter region, being more energetic (and, therefore, having higher velocities) diffuses towards region of lower temperature. The diffusion stops when the electric field generated because of movement of charges has established a strong enough field to stop further movement of charges. For a metal, carriers being negatively charged electrons, the colder end would become negative so that Seebeck coefficient is negative. For a p-type semiconductor on the other hand, holes diffuse towards the lower temperature resulting in a positive Seebeck coefficient. Performance of a thermocouple is determined by the Seebeck coefficient of the pair of metals forming the thermocouple.

2.5. Peltier Effect

The Peltier effect is the reverse phenomenon of the Seebeck effect. The electrical current flowing through the junction connecting two materials will emit or absorb heat per unit time at the junction to balance the difference in the chemical potential of the two materials (Figure 5).

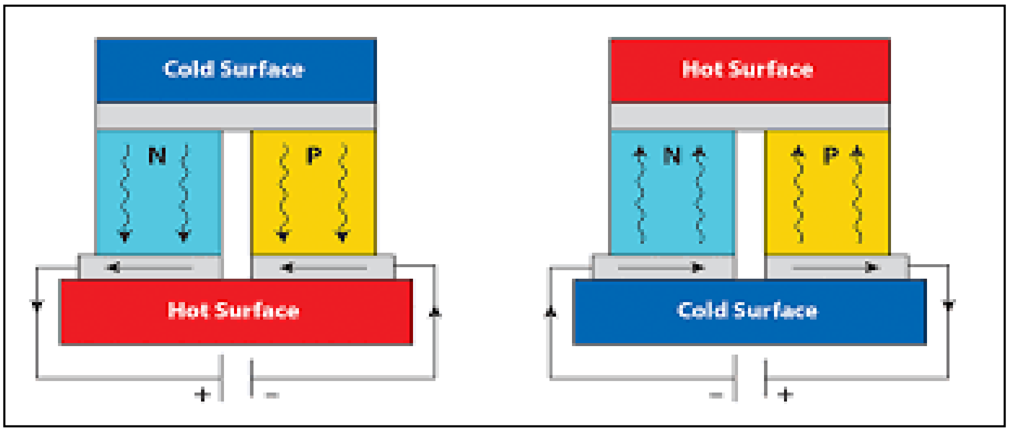


Figure 5: Peltier effect

Explanation: The Peltier effect states that, when an electric current flows through a circuit comprising dissimilar conductors, thermal energy is absorbed from one junction, and is discharged at the other, making the former cooler and the latter hotter. Thus, a thermal gradient develops from the flowing current, making the Peltier effect inverse of the Seebeck effect. The Peltier effect occurs due to the fact that, the average energy of the electrons involved in the transfer of electric current is different for different conductors. It is dependent on several factors, including the energy spectrum of the electrons, their concentration in the conductor, and their scattering under the influence of applied voltage. At the junction of two dissimilar conductors, the electrons pass from one conductor to the other. Depending upon the direction of flow of electric charge, these electrons will either transfer their excess energy to the surrounding atoms, or absorb energy from them. As such, in the former, heat is dissipated, while in the latter, it is absorbed.

2.5.1: Laws of thermocouple

Not in syllabus 2023

In measuring the emf in any circuit due to thermoelectric effects it is necessary insert a galvanometer somewhere in the circuit and this involves the presence of more than two original metallic junctions, it is important to formulate the laws accoprding to which the emfs produced by additional junctions may be added.

Law of Intermediate Metals: The insertion of an additional metal into any circuit does not alter the whole emf in the circuit provided that the additional metal is entirely at the temperature of the point of the circuit at which it is inserted. Consider a circuit consisting of three metals A, B & C as shown in the Figure 6.

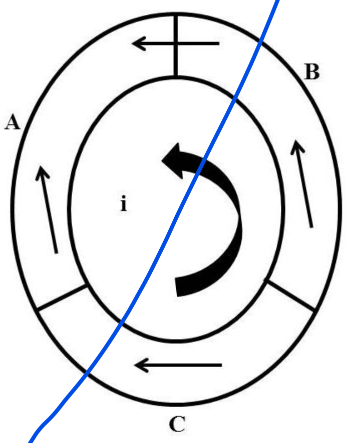


Figure 6: Law of Intermediate Metals

If in the circuit all the junctions are at the same temperature, then the algebraic sum of the three contact potential differences must be 0. i.e. $V_1+V_2+V_3=0$. When the temperature of junction AB is changed, the contact potential difference at this point changes to new value say V_1' but V_2 and V_3 remains the same. The resultant thermo e.m.f in the circuit will be given by $E=V_1'+V_2+V_3$. As $V_2+V_3 = -V_1$, the e.m.f e $=V_1'-V_1$. It shows that if the junction of the thermocouple of elements A & B is opened and third metal 'C' is inserted, the e.m.f for the couple AB remain the same provided both the junctions of the metal 'C' are at the same temperature.

Law of Intermediate Temperatures: Let e (1-2) be the e.m.f for the T1-T2 couple and e (2-3) be that for T2-T3 couple [See Figure 7 (a)]. If the junctions at the temperature T2 be placed in contact, no change is observed, because like metals at the same temperature are only joined. If then the junctions be opened to form the arrangement [See Figure 6 (b)], there is again no change in the resultant e.m.f; for the two contact destroyed, both had the same Peltier effect at temperature T2. We therefore conclude that e[1-3] = e[1-2] + e[2-3].

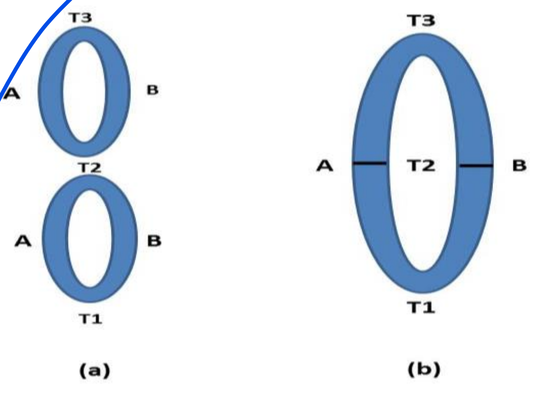
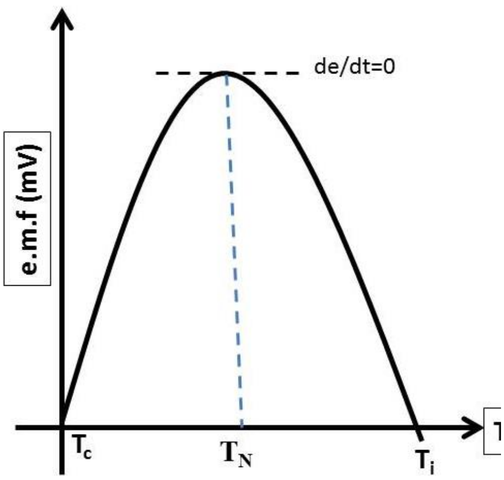


Figure 7: Law of Intermediate Temperature

Not in syllabus 2023: the marked ones in blue

In syllabus

Variation of e.m.f with temperature: In a thermocouple, as we increase the temperature of the hot junction, keeping the cold junction at 0° C, the thermo e.m.f increases with increase in temperature till it reaches to it its maximum limit. Then for further increase in temperature of hot junction, thermo e.m.f begins to decrease till it returns to zero.



$$E = at + \frac{bt^2}{2}$$

$$At \quad T_N; \quad \frac{de}{dt} = 0$$

$$\therefore a + bt = 0 \Rightarrow t = -\frac{a}{b}$$

Figure 8: Variation of e.m.f with respect to the Temperature

If we plot a graph of thermo e.m.f in mV and temperature difference between the two junctions, we get a parabola as shown in the Figure 8. The temperature of the hot junction at which the e.m.f achieves its maximum limit is called Neutral temperature T_N and it is constant for a given pair of dissimilar metals. The temperature at which the reversal of e.m.f takes place is called the Temperature of inversion T_i i.e. at T_i the direction of e.m.f is reversed. The value of neutral temperature can be calculated as $T_N = \frac{T_C + T_i}{2}$. T_N is independent of the cold junction temperature and inversion temperature. The inversion temperature T_i depends upon T_c and is as much above the neutral temperature T_N as the cold junction below it.

3. BIOLOGICAL SENSORS

The sensor integrates the biological elements with the Physiochemical transducer to produce an electronic signal is proportional to a single analyte and which is fetched into a detector.

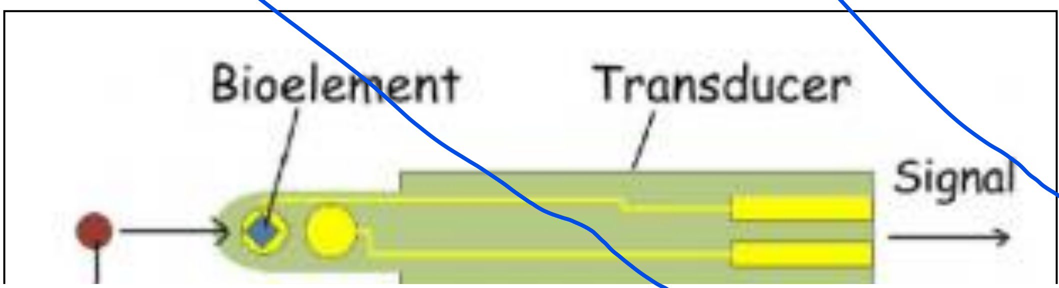


Figure 9: Biosensor