

Instrument Principles

Anemometer

Pressure Plate Anemometer

Measures the drag that the wind exerts on a solid body. The simplest form is a plate or ball which is free to swing about a horizontal axis above its center of gravity when acted upon by wind force. A measure of the angular deflection is taken. This device must be kept oriented towards the wind so a wind vane or tail is usually employed to rotate it about a vertical axis.

Advantages: Simple.

Disadvantages: Must be oriented into the wind. Not very responsive to gusts. Has a natural resonant frequency where it “flutters”

Keywords: “pressure plate anemometer” “pendulum anemometer” “normal-plate anemometer” “bridled-cup anemometer” “deflection anemometer”



Figure 1 Pendulum Anemometer

Cup Anemometer

Measures the speed of a wind powered turbine in the form of (usually hemispherical) cups mounted on radial spokes. Rotation speed can be measured by a number of different mechanisms, but often a magnet, affixed to the shaft, traversing past a fixed coil induces a pulse for each revolution, or a digital shaft encoder is used.

Advantages: Simple, omnidirectional (in one plane).

Disadvantages: Moving parts wear out, slow to react to gusts. Not sensitive to wind speeds of fractions of a meter per second.

Keywords: “cup anemometer” “Robinson anemometer”



Figure 2 Cup Anemometer

Propeller Anemometer

Measures the speed of a wind powered turbine in the form of a propeller or wind vane. Rotation speed measurements cover the same plethora of mechanisms as for the cup anemometer, but in some cases the rotation drives a generator with the output from the generator being proportional to speed.

Advantages: Simple. Compact – can be hand-held. More responsive to gusts than the cup anemometer.

Disadvantages: Moving parts wear out. Must be oriented into the wind.

Keywords: “propeller anemometer”
“rotating vane anemometer”



Figure 3 Propeller Anemometer

Hot Wire Anemometer

Measures change in wire resistance at a constant current (constant-current hot wire anemometer) or alternatively, the current required to keep the resistance of a wire at a set value (constant-resistance hot wire anemometer). Fluid (wind) passing over a fine wire that is heated by an electric current tends to cool the wire by convective heat transfer, and thus changes the resistance (unless the current is increased to compensate).

Advantages: Good spatial resolution (measures the flow in a precise location), used for “flow probes”. Responds quickly to changes in flow (with appropriate control circuitry).

Disadvantages: Costly, orientation sensitive, fragile and “wire” can accumulate debris in a dirty flow.

Keywords: “hot-wire anemometer” “thermal anemometer”

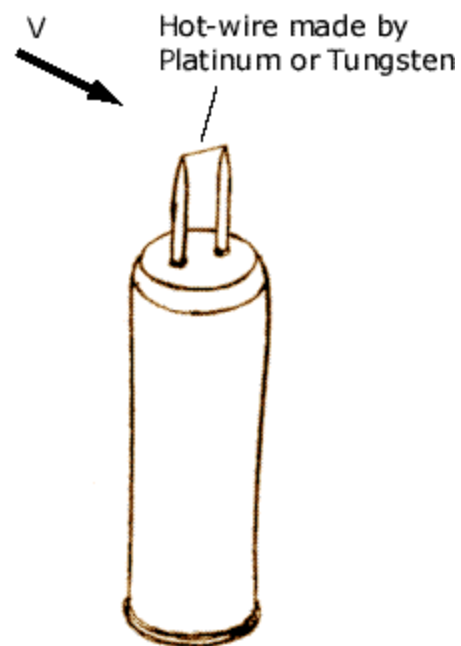


Figure 4 Hot Wire Anemometer

Tube Anemometer

Measures the height of liquid in a J or U tube which has one end bent into a horizontal direction to face the wind and the other end usually open and facing up so that wind passing over it will create a vacuum due to the Bernoulli effect.



Figure 6 Pitot Tube

The height of the liquid can be measured with a float connected by a mechanical linkage to a recording device.

Advantages: The Pitot tube can be inserted in small airstreams, i.e. inside ducts.

Disadvantages: Moving parts wear out. Liquid manometer is fragile. The Pitot tube must be turned into the wind.

Keywords: “Pitot tube” “Dines anemometer” “Lind’s anemometer”

Sonic Anemometer

Measures the time difference between an ultrasonic wave traversing through air and a reference signal. Air movement causes the ultrasonic wave's phase to advance or retard relative to the reference.

Advantages: No moving parts. Can take thousands of measurements per second, handling gusts and peak values.

Disadvantages: Costly, complex. Measures velocity only in one direction (illustration shows two orthogonal instruments used to overcome this).

Keywords: “sonic anemometer” “ultrasonic anemometer” “acoustic anemometer”

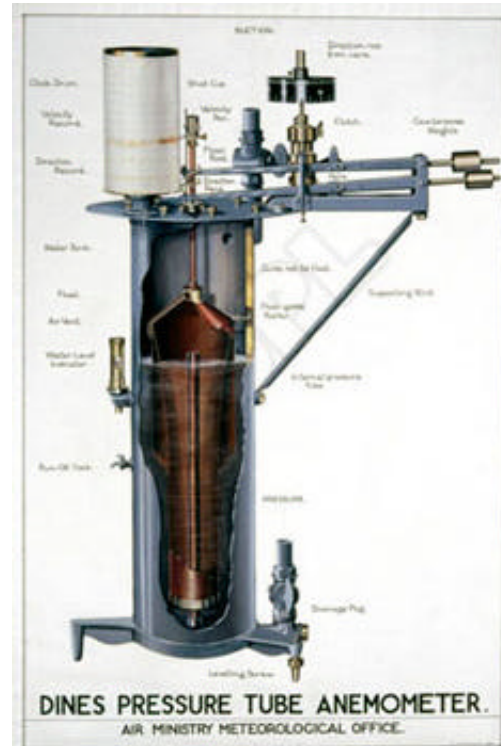


Figure 5 Tube Anemometer



Figure 7 Sonic Anemometer

Laser Anemometer

Bounces a laser beam off airborne particles (such as dust, pollen, water droplets) and measures the Doppler shift (change in frequency with velocity).

Advantages: No mast required to measure wind velocities at heights up to 150m. Can measure flow field, not just velocity at a point. Works for any “transparent” medium containing particles.

Disadvantages: Costly, complex.

Keywords: “laser anemometer” “doppler anemometer” “laser doppler anemometer” “particle anemometer”

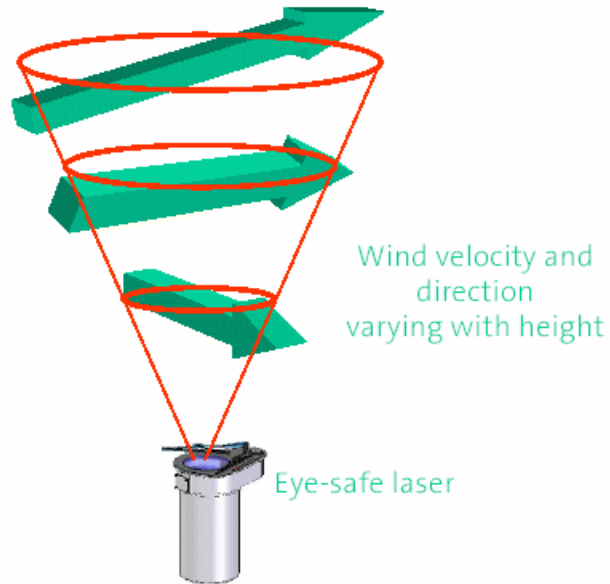


Figure 8 Laser Anemometer

Ion Anemometer

Measures ion current. Ionization of the atmosphere is performed either by nuclear radiation or high frequency discharge (arcs and sparks).

Advantages: No moving parts.

Disadvantages: Costly.

Keywords: “ion anemometer”

Barometer

Mercurial Barometer

Measures the height of a column of mercury prepared by inverting a closed tube filled with mercury into a pool of mercury. A vacuum is created at the closed end of the tube, and the height of the column above the surface of the pool indicates the air pressure directly. Compensation for elevation above sea-level is needed to obtain reported pressure.

Advantages: Accurate.

Disadvantages: Environmentally hazardous. Must be exactly plumb.

Keywords: “mercurial barometer” “stick barometer” “Fortin barometer” “Kew pattern barometer” “wheel barometer”

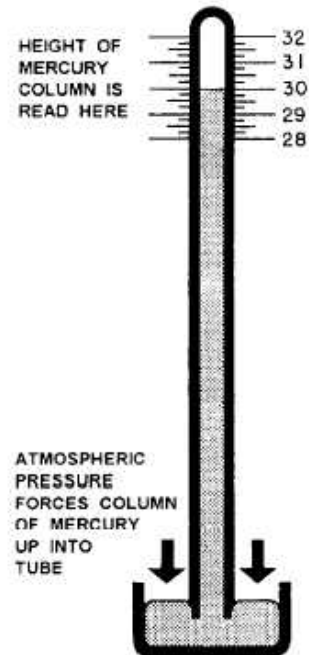


Figure 9 Mercury Barometer

Aneroid Barometer

Measures the change in size of a partially evacuated capsule, constructed so as to maximize the change in one dimension with changes in air pressure. The capsule 'length' change is connected via a lever linkage to a dial on which the pressure is shown

Advantages: Compact, portable.

Disadvantages: Inaccuracies due to temperature, hysteresis and drift.

Keywords: “aneroid barometer” “Vidie barometer”

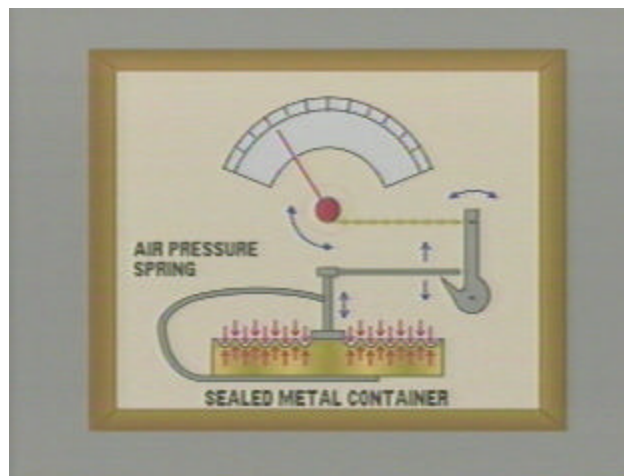


Figure 10 Aneroid Barometer

Capacitance Pressure Sensor

A pressure sensor measuring the distance between two metal plates, located on either side of a chamber, by measuring the change in capacitance between them. Capacitance is an inverse function of distance between the parallel plates.

Advantages: Robust, no moving parts.

Disadvantages: Complex electronics.

Keywords: “capacitance barometer”

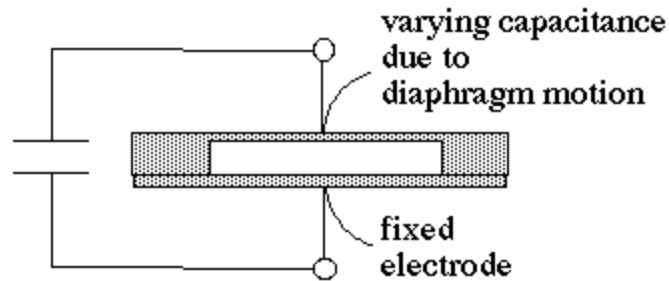


Figure 11 Capacitance Pressure Sensor

Strain Gauge Pressure Sensor

A pressure sensor measuring the deflection of a membrane by measuring the change in resistance of an attached strain gauge.

Advantages: Robust, no moving parts.

Disadvantages: Small signal.

Keywords: “strain gauge pressure sensor”

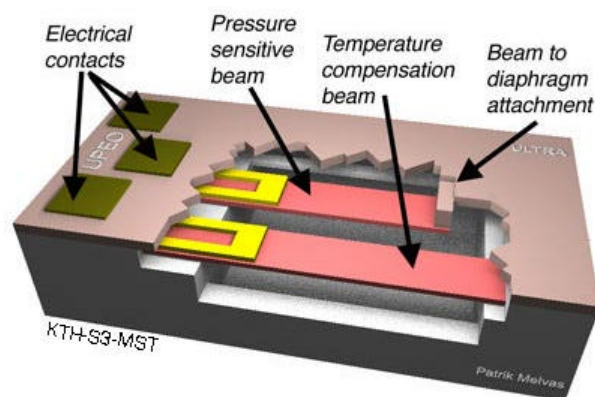


Figure 12 Strain Gauge Pressure Sensor

Bourdon Pressure Sensor

Measures the extension of a thin-walled closed tube with an oval cross section bent lengthwise into an arc of 270 to 300 degrees. Pressure applied to the interior of the tube tends to distend the flattened tube into its original round shape, which causes the tube to straighten slightly. The movement of the tip of the tube can drive a meter movement or be measured electrically.

Advantages: Robust. Works at high pressure.

Disadvantages: Not sensitive to low pressure differences.

Keywords: “Bourdon pressure sensor”
“Bourdon pressure tube”

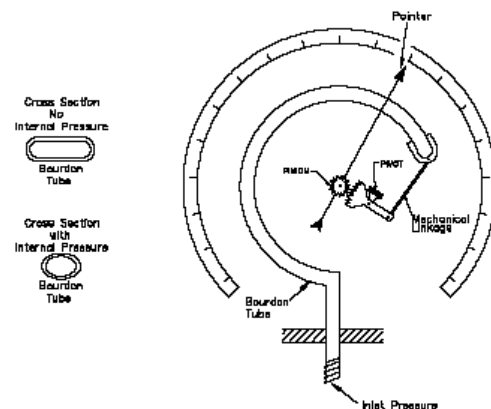


Figure 13 Bourdon Pressure Sensor

Resonant Pressure Sensor

Measures the change in frequency of a resonant circuit usually using a quartz or ceramic piezo-electric device. Advanced instruments use micromachined or MEMS devices with on-board compensation and calibration circuitry.

Advantages: Accurate.

Disadvantages: Costly.

Keywords : “resonant pressure sensor” “quartz resonant pressure sensor” “silicon resonant pressure sensor”

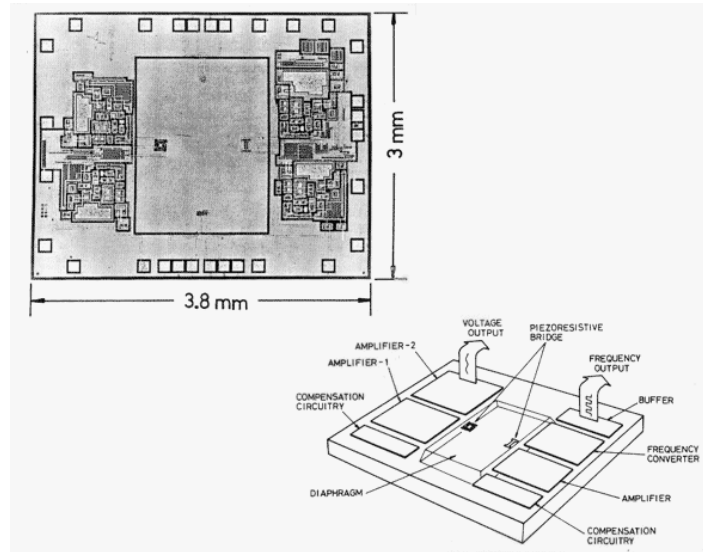


Figure 14 Resonant Pressure Sensor

Thermometer

Liquid Thermometer

Measures the expansion of a liquid. The most common is a mercury thermometer that measures the height of a thin column of liquid attached to a much larger reservoir.

Advantages: Simple.

Disadvantages: Imprecise. Environmentally hazardous.

Keywords: “mercury thermometer”



Figure 15
Mercury
Thermometer

Gas Thermometer

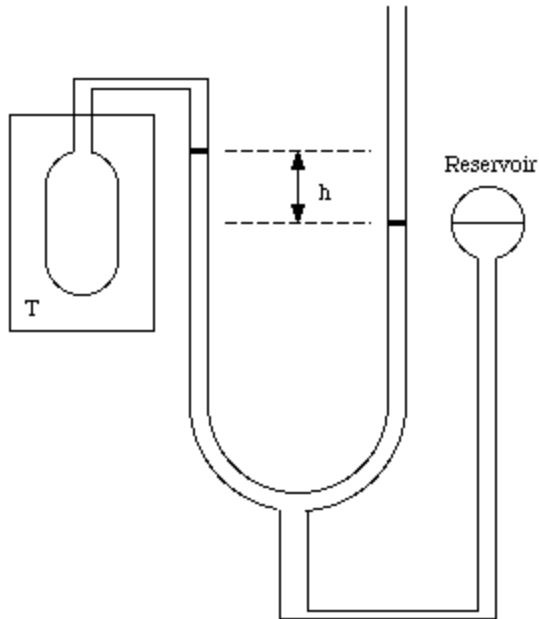


Figure 16 Gas Thermometer

Measures the volume or pressure variation of a gas. One common apparatus is a constant volume thermometer. It consists of a bulb connected by a capillary tube to a manometer. The bulb is filled with a gas and in thermal contact with the body whose temperature is to be measured. A reservoir of mercury is raised or lowered such that the volume of the gas in the bulb remains constant. The pressure of the gas in the bulb can be obtained by

measuring the level difference h of the manometer.

Advantages: Accurate.

Disadvantages: Bulky.

Keywords: “standard thermometer” “constant volume thermometer”

Metal Thermometer

Measures the thermal expansion of a metal. A bimetallic strip bends differentially with pressure.

Advantages: Passive.

Disadvantages:

Inaccurate.

Keywords : “bimetallic strip”

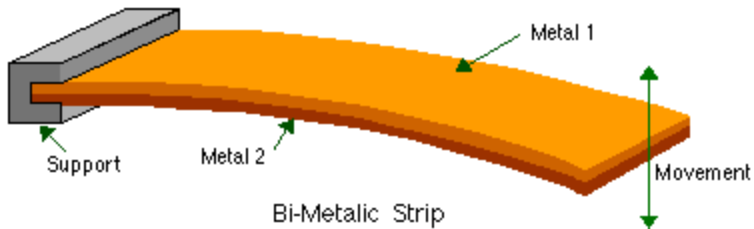


Figure 17 Bimetallic Strip

Resistance Thermometer

Measures the change in resistance of an object. Specially constructed semiconductor devices called thermistors are the most popular. Older Resistance Temperature Detectors (RTD) devices use a platinum, or nickel alloy (with iron and copper), wound as a fine wire coil.

Advantages: .

Disadvantages: .

Keywords : “platinum RTD” “thermistor”



Figure 18 Thermistors

Thermocouple Thermometer

Measures the voltage produced by the contact of two dissimilar bonded (welded) metal wires (Seebeck effect). Sometimes a pair of wires joined at both ends is used, where one end is held at a reference temperature. The bimetallic junction develops a small voltage that varies with temperature.

Advantages: Inexpensive. Wide temperature range.

Disadvantages: Small voltage (comparable to parasitic voltages of the connections to the measuring instrument).

Keywords : “thermocouple”

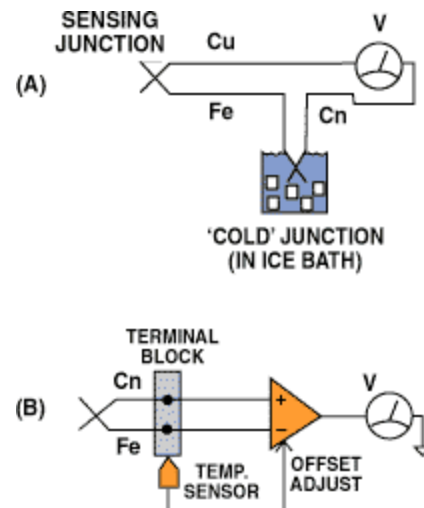


Figure 19 Thermocouple

Optic or Pyrometric Thermometer

Measures the energy a body radiates. Infrared radiation is usually measured. The radiation varies as the 4th power of the temperature of a body. Thermal detectors and direct quantum detectors are used. The former convert the radiation into heat while the latter convert radiation directly to electronic signals (illustrated).

Advantages: Remote sensing.

Disadvantages: Shiny objects are difficult to measure.

Keywords: “infrared thermometer” “optical thermometer” “pyrometer”

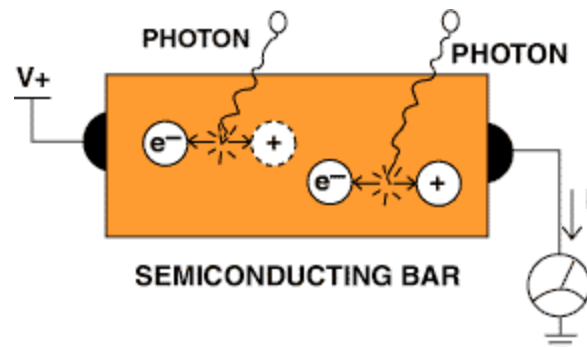


Figure 20 Pyrometric Thermometer

Capacitance Thermometer

Measures the change in capacitance with temperature.

Advantages: .

Disadvantages: .

Keywords: .

Semiconductor Thermometer

Measures the voltage across a P-N junction, often with clever circuitry and integrated on a chip to provide a linear output with temperature.

Advantages: Inexpensive. Fairly accurate.

Disadvantages: Some circuits are subject to supply voltage changes. Device characteristics vary from part to part.

Keywords: “proportional to absolute temperature”+“current source”

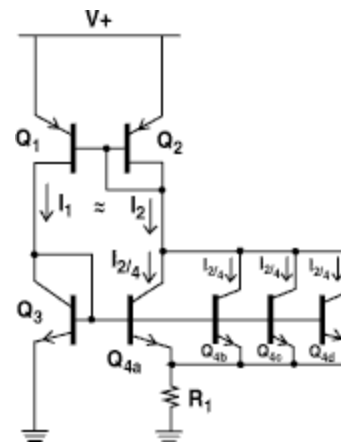


Figure 21 PN Junction Thermometer

Precipitation Gauge (Ombrometer, Pluviometer, Udometer, Disdrometer)

Graduated Cylinder Rain Gauge

Measures the accumulation (height) of precipitation in an open topped cylindrical container. Operator records the accumulation and empties the cylinder. Normally it has a funnel shaped accumulator at the top to gather precipitation from a greater area than the cylinder area.

Advantages: Simple

Disadvantages: Operator intervention required.

Keywords : “graduated cylinder rain gauge”



Figure 22 Graduated Cylinder Rain Gauge

Tipping Bucket Rain Gauge

Measures the number of times or frequency that a bucket or pair of buckets fills with water and overbalances.

Advantages: simple

Disadvantages: Moving parts

Keywords : “tipping bucket rain gauge” “tipping bucket precipitation gauge”

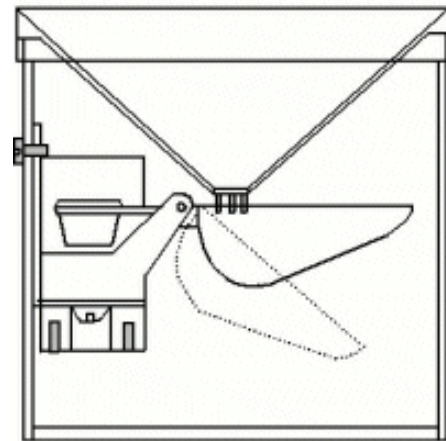


Figure 23 Tipping Bucket Rain Gauge

Weighing Precipitation Gauge

Measures the weight of accumulated precipitation in a bucket. The bucket empties by evaporation.

Advantages: No moving parts.

Disadvantages: Complex. Subject to debris (dirt, leaves) and wind.

Keywords: “weighing precipitation gauge” “vibrating wire rain gauge”



Figure 24 Weighing Rain Gauge

Optical Precipitation Gauge

An infrared or visible light optical device is used to measure the rain drop size, fall velocity and intensity. Basically, beams of radiation are interrupted by raindrops or video images are analyzed. Structured illumination (light beams formed into sheets or cones) is often used.

Advantages: Accurate

Disadvantages: Complex.

Keywords: “optical spectro pluviometer” “optical disdrometer”



Figure 25 Optical Rain Gauge

Hygrometer

Wet And Dry Bulb Psychrometer

Measures the temperature depression of a wet object due to evaporation. A wet and dry bulb psychrometer or hygrometer consists of two ordinary thermometers, one called the dry bulb measures simple air temperature, while the second thermometer has its working end (bulb) enclosed by a fabric sleeve which is kept wet with distilled water from a reservoir. By reading the temperatures of the dry and wet bulb, a record of the amount of cooling due to evaporation of water from the wet bulb is obtained in

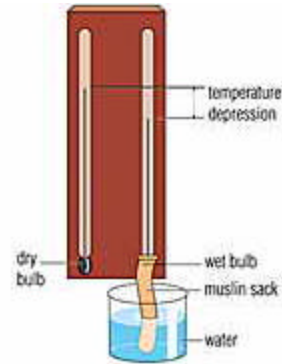


Figure 26 Wet & Dry Bulb Psychrometer

terms of degrees depression or lowering of the wet bulb thermometer temperature below that of the dry bulb thermometer. The higher the relative humidity the lower the wet bulb depression (closer to just the air temperature). Using psychrometric formulas or tables, these temperatures can be used to compute the humidity.

Advantages: Simple.

Disadvantages: Doesn't work much below the freezing point. Requires the reservoir to be kept full.

Keywords: “sling psychrometer” “atmometer” “clay atmometer” “evaporation pan” “evapotranspirometer” “Livingston sphere” “Piche evaporimeter” “radio atmometer”

Hair Hygrometer

Measures the change in the length of human hair. The hair acts hygrometrically due to the diffusion equilibrium between its water content and the water vapour content of its environment.

Advantages: Simple.

Disadvantages: Temperature sensitive. Fragile.

Keywords: “hair hygrometer” “human hair hygrometer” “hygroscope”



Figure 27 Hair Hygrometer

Capacitance Hygrometer

Measures the change of capacitance associated with a change of dielectric constant between capacitor plates. Dielectric materials such as polymers, silica gel or alumina desiccant are used to amplify the moisture content measurement. Usually one plate of the capacitor is porous to allow fast equilibration between the moisture level of the dielectric and the air.

Advantages: No moving parts.

Disadvantages: Complex electronics.

Keywords : “capacitance hygrometer”

Chilled Mirror Hygrometer

Measures the temperature at which vapor begins to condense on a chilled surface. The mirror is constructed from a material with good thermal conductivity such as silver or copper, and properly plated with an inert metal such as iridium, rubidium, nickel, or gold to prevent tarnishing and oxidation. The mirror is chilled using a thermoelectric cooler until dew just begins to form. A sophisticated control system monitoring the reflected light maintains the mirror temperature at the dew point. A temperature sensor embedded in the mirror monitors the mirror temperature at the established dew point.

Advantages: Accurate.

Disadvantages: Complex electronics. Requires air flow over the surface.

Keywords : “chilled mirror hygrometer”

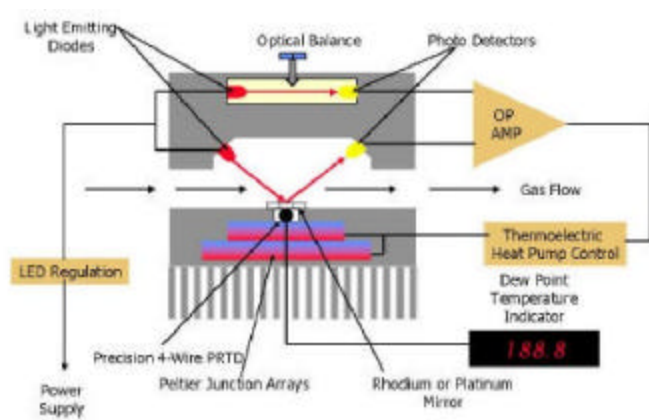


Figure 28 Chilled Mirror Hygrometer

A sophisticated control system monitoring the reflected light maintains the mirror temperature at the dew point. A temperature sensor embedded in the mirror monitors the mirror temperature at the established dew point.

Advantages: Accurate.

Disadvantages: Complex electronics. Requires air flow over the surface.

Keywords : “chilled mirror hygrometer”

Electrolytic Hygrometer

Measures the electrolysis (of water into oxygen and hydrogen) current. Since two electrons are required for electrolysis of each water molecule, the electrolysis current is a measure of the water present in the sample. If the volumetric flow rate of the sample gas into the electrolysis cell is controlled at a fixed value, then the electrolysis current is a function of water concentration in the sample.

Advantages:

Disadvantages: Requires flow into the electrolysis cell.

Keywords : “electrolytic hygrometer”

Impedance Hygrometer

This instrument measures the water content of a sample by means of a probe whose

electrical impedance is a function of the vapor pressure of moisture in the fluid. Impedance is the apparent opposition to the flow of alternating current. The probe consists of an aluminum strip, which is anodized to form a porous layer of aluminum oxide. A thin coat of gold is applied over the aluminum oxide. Leads from the gold and aluminum electrodes of the probe connect the sensing element to the measuring circuitry. Water vapor penetrates the gold layer and equilibrates on the aluminum oxide. The number of molecules adsorbed to the aluminum oxide is a function of the water vapor pressure in the sample.

Each water molecule adsorbed contributes a distinct increment to the total conductivity of the aluminum oxide. The total probe impedance, the reciprocal of probe conductivity, is thus a measure of water vapor pressure in the sample. Water vapor pressure of a gas sample uniquely determines the dew-point temperature and moisture content of the sample. The output is normally calibrated to these units since they are more convenient to use than vapor pressure.

Advantages: Accurate.

Disadvantages: Costly probes. Complex electronics

Keywords: “impedance hygrometer”

Piezoelectric Hygrometer

Measures the change in frequency of an oscillating crystal. The crystal is sensitive to deposits of foreign material on its surface. Commercially available crystals will show a frequency change of 2000 cycles per second (cps) per microgram of material deposited. For moisture measurement, the quartz crystals are coated with a hygroscopic material and exposed to the sample; water from the sample is absorbed by the crystal coating, thus increasing the total mass and decreasing the oscillating frequency of the crystal. In order to measure changes of decreasing moisture concentration and to simplify the frequency measurement, two crystals are used. One crystal is exposed to wet sample and the other to a dry reference gas for a short period. Then sample and reference gas flows are switched so that moisture is absorbed by one while being desorbed by the other crystal. Sample switching is controlled by a cycle timer in the instrument. The frequency difference between the two crystals is in proportion to their mass difference and the moisture content of the gas.

Advantages:

Disadvantages: Reference “dry” sample required.

Keywords: “piezoelectric hygrometer”

Heat Adsorption Hygrometer

Measures the heat generated by a material adsorbing water. The process of adsorption and desorption involves an exchange of energy. During adsorption, energy is released to and during desorption energy is removed from the environment. When wet gas is passed through a column of adsorbent, which selectively adsorbs moisture, the temperature rise due to heat liberation is in proportion to the amount of moisture adsorbed. Other factors which affect the heat of adsorption, such as the nature of the adsorbent and operating temperature, are selected to maximize the heat of adsorption.

Advantages:

Disadvantages:

Keywords : “heat adsorption hygrometer”

Infrared Absorption Hygrometer

Water absorbs electromagnetic radiation in the infrared (IR) region of the spectrum. Specifically, infrared radiation of 1.4 and 1.93 micron wavelength is absorbed strongly by water. By measuring the attenuation (decrease of light intensity) of a beam of this wavelength as it passes through a sample, the moisture content of the sample can be determined. However, other factors such as reflection and dispersion of the radiant energy will contribute to the attenuation. Therefore, it is necessary to either calibrate these factors out of the measurement, or to use a reference wavelength which is not absorbed by moisture but is affected by all other factors to the same extent as the measuring wavelength. The difference in attenuation of the measurement and reference wavelength is then a function of moisture content only.

Advantages:

Disadvantages:

Keywords : “infrared absorption hygrometer”

Microwave Absorption Hygrometer

In the microwave frequency band of 20 to 22 GHz (K band), the wavelength is about 13 to 15 mm. In this frequency band moisture (free water) is most specific, as it is only the water molecule that produces molecular resonance. The microwave radiation can be guided by waveguides or be transmitted through the process stream from source to receiver.

The principle of operation of this instrument is the same as that of the infrared absorption hygrometer; namely, selective absorption of electromagnetic energy by moisture in the sample. However, in this case, radiant energy in the microwave length is used. A transmitter provides a microwave beam, which can either be transmitted through or reflected by the sample material. The receiving unit senses wave attenuation and phase shift and provides a readout. The unit senses the mass of moisture in the beam path so that the readout is normally in terms of the mass of moisture per unit volume. However, with calibration, readout in weight percent can be achieved.

Several probe configurations are possible depending on the application. One has the transmitting and receiving probes welded into a section of pipe. Internally, Teflon contacts the sample. This type of arrangement can be used to advantage on slurries and pastes since there are no obstructions to flow. The units described above measure the attenuation by moisture of a microwave beam in the sample. The reflectance-type unit contains the source and detector in one housing. Rather than detecting the transmitted microwave energy, this design measures the amount of energy reflected by the sample. The probe of the reflectance unit does, however, require contact with the process material.

Advantages:

Disadvantages:

Keywords : “microwave absorption hygrometer”

Radiometer (Pyranometer, Pyrhelimeter)

Cadmium Sulfide Photocell

Measures the change in resistance of Cadmium Sulfide with light exposure.

Advantages: Inexpensive (\$.52).

Disadvantages: Slow response. Limited spectral response.

Keywords : “CdS photocell” “Cadmium Sulfide photocell”

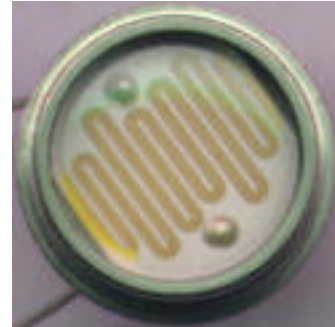


Figure 29 CdS Photocell

Photodiode

Measures the current produced by charge carriers created by radiation in a PN junction. There are a large number of types of photodiodes based on material, fabrication process, configuration, and so on.

Advantages: Inexpensive. Fast. Good spectral response.

Disadvantages: UV sensitive detectors (200-390nm wavelength or 290-325nm for a more limited definition of UV) are expensive.

Keywords : “silicon carbide photodiode”, “SiC photodiode” “silicon photodiode”, “germanium photodiode” “indium gallium arsenide photodiode” “GaAlAs photodiode”



Figure 30 Photodiode

Phototransistor

Measures the current produced by charge carriers created by radiation in a PN junction. Unlike a photodiode, phototransistors have current gain. Three common types are bipolar, photodarlington and photo field effect transistors.

Advantages: Large gain (suitable for low light levels).

Disadvantages: Slow. Can be saturated by too much light.

Keywords : “phototransistor” “photodarlington” “photo FET”

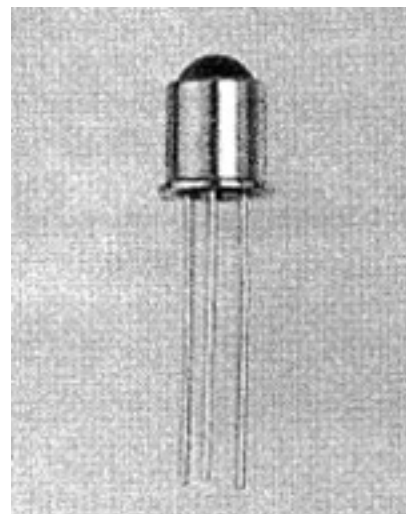


Figure 31 Phototransistor

Photomultiplier

Measures the voltage produced by photon amplification in a voltage ladder specially constructed in an evacuated tube.

Advantages: Low (electronic) noise. Very large gain (suitable for extremely low light levels).

Disadvantages: High voltage power supply required. Poor red sensitivity. Cost. Can be saturated by too much light.

Keywords : “photomultiplier” “PM”
“photomultiplier tube” “PMT”

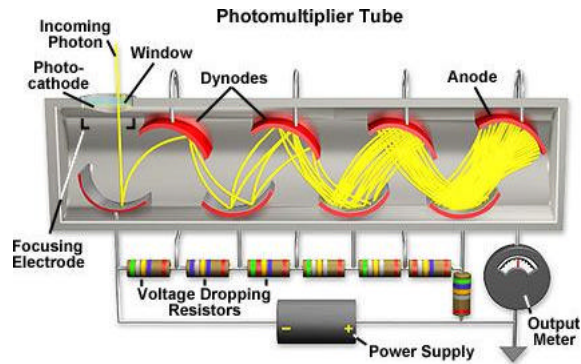


Figure 32 Photomultiplier

Thermopile

Measures the heat generated by radiation striking a (usually large) array of thermocouples. Many thermocouples are used to increase the sensitivity. Often a black absorption material covers the hot junctions.

Advantages: Wide spectral response.

Disadvantages: Costly.

Keywords : “thermopile”

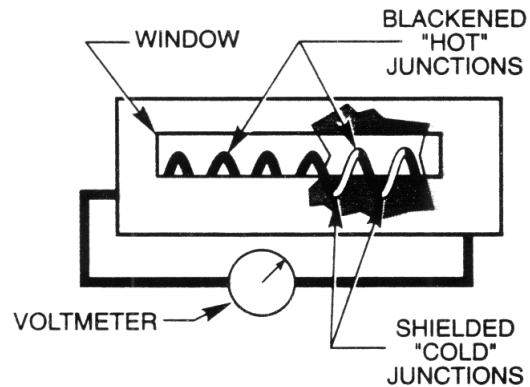


Figure 33 Thermopile