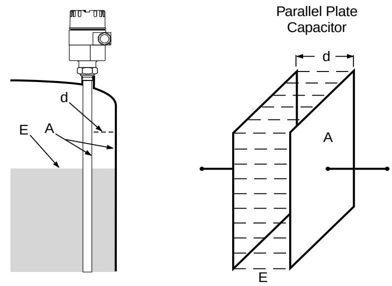
Introduction to Basic Measurement Technologies

Level: RF Capacitance Measurement



Capacitance level measurement systems take advantage of the dielectric constant in all materials to determine changes in level.

A capacitor is no more than a pair of conductive electrodes, or plates, with fixed spacing and a dielectric (process material) between them. In the most common applications, the probe element (a metal rod or cable) serves as the active plate, while the process vessel serves as the ground plate. When the “empty space” or air in the vessel is replaced by the process material, the capacitance electronics register the change in capacitance. This change is converted to an electrical signal and used to provide an output from a point or continuous level system. Level switches and continuous level measurements can be accomplished with the right probe configurations and electronics.

Level: Conductive vs. Nonconductive

In the simplest capacitance level measurement system, the dielectric material is the process material, which is nonconductive. The capacitance probe has no insulation. In this case, introducing a conductive material between the plates will “short” the plates together, nullifying the ability to measure capacitance. In continuous level applications with conductive process material, the sensing probe will be insulated, usually with Teflon®.

With conductive material the process fluid is grounded by virtue of its contact with the vessel wall, which serves as a ground plate. This brings the ground plate into contact with the insulated probe, leaving the plates separated only by the thickness of the probe insulation which serves as the dielectric material. In this case, the rising process material does not increase the capacitance by inserting itself between the plates; it increases capacitance by bringing more of the ground plate in contact with the probe insulation. Such capacitance increases are easily calculated. The measurement becomes independent of changes in the process material’s dielectric constant.

For our purposes, water-based fluids and acids may always be characterized as conductive. Nonconductive materials include hydrocarbons, oils, alcohol, dry solids, etc. When this distinction is not clear, a good numerical criterion is that materials with a relative dielectric constant of 19 or more, or a conductivity of 20 micromhos or more, may be considered conductive.

Level: Vessel Construction

A “vessel” may fit into one of two groups. The first group consists of vessels with metal interiors that come in contact with the process material. The second group is made up of fiberglass or plastic walls, or metal tanks lined with rubber, glass, or other non-conductive materials. The second group will require something other than the vessel wall to be the ground plate. Normally, this second plate is provided by Endress+Hauser as an integral part of the probe (ground tube).

Teflon is a registered trademark of DuPont.

Level: Vibration Level Switch

Amplitude Shift Tuning Fork

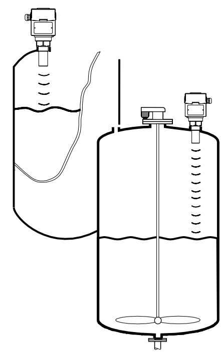
A simple, but effective level measurement technology uses the concept of a vibrating tuning fork. The sensor detects the level of solids with a freely oscillating tuning fork. The electronics drive a piezoelectric crystal system that causes the fork assembly to vibrate. Level is detected by the materials damping the vibrations of the fork. The natural resonance is approximately 120 Hz.

The fork is installed through the top or side wall of a vessel at the point where level detection is desired. As the fork becomes covered with material, the vibration stops, causing a switch point for relay output. Level can also be detected as it decreases. As the forks become uncovered by material, they begin to vibrate, causing a switch point to occur. The tuning fork is typically used in solids applications, such as polystyrene granules, powdered milk, plastic granules, sawdust, shavings and flour.

Frequency Shift Tuning Fork

The frequency shift tuning fork is vibrated by a patented bimorph piezoelectric drive electronics at about 1000 Hz. As the tuning fork is progressively covered by a liquid or slurry, there is a corresponding shift in frequency. This shift is monitored and, at an appropriate change in frequency, the switching logic is activated.

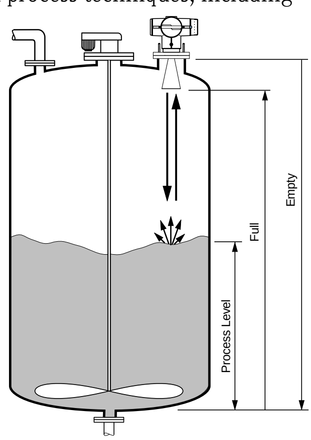
Changes in the amplitude of the tuning fork vibrations are not measured and can be ignored. This provides protection against buildup, gas bubbles and turbulence. Materials with varying density, viscosity, foam, suspended particles and composition changes do not affect the switch point of the tuning fork. The frequency shift tuning fork is typically used in liquid applications, such as syrups, sauces, slurries, and oils.



Level: Ultrasonic Level Measurement

Ultrasonic continuous level measurement involves no contact with the measured material, making it ideal for applications in hostile environments. Ultrasonic measurement is versatile and commonly used for continuous, non-contact measurement of liquids, slurries and solids. Calibration is independent of process material. A tank with an ultrasonic system can be emptied and then filled with a different material and the level reading will still be accurate.

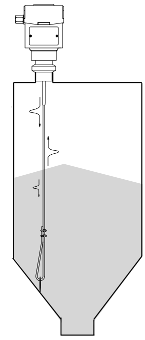
In ultrasonic level measurement the operating principle is based on the measurement of the travel time of a sound signal transmitted from and received by the same sensor after reflection from the liquid or solid surface. The travel time of a sound pulse is a direct measure of the height of the material in a silo or tank. The distance in air traveled by the pulse in feet is equal to the travel time in seconds multiplied by the speed of sound in feet per second. Ultrasonic will not work in vacuums or gasses other than air. Signal process techniques, including temperature compensation and the rejection of false echoes returned by tank obstructions, are used to maintain the integrity of the level information.



Level: Radar Level Measurement

Radar level measurement is designed for challenging applications requiring non-contact, continuous level measurement. Radar level instruments are ideal for dynamic process applications with rapid level changes or agitator blades involving liquids and slurries. The radar systems from Endress+Hauser are suitable in areas of high temperature or pressure, in the presence of gas vapors, vacuum, turbulence, or dust.

Endress+Hauser uses the pulse time-of-flight (PTOF) principle. Short radar pulses are emitted towards the material from an antenna. These pulses are reflected from the material surface and detected by the same antenna, now acting as the receiver. The distance to the material surface is proportional to the run time of the radar pulse.



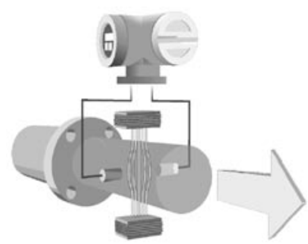
The system operates in a frequency band assigned for industrial, scientific and medical applications. Its low beam power allows safe installation in metallic and nonmetallic vessels, with no risk to humans or the environment. This technology does not require an FCC site license and can be used without restrictions.

The newest Endress+Hauser radar instrument, Levelflex, is a “downward-looking” time-of-flight system, which measures the distance from the probe mounting (top of silo) to the material level. An electrical impulse is launched and guided down the probe or cable, which acts as a surface wave transmission line. When the surface wave meets a discontinuity in the surrounding medium (a sudden change in dielectric constant), it is partially reflected. The reflected impulse travels back up the cable probe to the pulse sampler where it is detected and timed.

Each point along the probe is sampled for its pulse reflection behavior. The information accumulated over the sampling cycle is captured and passed on to the signal processing, which identifies the signal produced by the change in dielectric constant at the air/product interface. The Levelflex can measure level in both liquids and solids.

Flow: Electromagnetic Flow Measurement

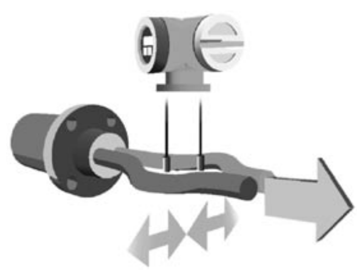
Electromagnetic flowmeters measure the volume flow rate of electrically conductive fluids. The measuring sensor consists of a lined pipe, an electromagnetic coil, and corrosion-resistant electrodes (not to all process materials). When the conductive liquid or slurry passes through the magnetic field (produced by the magmeter electronics), it generates a voltage proportional to the average velocity of the material. It is based on Faraday’s law of induction: if a conductor moves within a magnetic field, a voltage will be induced therein. Liquid media can be accurately measured with conductivities of 1 µS/cm and above.



The voltage induced by the flowing fluid is proportional to the flow rate. The measuring electrodes detect the voltage signal which is sent to an amplifier where it is digitized and communicated to the transmitter. The transmitter processes the signals and outputs current and pulse signals which are used for totalizing, pump control, limit values, batch functions, etc.

Flow: Coriolis Mass Flow Measurement

The measuring principle is based on the controlled generation of Coriolis forces. The sensing meter contains a flow tube(s), which in the absence of flow, the inlet and outlet sections vibrate in phase with each other. When liquid is flowing, inertial (Coriolis) forces cause a phase shift between inlet and outlet sections. Two sensors measure the phase difference, which is directly proportional to flow.



The amplitude of the Coriolis force depends on the moving mass (process material), its velocity in the system, and therefore its mass flow. The flowing material causes the tube(s) to oscillate, acting like a tuning fork. As the mass flow increases, the phase difference also increases. The oscillations of the measuring pipe(s) are determined using electro dynamic sensors at the inlet and outlet of the measuring tube assembly. The measurement principle operates independent of temperature, pressure, viscosity, conductivity or flow profile.

The Promass I has a full bore, straight-through, single-tube design which operates somewhat differently than the dual-tube design. In order to maintain balance for flawless measurement, a patented Torsion Mode Balanced (TMB) system is used. By exciting an eccentrically located, counter-oscillating pendulum mass, the single tube system provides accurate measurement, even with changing process and ambient conditions.

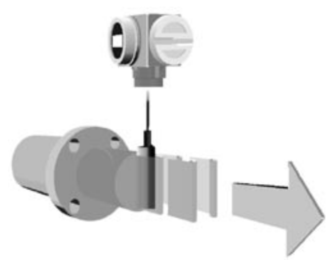
The sensor signals are processed by the transmitter electronics and provide the user with various outputs to monitor or control the process.

The Promass measuring system is used wherever mass flow measurement is critical in mixing and batching of raw materials, process control, measurement of quickly changing densities and control of product quality. Coriolis meters can measure mass flow, volumetric flow, density, temperature, and/or viscosity as well as special density units such as percent solids, °BRIX, and other units of measure.

Flow: Vortex Shedding Flow Measurement

The vortex sensor measures flow rate using the Karman Vortex Street principle. As fluid flows past a bluff body, vortices are produced on alternate sides of the body. The frequency at which these vortices are produced (or shed) is directly proportional to the flow rate and is independent of fluid density, viscosity, pressure, or temperature.

The principle function of the flowmeter is threefold: the bluff body disrupts the fluid stream creating vortices, the DSC sensor and front-end electronics detect the shedding vortices and process a pulse output signal, the electronics convert the signal to a useable scaled output signal. The DSC (Differential Switched Capacitor) sensor improves the signal-to-noise ratio and eliminates the effects of vibration on the measuring signal.



The DSC sensor detects the vortices shed by the bluff body. The lower sensor section contains the capacitance pickup system which projects into the radial bore of the bluff body.

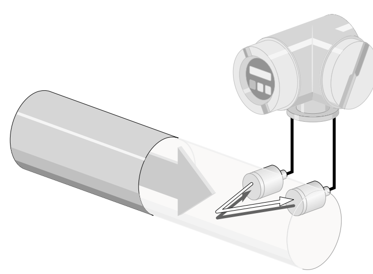
Vortex pulses acting on the tongue mistune the capacitors and this change is detected by the capacitor circuit. The elastic behavior of the carrier rod and tongue are matched by computer design which effectively cancels any pipe vibration acting on the sensor. The carrier rod and tongue move in absolute synchronism regardless of the vibration axis, including rotational vibration. By eliminating any external effects of vibration, only the vortex pulse signals are processed by the electronics.

The Prowirl vortex measuring system from Endress+Hauser is ideal for liquids, gases, and steam. Applications for oxygen, nitrogen, cryogenics, and solvents are well within the measuring techniques of the vortex system.

Flow: Ultrasonic Flow Measurement

The ultrasonic flow system is a non-intrusive, externally mounted measuring system which uses ultrasonic sound waves to measure the flowing fluid in a pipeline. The Prosonic flow system operates on the principle of transit time differences. An acoustic signal (ultrasonic) is transmitted from one sensor to another.

The time (transit) that the signal requires to arrive at the receiver is then measured. According to physical principles, the signal sent against the direction of flow requires longer to return than the signal in the direction of flow; therefore, the difference in the transit time is directly proportional to the velocity of the flow. The transmitter converts the measured values supplied by the sensor(s) into standarized output signals.



The DMU Prosonic Flow sensors (clamp on version) are mounted directly onto existing piping. Isolating or opening the piping is not required. The system is ideal for bidirectional measurement of pure or slightly dirty liquids. The Prosonic Flow is especially suitable when retrofitting equipment as no interruption of the process is necessary.

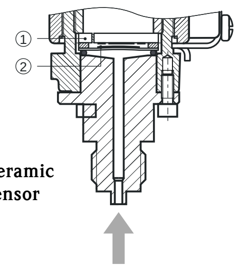
Endress+Hauser offers insertion sensors which extends ultrasonic flow measurements to piping with material of insufficient sonic conductivity. It is equally suitable for retrofitting, but requires a process interruption for installation. Once installed, the sensors can be replaced without process interruption. Sensors are available as single path (2 sensors) or dual path (4 sensors). Dual path systems offer measurement reduncancy, improved linearity and reduces requirement for upstream straight piping.

Pressure: Gauge/Absolute Pressure Measurement

Pressure measurement for gauge, absolute, vacuum and compound are based on two technologies; capacitance ceramic sensors (for up to 600 psig) and polysilicone sensors (for up to 6000 psig).

Ceramic Sensor

The operating principle of the ceramic sensor is based on capacitance technology. As pressure is applied to the ceramic diaphragm, the measuring capacitor deflects by a maximum of less than 0.001 in. A change in capacitance proportional to pressure is measured between the substrate electrode and the measuring (diaphragm) electrode. The electronics convert this differential capacitance into a useable output signal.



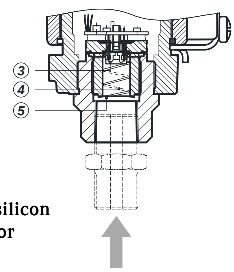
Ceramic Sensor

Using thick-film technology, the surfaces of the measuring capacitor are gold-plated and directly connected to the laser-trimmed hybrid electronics. With no diaphragm seal oil, this direct pressure signal conversion also ensures an extremely high measuring accuracy, independent of temperature, even at lower pressure ranges.

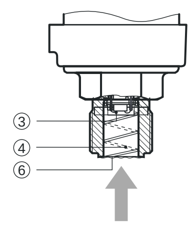
① Ceramic substrate
② Ceramic diaphragm

③ Polysilicon measuring element
④ Channel with filling fluid
⑤ Metallic separating diaphragm
⑥ Flush mounted and welded diaphragm

The actual measuring range is determined by the thickness of the ceramic diaphragm which, with overload, stops on the ceramic substrate without sustaining damage. When conventional transmitters with metal diaphragms are exposed to high pressure, they tend to deform, which results in a pressure measuring shift. By comparison, the ceramic sensor from Endress+Hauser has an overpressure rating of up to 100 times the measuring range.



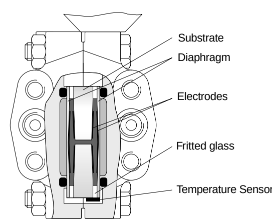
Polysilicon Sensor



Polysilicone Sensor

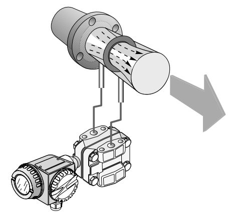
The polysilicone sensor incorporates insulated thin film strain gauges. The line pressure deflects the separating diaphragm and the filling fluid transmits the pressure to a resistance bridge. The bridge output voltage, which is proportional to pressure, is then measured and processed.

The polysilicone sensor offers a wide temperature range, a small and easily compensated temperature coefficient and long-term stability. Its good elasticity properties ensure high reproducibility, low hysteresis and fourfold resistance to overload.



Ceramic Sensor

Pressure: Differential Pressure Measurement

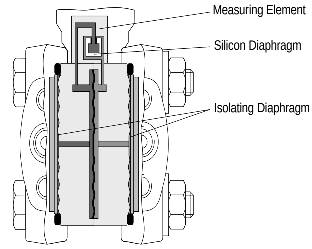


Differential pressure sensors are available in two versions; single chamber ceramic sensors (for up to 1200 inH_2O) or silicon sensors (for up to 580 psi).

The ceramic sensor consists of a substrate and two diaphragms. The diaphragms and substrate constitute two measuring surfaces and are connected by a capillary. Silicone oil, mineral oil or inert oil serves as the filling fluid in the capillary. A differential pressure-proportional change in the capacitance is measured by the electrodes on the ceramic substrate and diaphragms.

The silicon measuring sensor is comprised of a silicon diaphragm which has pressure sensitive thin-film resistors. The differential pressure acting at the isolating diaphragms is transmitted to the measuring element by silicon or inert oil. The silicon diaphragm deflects accordingly causing a change in resistance which is measured and processed by the transmitter electronics.

The silicon sensor offers a wide temperature range, a small and easily compensated temperature coefficient and long-term stability. Its good elasticity properties ensure high reproducibility and low hysteresis.



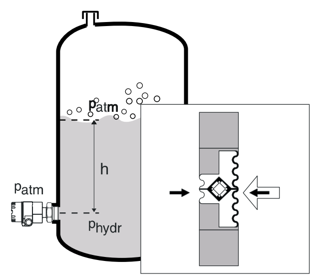
Silicon Sensor

Pressure: Hydrostatic Pressure Measurement

Hydrostatic level measurement provides both continuous and limit control of liquids and pastes. Together with an appropriate transmitter, they can be used to determine level, volume, differential pressure, product weight, density and can be integrated into various automation systems.

The weight of a column of liquid generates a hydrostatic pressure. At constant density, the hydrostatic pressure is a function of the height of the liquid only.

The core of the system is the CONTITE™ chrome/nickel resistive measuring cell. It is hermetically sealed and fully protected against external influences. No condensation, dust or moisture can penetrate or affect the measurement process. The measuring element is a copper beryllium alloy diaphragm on which there is a thin film measuring bridge. It is mechanically connected to the measuring diaphragm and embedded in a small amount of oil (approximately 3 drops) between the process and the measuring diaphragm.



The atmospheric pressure acts on the measuring cell through a pressure compensation system and thus is self-compensating. An overload substrate protects the measuring cell from pressure peaks to 20 times those of the nominal rating (maximum 360 psig). This ensures that accuracy remains unaffected. The measuring cells cover a pressure range from 15 inH_2O to 58 psig. Vacuum can be measured to 1.7 psia.

Analysis

Water, the most abundant substance on earth is used throughout the industrial world as a critical substance in the manufacturing processes. From the Chemical, Oil, and Gas Industries to the Automotive Industry, within the Pulp and Paper Industry to the precise manufacturing environment of a Semiconductor plant, water is there, providing the medium in which many products are made, modified, and/or cleaned. The purity of our drinking water has increasingly become a matter of public concern. Most drinking water supplies today require special treatment before it can be distributed and utilized. This is to eliminate possible toxic and infectious contaminants and make it safer for human consumption.

Endress+Hauser offers a full line of analytical systems important to different interests and industries. Examples of available technologies and industries include:

pH	Environmental
Oxidation/Reduction (ORP)	Corrosion
Conductivity	Scaling
Dissolved Oxygen	Power
Chlorine	Disinfecting
Turbidity	Dissolved Solids

Analysis: pH

pH is the measurement of hydrogen ion activity. It is measured on a scale of 0 to 14, where 0 is extremely acid and 14 is extremely alkaline. The mid point of 7.0 pH is distilled water. It is the most widely used liquid analysis measurement, and is found in all industries. Used to determine the degree of acidity or alkalinity of a sample, pH measurement is a number that is directly related to the ratio of H^+ (hydrogen ion) and OH^- (hydroxyl ion) concentrations in a solution.

Endress+Hauser offers two groups of pH electrodes. CPF compact electrodes, which are inserted directly into the process, or CPS glass electrodes which are placed in a separate holder.

Analysis: ORP

ORP (Oxidation-Reduction Potential) measurements are used to monitor chemical reactions, quantify electron activity or determine the oxidizing or reducing properties of solutions. ORP is related to pH in that it utilizes a similar measuring system, and delivers millivolts, as does pH. ORP is a specialized measurement that can follow the progress of a chemical reaction that involves the loss and gain of electrons (Oxidation or Reduction) between species in solution. ORP only measures in millivolts, whereas pH measurements are related to a scale. As in pH measurement, the electrodes are of the same type.

Analysis: Conductivity

Conductivity is a common measuring technique. The range of conductivity is wide, from the purest water to the high conductivity of acid and alkali concentrations. Conductivity is a straightforward and reliable way to determine the purity of water, or the concentration of an acid or alkali.

The principle of conductivity measurement for analysis is defined as the ability of a solution to conduct an electrical current between two electrodes. In a solution, the current flows by ion transport. Therefore, the higher the ion concentration, the more current can flow. Chemical compounds which produce conducting solutions are called electrolytes.

Endress+Hauser offers two basic types of sensors for conductivity measurement. The contacting (conductive) sensor and electrodeless (inductive) sensor.

Analysis: Dissolved Oxygen

Dissolved oxygen (DO) is the term commonly used in liquid analytical work for the measurement of the amount of oxygen dissolved in a unit volume of water. It is an important indicator of the degree of usefulness of a sample of water for a specific application. The process requirements of a given application determine the level of dissolved oxygen that can be tolerated.

Water, by its nature, is an excellent solvent not only for compounds which dissociate into ions, but also for dissolved gases, including molecular oxygen. Different samples at the same temperature, saturated with oxygen, can have different concentrations of oxygen. They all may be 100% saturated, but have different concentrations of oxygen.

The primary application for parts-per-million (ppm) dissolved oxygen systems is measurement and control in aeration basins used in aerobic digesters in wastewater treatment plants. Correct levels of oxygen must be maintained to nourish the bacteria that are used to digest the waste.

Endress+Hauser offers a single sensor style for measuring dissolved oxygen. The membrane covered sensor provides a sealed system which measures the oxygen molecules transferred through a gas permeable membrane to the electrodes.

Analysis: Chlorine

As a common last step of water treatment, a chlorination takes place, not only to destroy remaining bacteria but also to prevent the growth in the water pipe system which delivers clean water to households and industrial locations. Chlorine is a building block for nearly all chemical processes. It plays a vital role in the health of the population and in maintaining a clean and safe environment.

The chlorine measuring sensor is similar to the dissolved oxygen sensor, in that it is a membrane covered sensor. The chlorine sensor only allows hypochlorous acid molecules to diffuse through the membrane to react at the electrodes. Detected hypochlorous acid is a proportion of the active chlorine, which acts as a depolarizer at the cathode after diffusion by the membrane.

Analysis: Turbidity

Water can contain solid matter of many different sizes. Some suspended solids will be large enough and heavy enough to settle to the bottom of a container if the water is left to stand. Other solids which are finer will remain in the water above the settled matter. These solids are called turbidity. Since the individual particles are often too small to see, turbidity usually appears as a cloudiness or haziness to the water; therefore, turbidity describes the relative clarity of water.

Turbidity uses an optical measurement to measure the content of undissolved particles in fluids, mainly water. A beam of light passing through a sample of water is absorbed and scattered by the particles, thereby permitting a qualitative statement to be made concerning the water quality. Turbidity measurement is unable to provide any direct conclusions as to the number of particles contained in the water.

Endress+Hauser turbidity sensors use the 90 degree scattered light method with a measuring frequency in the near infrared range. Digital filtering with excellent interference signal suppression and sensor self monitoring ensure measurement reliability.

Temperature

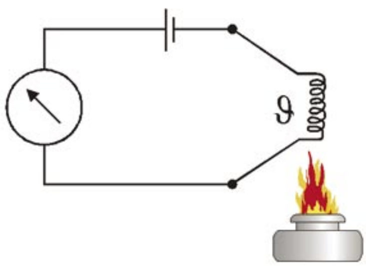
Of all process variables, Temperature is the one with which people have the most personal familiarity. Yet, many of the measurement issues are not clearly understood by the average person. Further, the concepts of temperature and heat are often confused.

Fundamentally, temperature is indicative of the average amount of kinetic energy in a group of molecules. That is, it is a direct indication of the average amount of molecular motion in the studied object. Even the human senses detect temperature changes, and can sense which of two objects has the higher temperature. Yet temperature is not a measure of the amount of heat (or heat energy) contained within an object. An iceberg, although colder than a lit match, contains vastly more heat than a lit match. Heat may be thought of as the sum of all the kinetic energy of all the molecules-in-question. If temperature tells us nothing about the energy contained in an object, what then does temperature tell us?

Our concepts of “colder” and “warmer” are directly related to relative temperatures. And temperature tells us one very important thing—which way heat will flow. When two bodies are in contact, heat (or energy), always moves from a body of higher temperature to a body of lower temperature*. Two simple bodies in contact and left alone, will eventually reach the same temperature.

The expression of a measured temperature value may be in any one of several different “temperature scales”. That is, there are different temperature “units”, all called “degrees”. The specific unit used is indicated by the “type” of degree stated. All temperature scales seek to create a one-to-one correspondence between the indicated temperature value and a specific level of molecular activity. The most commonly used scales are the Celsius (formerly Centigrade) and Fahrenheit. These linear scales have somewhat arbitrary “starting points” for what they consider to be “zero degrees”. In contrast the Kelvin and Rankine scales set zero degrees to correspond to the theoretical “absolute zero” where all molecular motion would cease. These latter scales are a bit more convenient when the goal is to relate a temperature measurement directly to heat content or kinetic energy, since the temperature is directly proportional to both, and requires no offset to the more arbitrary zero points of the Celsius and Fahrenheit scales.

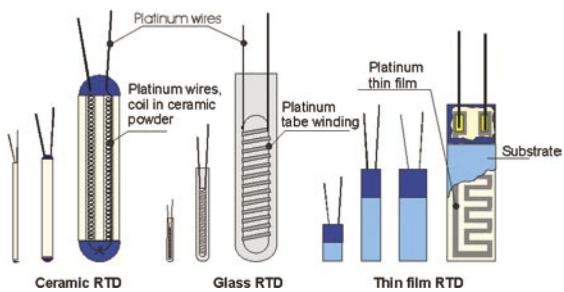
What is it, fundamentally, that causes a temperature sensing device (or even your skin) to get a “reading” of the temperature? At the molecular level, it is the result of the aggregate momentum transferred to the sensing device by all the collisions of moving molecules.

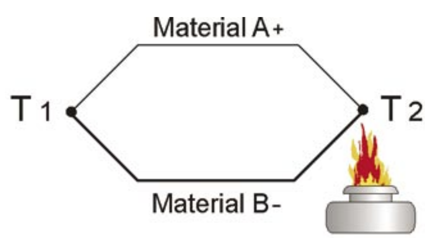


Resistance temperature devices capitalize on the fact that the electrical resistance of a material changes as its temperature changes. As their name indicates, RTD's rely on resistance changes in a metal, with the resistance rising more or less linear with temperature.

In industrial processes, the measurement of temperature is not only critical for numerous reasons, but it is also the single most common process variable measured.

Although there are several sensor types used to transducer sensed temperature into a measurable and useable electrical signal, the vast majority used are one of two types---the “RTD” (Resistive Temperature Device), or the Thermocouple.





When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit.

Thomas Seebeck made this discovery in 1821.

*Exception: using a clever technique, a powered device called a “heat pump” can extract heat from a colder object, cooling it even further, and pass that heat into a warmer object, raising its temperature.