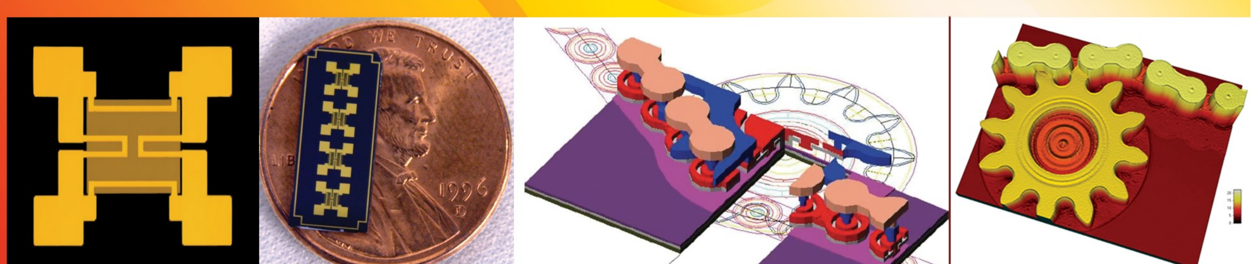
# Introduction to Transducers, Sensors and Actuators

## Introduction to Transducers, Sensors and Actuators PK Activity

## Participant Guide

Southwest Center for Microsystems Education



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**Southwest Center for Microsystems Education (SCME)**
**University of New Mexico**

## MEMS Fabrication Topic

# Introduction to Transducers, Sensors, and Actuators

**Primary Knowledge (PK)**

**This PK is part of the Learning Module**
**Transducers, Sensors, and Actuators**

Target audiences: High School, Community College.

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# Introduction to Transducers, Sensors, and Actuators

## Participant Guide

**Description and Estimated Time to Complete**

This unit familiarizes you with transducers, sensors, and actuators and helps you understand the difference between them. The following topics are discussed:

- Introduction to Transducers
- Introduction to Types of Transducers
- Introduction to Sensors
- Introduction to Types of Sensors
- Introduction to Actuators
- Introduction to Types of Actuators

The understanding of this information is important to microelectromechanical (MEMS) or microsystems technology. The majority of MEMS are or consists of sensors, transducers or actuators.

<u>Estimated Time to Complete</u>
Allow approximately 30 minutes.

## Introduction

*Three types of transducers:  light bulb,  microphone, and electric motors*

A transducer is any device which converts one form of energy into another.  Examples of common transducers include the following:

- A microphone converts sound into electrical impulses and a loudspeaker converts electrical impulses into sound (i.e., sound energy to electrical energy and vice versa).
- A solar cell converts light into electricity and a thermocouple converts thermal energy into electrical energy.
- An incandescent light bulb produces light by passing a current through a filament.  Thus, a light bulb is a transducer for converting electrical energy into optical energy.
- An electric motor is a transducer for conversion of electricity into mechanical energy or motion.

An actuator is a device that actuates or moves something.  An actuator uses energy to provide motion.  Therefore, an actuator is a specific type of a transducer.  Which of the previously mentioned examples is an actuator?

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. Based on this explanation of a sensor, you should see that sensors are used in all aspects of life to detect and/or measure many different conditions.  What are some sensors that you are familiar with or use daily?

Human beings are equipped with 5 different types of sensors.


Eyes detect light energy, ears detect acoustic energy, a tongue and a nose detect certain chemicals, and skin detects pressures and temperatures.  The eyes, ears, tongue, nose, and skin receive these signals then send messages to the brain which outputs a response.   For example, when you touch a hot plate, it is your brain that tells you it is hot, not your skin.

This unit describes the basic concepts of transducers, sensors, and actuators and introduces the different types in both the macro and micro scales.

**Objectives**

- Explain the differences between sensors, transducers, and actuators.
- Describe three types of sensors.  Include at least one microsensor.
- Describe three types of transducers. Include at least one microtransducer.

**Key Terms  (These terms are defined in the glossary at the end of this unit.)**

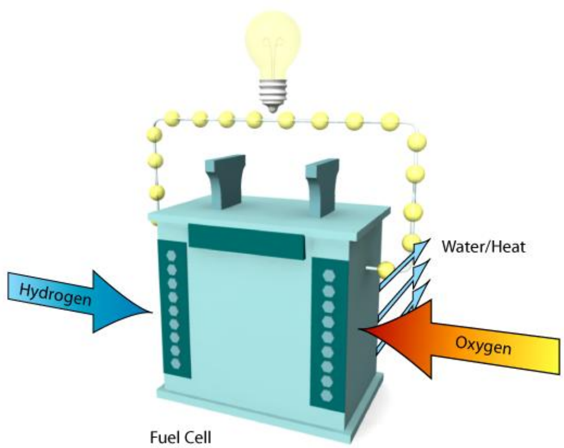
actuator
electroacoustic
electrochemical
electromagnetic
electromechanical
electrostatic
energy
mechanical
optical
photoelectric
sensors
transducer

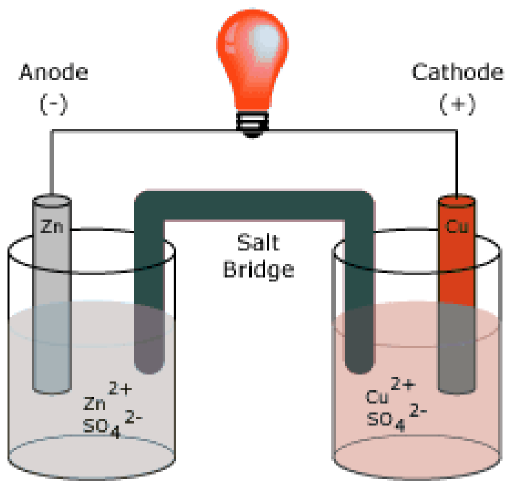
## Basic Concepts of Transducers

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 situations these variables are continuously monitored. It is these variables that are the feedback that is used to control the speed of a car, the operation of an air conditioner, heater levels, and oven temperatures. The elements that sense these variables and convert them to a usable output are transducers. For example, a transducer known as a thermocouple, is able to sense changes in temperature and produce output voltages representative of those changes.

A transducer is defined as a substance or a device that converts (or transfers) an input energy into a different output energy. Because of this broad definition, transducers come in many varieties converting many different types of energy. Following are different types of transducers.

## Electrochemical Transducers




*Converting a Chemical Reaction to Electrical Energy (left: Fuel Cell, right: battery)*

Some common electrochemical transducers include the following:
- pH probe – Converts chemical energy into an electrical energy
- Molecular electric transducer – Converts motion in an electrolytic solution into electrical energy
- Battery – Converts chemical energy directly into electrical energy
- Fuel cell – Converts the energy from a reaction within a fuel cell to electrical energy

Let's take a closer look at the electrochemical battery illustrated above. This battery converts chemical energy directly into electrical energy. A cathode and an anode (typically two dissimilar metals) are each immersed in an electrolyte solution containing salts of their respective metals. A medium (the salt bridge) separates the two electrodes, but allows ions to flow between the two solutions. Due to the flow of ions between the two solutions a potential difference (or voltage) is created. An electrical current flows if a wire is connected between the two pieces of metals. The amount of voltage developed between the cathode and the anode depends on the materials that make up the battery.

The fabrication of microbatteries has been a challenge but a challenge that needs to be met. Micro-sized sensors require micro-sized batteries in order to operate, especially when those sensors are placed in remote areas such as the ocean floor or embedded below the surface of bridges and roads. So how do you get a long-lasting electrochemical battery from a device that is smaller than the diameter of a strand of hair? "Traditional batteries have a two-dimensional array of positive and negative electrodes stacked on top of one another like sheets of paper. Increasing battery power means adding more electrode layers, more weight and more size."[1] One solution to this problem is to fabricate 3-dimensional microelectrode arrays consisting of high aspect ratio (tall and thin) carbon posts. These posts serve as the electrodes for electrochemical micro-sized batteries.[2]

**Electroacoustic, Electromagnetic, and Electrostatic Transducers**

Common electroacoustic transducers:

- Loudspeaker – Converts an electrical signal into sound
- Microphone – Converts sound waves in air into an electrical signal
- Hydrophone - Converts sound waves in water into an electrical signal.

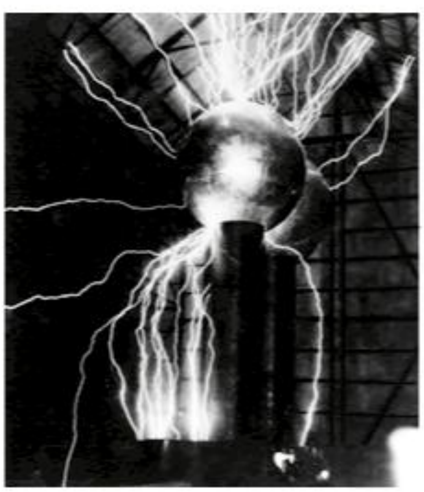
Common electromagnetic transducers:

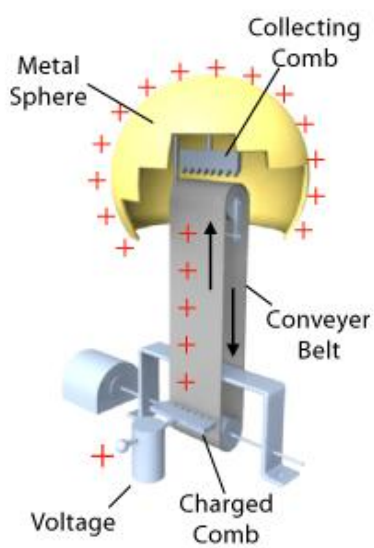
- Magnetic cartridge – Converts motion in a magnetic field into an electrical energy
- Generator – Converts motion in a magnetic field into electrical energy

Common electrostatic transducers:

- Electrometer – Converts static or energy from a vibrating reed into electricity
- Van de Graaf generator – Converts static into high voltage *(see figure below)*

MEMS hydrophones are currently being used to detect various sounds within our oceans. Anchored to the bottom of the ocean or dragged behind a ship, micro-sized hydrophones detect the sounds generated by ships, submarines, ocean waves and marine animals They also hear tertiary waves created by earthquakes or any movements within the earth's crust.[3]



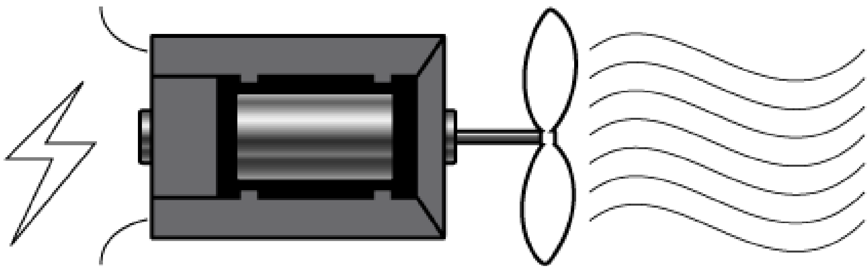



*Van de Graaf Generator: Converts a built up charge of static electricity into a high voltage*

## Electromechanical Transducers

Electromechanical Transducers – (Some are also called actuators)

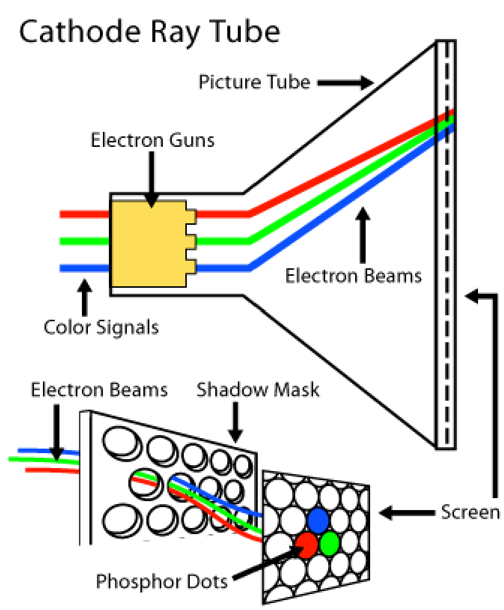
- Strain gauge – Converts the deformation (strain) of an object into electrical resistance
- Galvanometer – Converts the electric current of a coil in a magnetic field into movement
- Generators – Converts mechanical energy (motion) into electrical energy.
- Motor – Converts electrical energy into mechanical energy *(graphic below)*



**A motor converts electrical energy into mechanical energy**

As with other types of transducers, electromechanical transducers come in all sizes from macro to micro. Microgenerators have been developed that may someday replace batteries. A Georgia Tech MEMS Project has developed a 10 millimeter wide generator that spins a micro-sized magnet above a mesh of coils fabricated on a chip. The micromagnet spins at 100,000 rpm, producing 1.1 watts, enough power for a cell phone.[4]

## Other Types of Transducers




*Converts Electrical Signals into Light Energy*

Photoelectric Transducers:

- Cathode ray tube (CRT) –Converts electrical signals into light energy for a visual output *(graphic above)*
- Light bulb –Converts electrical energy into visible light and heat *(explained in next section)*
- Laser diode – Converts electrical energy into light energy
- Photodiode - Converts light energy into electrical energy

Thermoelectric Transducers:

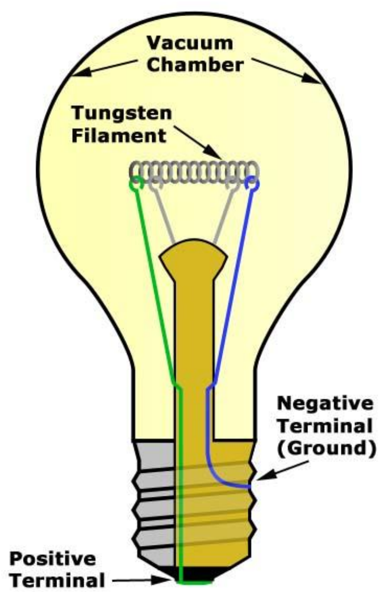
- Thermocouple – Converts heat energy into electrical energy
- Temperature sensitive resistor (Thermister) – a variable resistor affected by temperature changes (heat energy to electrical energy)

Other types of Transducers:

- Geiger-Müller tube – Converts radioactive energy into electrical energy
- Quartz Crystal – Converts mechanical stress into electricity (electrical energy)

Micro-sized transducers that use temperature, chemical reactions, and mechanical stress to produce changes in voltage, resistance, resonant frequency, or light are used throughout microsensors. Such transducers are used in MEMS pressure sensors, temperature sensors, chemical sensor arrays, and optical modulators.

## The Incandescent Light Bulb (a transducer)




*Schematic of an incandescent light bulb. A power source's positive and negative terminals are connected to the bulb's terminals. An electrical current flows through the filament. The resistance of the tungsten filament converts the electrical energy into heat and light.*

Light bulbs convert electrical energy into light and heat.  Specifically, an incandescent light bulb consists of a vacuum chamber (the glass bulb), a filament (typically made of tungsten), and a positive and a negative terminal (or contain points) (*see the figure above*).  The negative terminal is the part that screws into the socket to prevent electrical shock.  A voltage source is placed across the positive and negative terminals causing current to flow through the filament.  Due the electrical resistance of the tungsten filament, the filament heats up and gives off light (i.e., electrical energy, to heat energy, to light energy).

**Basic Concepts of Sensors**

Sensors detect the presence of energy, changes in or the transfer of energy.  Sensors detect by receiving a signal from a device such as a transducer, then responding to that signal by converting it into an output that can easily be read and understood.  Typically sensors convert a recognized signal into an electrical – analog or digital – output that is readable.  In other words, a transducer converts one form of energy into another while the sensor that the transducer is part of converts the output of the transducer to a readable format.

Consider the previous examples of transducers.  They convert one form of energy to another, but they do not quantify the conversions.  The light bulb converts electrical energy into light and heat; however, it does not quantify how much light or heat.  A battery converts chemical energy into electrical energy but it does not quantify exactly how much electrical energy is being converted.   If the purpose of a device is to quantify an energy level, it is a sensor.

So let's take a look at a sensor that should be familiar to everyone – a temperature sensor.

*Digital Readout and Mercury Thermometers*

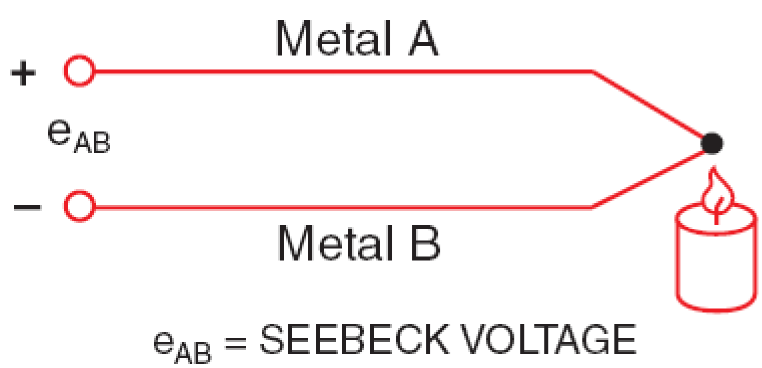
An environmental energy condition that is commonly sensed is temperature. A thermometer senses and converts temperature into a readable output, thus it is a sensor. This output can be direct or indirect. A mercury thermometer which uses a level of mercury against a fixed scale is a direct output. A digital readout thermometer is an indirect output. *(see images above)* For a digital readout thermometer, a converter is used to convert the output of the temperature transducer to an input for the digital display. The measured temperature is displayed on a monitor. The thermometer is both a transducer (usually a thermocouple that transfers heat energy to voltage) and a sensor (quantifies the transducer output with a readable format).

The mercury thermometer utilizes mercury's property of expanding or contracting when heated or cooled, respectively. In a mercury thermometer a temperature increase is sensed by the mercury contained in a small glass tube. The thermal energy from the temperature increase is transferred into the mercury (the transducer) causing the mercury to expand. The expansion of mercury is scaled to numbers on the tube indicating the temperature.
Following are different types of sensors which are classified by the type of energy they detect.

**Thermal Sensors**

- Thermometer – measures absolute temperature (*discussed in the previous section)*
- Thermocouple gauge– measures temperature by its affect on two dissimilar metals
- Calorimeter – measures the heat of chemical reactions or physical changes and heat capacity

A thermocouple is a device that directly converts thermal energy into electrical energy. When two dissimilar metal wires are connected at one end forming a junction, and that junction is heated, a voltage is generated across the junction (*see the figure below)*. If the opposite ends of the wires are connected to a meter, the amount of generated voltage can be measured. This effect was discovered by Thomas Seebeck, and thus named the Seebeck Effect or Seebeck coefficient. The voltage created in this situation is proportional to the temperature of the junction..



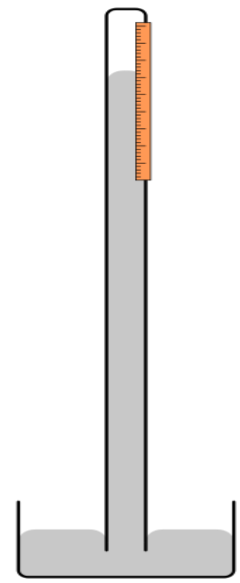

*Thermocouples operate due to the Seebeck Effect*

**Mechanical Sensors**

- Pressure sensor – measures pressure
- Barometer – measures atmospheric pressure
- Altimeter – measures the altitude of an object above a fixed level
- Liquid flow sensor – measures liquid flow rate
- Gas flow sensor – measures velocity, direction, and/or flow rate of a gas
- Accelerometer – measures acceleration

Barometers determine the level of atmospheric pressure. The figure to the right illustrates a simple mercury barometer. A tube is initially filled with mercury and then inverted into a dish. Some of the mercury from the tube flows into the dish (reservoir) creating a vacuum in the upper portion of the tube. The flow stops when equilibrium is reached between the pressures on the surfaces of the mercury inside the tube and in the reservoir. When the atmospheric pressure increases, the level of the mercury in the tube rises. This is due to an increase in pressure on the mercury's surface in the reservoir. A decrease in the level of mercury in the tube is seen when the atmospheric pressure drops.

Markings on the tube *(in orange)* indicate the barometric pressure by measuring the level of mercury. Therefore, a barometer converts the energy from the pressurized gases of the atmosphere into a change in the mercury's height (potential energy) in the column, as read by the markings. Question for thought: How does a mercury barometer differ from a mercury thermometer?



*Schematic of a mercury barometer*

Another type of barometer is the aneroid barometer which senses changes in atomospheric pressure by the expansion or compression of an aneroid capsule (a thin, disk-shaped capsule, usually metallic, and partially evacuated of gas). An external spring is connected to the capsule and a needle is mechanically linked to the spring. As the pressure on the outside of the capsule increases, the spring moves the needle indicating an increase in barametric pressure. As the pressure drops, the spring moves in the opposite direction as the capsule expands, moving the needle to show a decrease in barametric pressure.

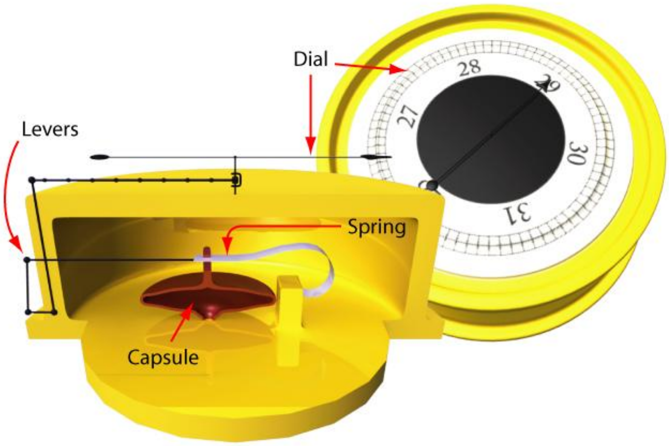
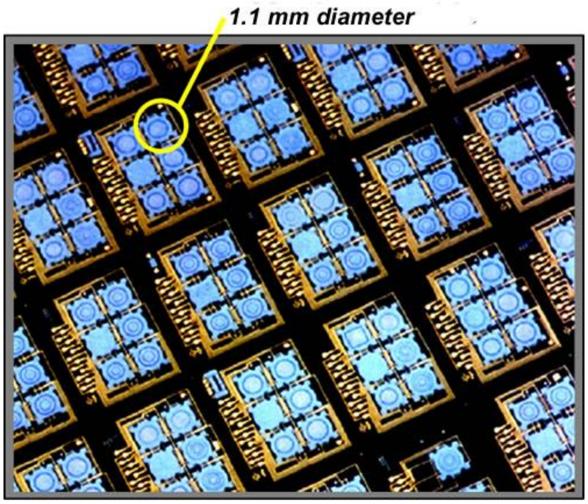
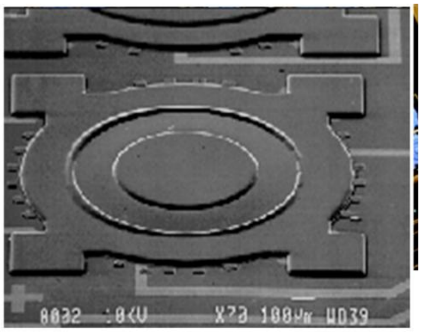



*Diagram of Aneroid Barometer*

The images below are of a MEMS barometric pressure sensor that uses a diaphram over a reference vacuum (similar to the aneroid barometer) to measure small changes in barometric pressure. The left image shows several electromechanical sensor chips each with an array of 6 pressure transducers. The right image shows the pressure transducer, a micro-sized unit that converts motion from changes in pressure to an electrical signal. These MEMS sensors are currently being used in wind tunnels and for various weather monitoring applications.

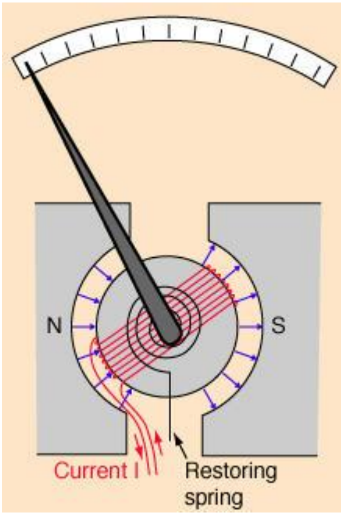


*Barometric Pressure Sensors (Photo courtesy of Khalil Najafi, University of Michigan)*

**Electrical Sensors**

- Ohmmeter – measures resistance
- Voltmeter – measures voltage
- Galvanometer – measures current
- Watt-hour meter – measures the amount of electrical energy supplied to and used by a residence or business





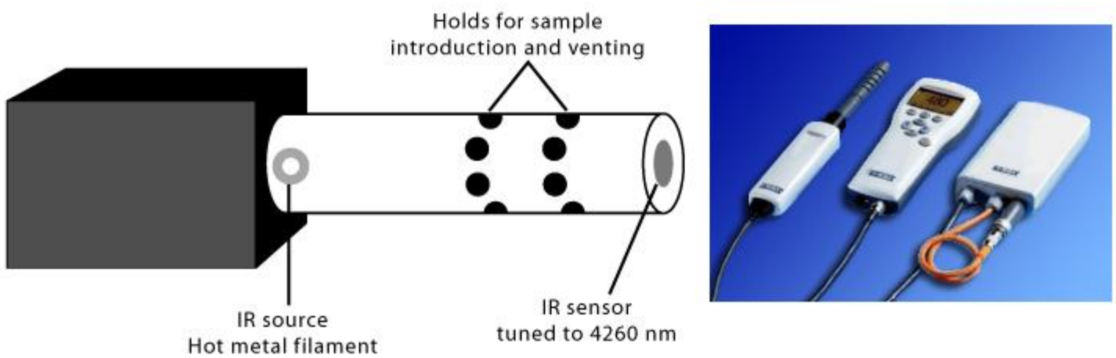
*Schematic and photograph of a Galvanometer used for sensing electrical currents*

A Galvanometer is a specific type of ammeter used for sensing an electrical current (see figure). Current flows through a coil (the red wire wound around a metal cylinder) creating a magnetic field. Permanent magnets surround the coil. The interaction of these two magnetic fields causes the coil/cylinder combination to pivot around its central axis. The amount and direction of the pivot moves the needle on a readout *(right image)* left or right, indicating the level of current and its polarity (negative or positive, respectively). This device uses two energy conversions to sense and quantify an electric current: electrical to magnetic and magnetic to mechanical rotation.

**Chemical Sensors**

Chemical sensors detect the presence of certain chemicals or classes of chemicals and quantify the amount and/or type of chemical detected.

- Oxygen sensor – measures the percentage of oxygen in a gas or liquid being analyzed
- Carbon dioxide detector – detects the presence of $CO_2$ *(see diagram below)*




*Schematic and Photo of a Carbon Dioxide Sensor*

Chemical sensing is an application that really benefits from the use of microtechnology. Just like the macro-sized components, MEMS chemical sensors can detect a wide variety of different gases. The advantage of the MEMS sensors is that they can be incorporated into objects for continuous sensing of a gas or selection of gases. These devices have numerous medical, industrial, and commercial applications such as environmental, quality control, food processing, and medical diagnosis. Such devices are sometimes referred to an ENose or electronic nose.[5]

## Other Types of Sensors

Optical

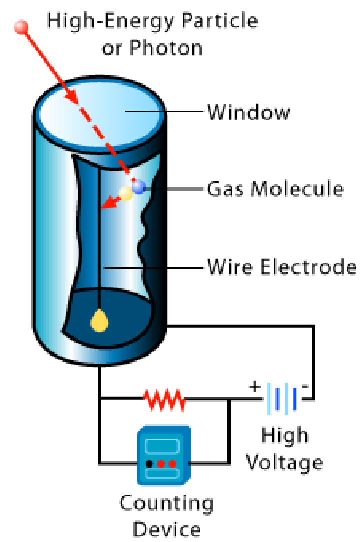
- Light sensors (photodetectors) – detects light and electromagnetic energy
- Photocells (photoresistor) – a variable resistor affected by intensity changes in ambient light.
- Infra-red sensor – detects infra-red radiation

Acoustic

- Seismometers – measures seismic waves
- Acoustic wave sensors – measures the wave velocity in the air or an environment to detect the chemical species present

Other

- Motion – detects motion
- Speedometer – measures speed
- Geiger counter – detects atomic radiation *(see graphic)*
- Biological – monitors human cells




*Geiger Counter: Detects Atomic Radiation*

Biological sensors in another area being expanded with the use of microtechnology. Already on the commercial market are biological sensors that detect and measure the amount of glucose in one's blood *(diagram below)*. The glucometer shown in the picture monitors glucose (C) using a chemical transducer and delivers insulin on an as-needed basis (A/B) using a micropump. D is the transmitter that relays the information from the glucose sensor (C) to the computer (A).[6]


*MiniMed Paradigm[R] REAL-Time System from Medtronic Diabetes [Printed with permission from Medtronic Diabetes].*

## Basic Concepts of Actuators

An actuator is something that actuates or moves something. More specifically, an actuator is a device that coverts energy into motion or mechanical energy. Therefore, an actuator is a specific type of a transducer.

## Thermal Actuators

One type of thermal actuator is a bimetallic strip. This device directly converts thermal energy into motion. This is accomplished by utilizing an effect called thermal expansion.

Thermal expansion is the manifestation of a change in thermal energy in a material. When a material is heated, the average distance between atoms (or molecules) increases. The amount of distance differs for different types of material. This microscopic increase in distance is unperceivable to the human eye. However, because of the huge numbers of atoms (or molecules) in a piece of material, the material expands considerably and, at times, is noticeable to the human eye.

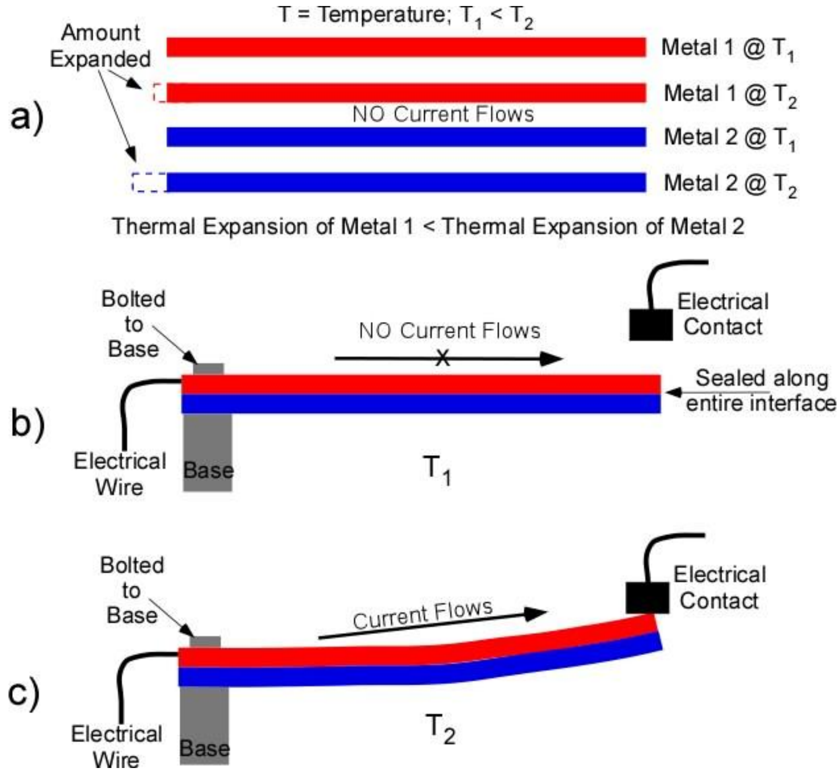
The opposite reaction occurs for a decrease in temperature when most materials contract. When exposed to the elements, a material constantly expands and contracts with ambient temperature changes. Consider a piece of steel 25 meters long. If the temperature of the steel increases by $36^oC$, (the difference between a cold winter day and a hot summer day), that piece of steel lengthens approximately 12 cm. This change in length is the thermal linear expansion. It is calculated by using the following formula:

$$\delta_L = aL_o\Delta T$$

Where $\delta_L$ is the change in length, $a$ is the coefficient of linear expansion, $L_o$ is the original length, and $\Delta T$ is the change in temperature in Celsius. If we are considering steel, the coefficient of linear expansion is $1.3 \times 10^{-5}$, the original length is 25 meters, and of course the change of temperature is $36^oC$. This results in an expansion of .12 m or 12 cm.[11,12]

Now consider 40 pieces of steel 25 meters long laid end to end to make a 1 km long bridge. The bridge's length will change roughly 480 cm between the winter and summer! Fortunately, expansion joints are built into bridges allowing for this expansion, ensuring bridges are safe in all seasons.

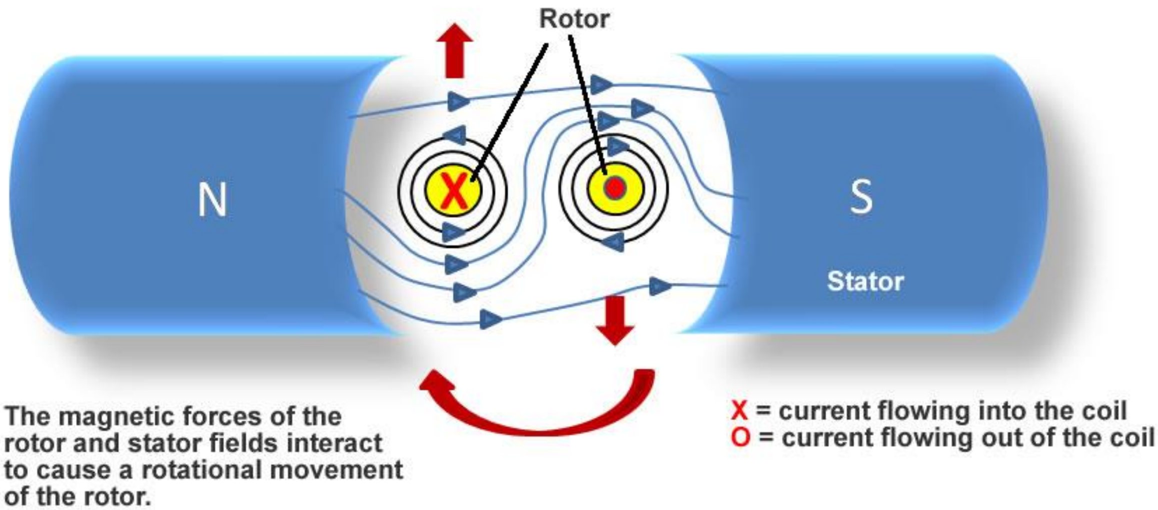
A bimetallic strip takes advantage of the thermal expansion effect to generate motion. Two dissimilar strips of metal are joined together along their entire lengths. When heat is applied, the bimetallic strip bends in the direction of the metal with the smaller coefficient of thermal expansion, *(see the figure below).* Bimetallic strips have many uses. One common use is in thermostats used to control the temperature in homes and offices. At the microscale, bimetallic actuators are used in microthermostats and as microvalves.



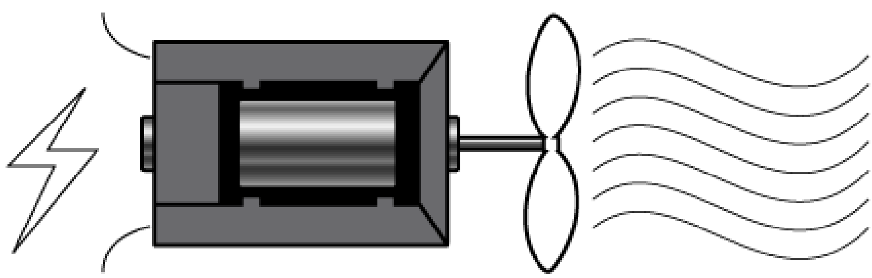

*Schematic showing how a bimetallic strip works.*

*This particular bimetallic strip is being used as a thermostat. a) Two dissimilar strips of metal are used that have different coefficients of thermal expansion, b) The two strips of metal are joined along their entire interface at some temperature ($T_1$), c) When the temperature increases temperature, $T_2$, the bimetallic strips deflect enough to touch the upper contact and allow a current to flow in the bimetallic strip turning on the air conditioner.*

**Electric Actuators**




An electric motor is a type of an electric actuator *(see graphic).* Most direct current (DC) motors operate by current flowing through a coil of wire and creating a magnetic field around the coil. The coil is wrapped around the motor's shaft and is positioned between the poles of a large permanent magnet or electromagnet. The interaction of the two magnetic fields causes the coil to rotate on its axis, rotating the motor's shaft *(see figure above).* Thus, an electric motor is a transducer AND an actuator because it converts electrical energy to magnetic energy to mechanical energy or motion.



*An electric motor is an actuator that transforms electrical energy into mechanical energy or motion.*

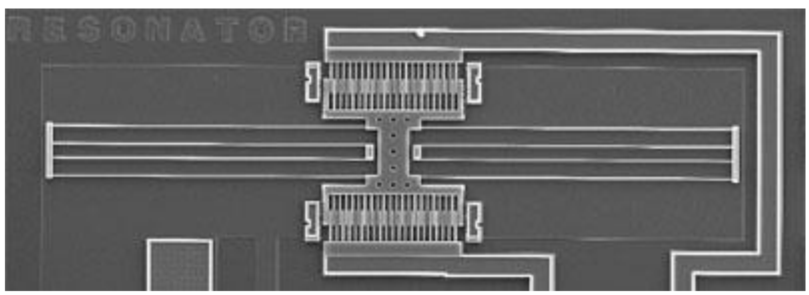
**Mechanical Actuators**

Mechanical actuators convert a mechanical input (usually rotary) into linear motion. A common example of a mechanical actuator is a screw jack. The figure below shows a screw jack in operation. Rotation of the screw causes the legs of the jack to move apart or move together. Inspecting the motion of the top point of the jack, this mechanical rotational input is clearly converted into linear mechanical motion.

Mechanical actuators can produce a rotational output with the proper gearing mechanism.

*A screw jack  converting rotational energy into linear motion (to lift a car possibly)*

An example of a microdevice which acts as an actuator is the electrostatic combdrive. These combdrives are used in many MEMS applications such as resonators, microengines, and gyroscopes. The force generated is low, usually less than 50μN. However, these devices are predictable and reliable making them highly used.[13]




*SEM of a typical comb-drive resonator [Courtesy of Sandia National Laboratories]*

The image above is an example of a MEMS electrostatic combdrive resonator. A resonator is a device which naturally oscillates at its resonance frequencies. The oscillations in a resonator can either be electromagnetic or mechanical (i.e acoustic). Resonators are used to generate waves of desired frequencies or to extract specific frequencies from a given signal.[14]

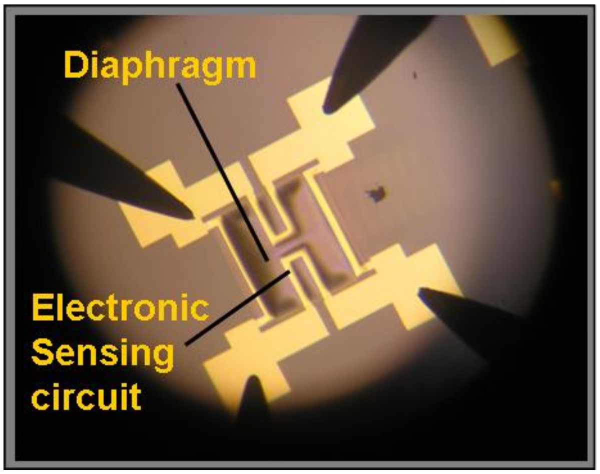
**Summary**

A transducer is a device which converts one form of energy into another. Transducers are used in all aspects of life to measure changes in the environment, to enhance everyday applications, and to learn more about the world around us. An actuator is a device that converts energy into motion. Therefore, it is a specific type of a transducer. When the output of the transducer is converted to a readable format, the transducer is called a sensor.

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. Once a sensor detects one or more of these signals, it converts it into an analog or digital representation of the input signal.

Transducers, sensors and actuators can be found in the macroscale (those visible to the naked eye) and the microscale (microscopic). Nanotechnology is enabling such devices in the nanoscale. Microsystems use microtransducers, such as temperature sensitive resistors and strain gauges, as elements in microsensing devices, such as flowmeters and pressure sensors. Microsensors can be found in chemical sensor arrays, optical sensors and acoustical sensors. Microacuators have been used for years in automobile airbags. These actuators sense a crash and actuate the airbag.

Regardless of the scale, the operation of these devices remains the same. With all such devices, as the sensing elements shrink, so do the components for the output circuitry. The diaphragm micropressure sensor in the picture below is only a few micrometers square. The electronics that communicate with this device are also in the microscale. This allows for a microsized package that can be mounted in the smallest of places. With nanotechnology, there are many transducers in the nanoscale. These nanotransducers require nano to microscale components to complete the sensor or actuator.




*Example of a Diaphragm MicroPressure Sensor [University of New Mexico, MTTC]*

**Coaching Question**

Is it possible for a device to be defined as both a sensor and a transducer?  Give an example.

**Key Terms**

Actuator – a specific type of transducer that coverts energy into motion

Electroacoustic: The interaction between electrical and acoustic phenomena.

Electrochemical: The transfer of electric charge between matter.

Electromagnetic: Objects made magnetic by an electric current.

Electromechanical: A mechanical device which is controlled by an electronic device.

Electrostatic: Of or related to electric charges at rest or static charges.

Energy: The sources of energy encompass electrical, mechanical, hydraulic, pneumatic, chemical, thermal, gravity, and radiation energy. There are two types of energy---kinetic and potential. Kinetic energy is the force caused by the motion of an object for example a spinning flywheel. Potential energy is the force stored in an object when it isn't moving.

Mechanical: Pertaining to or concerned with machinery or tools.

Optical: Referring to the behavior and properties of light and the interaction of light with matter.

Photoelectric:  Relates to the electrical effects caused by light.

Sensors: A device that responds to a stimulus, such as heat, light, or pressure, and generates a signal that can be measured or interpreted.

Transducer: A substance or device that converts input energy of one form into output energy of another.

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## Disclaimer

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# Introduction to Transducers, Sensors, and Actuators Research Activity

## Participant Guide

**Description and Estimated Time to Complete**

This activity provides you the opportunity to enhance your knowledge of sensors and transducers. The primary knowledge unit provides a brief introduction to sensors, transducers, and different types of each. You may use the primary knowledge unit to choose different types of sensors or transducers to research further or choose ones that were not covered.

Estimated Time to Complete
Allow 4 hours for research and documentation

**Introduction**

A transducer is any device which converts one form of energy into another. For example, a microphone converts sound into electrical impulses and a loudspeaker converts electrical impulses into sound (i.e., sound energy to electrical energy and vice versa). A solar cell converts light energy into electricity (electrical energy) and a thermocouple converts heat energy into electrical energy.

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. In many cases, the energy input to a sensor is the output of a transducer.

Transducers and sensors are used in all aspects of life to detect and measure many different conditions or changes in conditions. The primary difference between a transducer and a sensor is that the sensor converts its input into an analog or digital readout that indicates quantifies the amount of energy or amount of change being sensed.

**Activity Objectives and Outcomes**

Activity Objectives

- Describe the use of sensors and how they are used.
- Describe the use of transducers and how they are used.
- Describe the difference between a sensor and a transducer.

Activity Outcomes
Upon completion of this activity you should have a more in-depth understanding of the sensors, transducers, their different types, and the differences between a sensor and a transducer.

## Documentation

The documentation for this activity consists of two written reports, one on a type of sensor and another on a transducer. Details of each report are given in the following procedure. Documentation should include the following:

- Graphics (if available)
- References for materials, information, and graphics
- Answers to the Post-Lab Questions

## Procedures I and II

### Procedure I: Sensors

Description: This activity will enhance your understanding of sensors, the different types of sensors, and the different applications of sensors. It will also exercise your understanding of the differences between a sensor and a transducer.

1. Select a sensor that you would like to research. You may use a sensor that was discussed in the Introduction to Transducers, Sensors, and Actuators Primary Knowledge unit.
2. Research that sensor.
3. Write a report addressing the following:
   a. Type of sensor
   b. Its applications (What it is used for?)
   c. How does the sensor work?
   d. Applications where this sensor could be required or beneficial as a microsensor.
   e. Applications where this sensor can be coupled with a transducer or another sensor.

### Procedure II: Transducers

Description: This activity will enhance your understanding of transducers, the different types of transducers, and the different applications of transducers. It will also exercise your understanding of the differences between a sensor and a transducer.

1. Select a transducer that you would like to research. You may use a transducer that was discussed in the Introduction to Transducers, Sensors, and Actuators Primary Knowledge unit.
2. Research that transducer.
3. Write a report addressing the following:
   a. Type of transducer
   b. Its applications (What it is used for?)
   c. How the transducer works?
   d. Applications where this transducer could be required or beneficial as a microtransducer.
   e. Applications where this transducer can be coupled with a sensor or another transducer.

## Post-Lab Questions

1. Discuss the differences between a sensor and a transducer.
2. What are at least two examples of devices which act as both a sensor and a transducer?
3. Identify at least five applications of biosensors.
4. Identify at least five types of transducers or sensors found in your home.
5. Identify at least five types of transducers or sensors that are found in or used as MEMS devices.

## Summary

A sensor is a device that is used to detect and measure the presence of energy. It can also detect and measure changes in energy from a transducer. A sensor converts or quantifies the amount of energy or the amount of change in energy into a readable or useable output.

A transducer is a device which converts one form of energy into another. Transducers are used in all aspects of life to measure changes in the environment, to enhance everyday applications, and to learn more about the world around us. Transducers are the "detecting" component of sensor devices.

A transducer that transforms one form of energy into another form of energy and provides a readable output without additional circuitry is both a transducer and a sensor (e.g., mercury thermometer in a glass tube, mercury barometer)

## Disclaimer



*Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.*

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## MEMS Introductory Topics

MEMS History
MEMS: Making Micro Machines DVD and LM (Kit available)
Units of Weights and Measures
A Comparison of Scale: Macro, Micro, and Nano
Introduction to Transducers, Sensors and Actuators
Wheatstone Bridge (Activity Kit available)

## MEMS Applications

MEMS Applications Overview
Microcantilevers (Activity Kit available)
Micropumps Overview

## BioMEMS

BioMEMS Overview
BioMEMS Applications Overview
DNA Overview
DNA to Protein Overview
Cells – The Building Blocks of Life
Biomolecular Applications for bioMEMS
BioMEMS Therapeutics Overview
BioMEMS Diagnostics Overview
Clinical Laboratory Techniques and MEMS
MEMS for Environmental and Bioterrorism Applications
Regulations of bioMEMS
DNA Microarrays (Activity Kit available)

## MEMS Fabrication

Crystallography for Microsystems (Activity Kits available)
Oxidation Overview for Microsystems (Activity Kit available)
Deposition Overview Microsystems
Photolithography Overview for Microsystems
Etch Overview for Microsystems (Activity Kits available)
MEMS Micromachining Overview
LIGA Micromachining Simulation Activities (Kit available)
Manufacturing Technology Training Center Pressure Sensor Process (Activity Kits available)
MEMS Innovators Activity (Activity Kit available)

## Safety

Hazardous Materials
Material Safety Data Sheets
Interpreting Chemical Labels / NFPA
Chemical Lab Safety
Personal Protective Equipment (PPE)

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