used to measure steady or slowly changing temperature. For accurate results the entire thermometer coil must be exposed to the temperature to be measured.

Pyrometers

The pyrometer is the usual instrument for measuring high temperatures such as those of incandescent bodies or furnace interiors. There are two types. In the radiation pyrometer the radiant energy from an observed surface falls on a thermopile, and the emf generated by the pile, measured by a galvanometer or potentiometer, is an index of the surface temperature. With the optical pyrometer a narrow spectral band, usually red, emitted by the surface, is matched visually with the filament of a special electric lamp. The emf necessary to cause the filament to match the surface in brightness is the index of the temperature of the surface. Pyrometers are calibrated by means of various metals with known melting or freezing points. Portable as well as laboratory models are manufactured.

Color Indicating Crayons

Crayons are available, the marks of which change color or melt at specified temperatures. Such crayons have been sold in boxes covering the range from about 100 F to about 800 F in 100 deg steps, with a precision of some 10 deg. They are a rough but convenient means of determining temperatures, and of locating isothermal lines on surfaces below red heat.

Sampling and Averaging

Temperature is usually a point measurement, but is frequently assumed representative of the value over an area, as on a surface or in a flowing stream. However, such an assumption is rarely safe without an exploration. For accurate determination of average stream temperature, it is well to divide the cross-section into smaller areas and measure the temperature of each of these. The temperatures measured should be combined into a weighted mass-flow average by either (1) using equal areas and multiplying each temperature by the fraction of total mass flow in its area, or (2) using areas of size inversely proportional to mass flow and taking a simple arithmetic average of the temperatures in each. Such procedures are cumbersome, however, and some means of mixing or selective sampling is preferable. While mixing may be obtained by turbulence alone, transposition is much more effective for mixing. In transposition, the stream is divided into parts determined by the type of stratification and alternate parts passed through each other.

Static Temperature vs Total Temperature

When a fluid stream impinges on a temperature-sensing element such as a thermometer or thermocouple, the element will be at some temperature greater than the true stream (*static*) temperature. The difference will be some fraction of Δt_s the temperature equivalent of the stream velocity.

$$\Delta t_s = V^2/(2gJc_p)$$

where

V = velocity of stream, feet per second.
g = acceleration due to gravity, feet per (second) (second).
J = mechanical equivalent of heat, 778.3 ft-lb per Btu.
c_p = specific heat at constant pressure, Btu per pound.

For air, $\Delta t_s = 0.81\ (V/100)^2$. This fraction of the temperature equivalent of the velocity is called the *recovery factor* and varies from 0.6–0.8 for bare thermometers to 0.95 for aerodynamically shielded thermocouples. For extremely precise temperature measurement it is necessary to calibrate each temperature sensor individually to determine its recovery factor. However, for most applications where air velocities are below 5000 fpm this effect can be neglected.

A variety of temperature sensors are becoming available for temperature measurement in fluid streams. Principal of these are the *static temperature thermometer*, which indicates true stream temperature but is very cumbersome, and the *thermistor* used for very accurate temperature measurement within a limited range.

MEASUREMENT OF ABSOLUTE PRESSURE

Instruments for measuring absolute pressure are listed in Table 2, together with brief comments on each. The principal instruments will be described.

Instruments for Extremely Low Pressures

Absolute pressures in the order of 25 to 5,000 microns of mercury may be measured by means of the McLeod, the Pirani, or the electronic discharge gage. In the *McLeod gage*, a known volume of gas is trapped and raised to a predetermined pressure at which its remaining volume indicates the initial pressure. Accuracy is good but the instrument is not direct-reading and not suitable for use with gases which contain vapors that would condense during the compression. The *Pirani gage* measures the thermal conductivity of a gas to determine its pressure and, therefore, depends upon accurate knowledge of the composition of the gas. Electrical discharge instruments use the discharge of electrically-charged particles impinging on a screen to determine pressure.

Barometer

The simplest and earliest type of barometer consists of a glass tube somewhat more than 30 in. long filled with mercury, and inverted in a cup partially filled with mercury. The height of the mercury column in the tube above the mercury surface in the cup is a measure of the existing atmospheric pressure, except for the slight pressure of the mercury vapor in the space above the mercury in the tube. This can ordinarily be ignored.

Elaborate mercury barometers, fitted with vernier scales, are available. For precise work, corrections must be made for the thermal expansion of the mercury and of the scales.[9] The instruments are usually calibrated for 32 F mercury and 62 F scale temperature, and the correction C to be subtracted from the observed barometer's height is obtained by means of Equation 2.

$$C = \frac{h(t - 28.630)}{(1.1123t + 10978)} \qquad (2)$$

where

C = correction to be subtracted, inches of mercury.
h = observed height, inches of mercury.
t = observed temperature of the barometer, Fahrenheit degrees.

Standard atmospheric pressure at sea level is 29.921 in. Hg, and since normal atmospheric pressure decreases about 0.01 in. Hg for each 10 ft increase in elevation, it is important to make a correction if the elevation of the barometer is not that of the test apparatus. In many cases the barometric reading may be obtained from a nearby Weather Bureau Station, in which case inquiry should be made as to whether the value is for *station* or *sea level* pressure.

Table 2 . . . Measurement of Absolute Pressure

No.	Measurement Means	Application	Range	Precision	Limitations
1	McLeod gage	Very low abs press.	0–0.1 in. Hg	2–5%	Not direct reading; vapors tend to condense out
2	Pirani gage			2–5%	Must be calibrated for gas composition on which used
3	Absolute-pressure manometer	Moderately low abs. press.	0–30 in. Hg or above	0.01 in.	Not readily portable
4	Barometer, mercury—manometer type	Atmospheric press.		0.001–0.01 in.	
5	Differential manometer and barometer	Moderately low abs. press.	0–60 in. Hg or above	0.01 in.	Awkward observation; requires two readings
6	Evaporating liquid temp.	On refrig. machine and for use during evacuation	Depends on liquid	1%	Liquid must be kept supplied; can only be used where liquid evaporation will not damage system
7	Pressure Transducers—strain gage, capacity, potentiometer, crystal, magnet	Remote Reading, responds to rapid changes of pressure	0.05 to 50,000 psi	0.1%	Must be calibrated

Atmospheric pressure may also be measured by an *aneroid barometer* which is easily portable. In this type, variations in atmospheric pressure deflect the thin surface of a sealed diaphragm capsule. Most commercially available aneroid barometers are not as accurate as the mercurial type, and the best require occasional recalibration. Open-scale aneroid barometers are more expensive than common mercurial barometers.

Most of the pressure gages used in engineering work indicate gage pressures, that is, the difference between the pressure being measured and the atmospheric pressure. Such pressures are called gage pressures. Absolute pressure may be obtained by adding barometric pressure and gage pressure algebraically.

Indirect Pressure Measurement

In refrigerating systems, the high- or low-side pressure is frequently determined by the measurement of the temperature of condensing or evaporating refrigerant. In obtaining this measurement, care must be taken that there is no sub-cooling, superheat or non-condensable gas present.

MEASUREMENT OF DIFFERENTIAL PRESSURE

Instruments for measuring differential pressure are shown in Table 3. A pressure differential can also be measured by using absolute-pressure instruments and taking the difference in their readings.

Manometers

The manometer is a simple and useful means for measuring partial vacuum and low pressure. It is, moreover, a primary instrument; it does not require calibration, and it is often used as a standard for the calibration of other instruments. It is so universally used that both the inch of water and the inch of mercury have become accepted units of pressure measurement. In its simplest form, the manometer consists of a U-shaped glass tube partially filled with a liquid. A difference in height of the two fluid columns denotes a difference in height of the two legs, which is proportional to the difference in height.

For converting manometer readings into other pressure units, certain proposed standard factors are applicable for

Table 3 . . . . Measurement of Differential Pressures (Gage)

No.	Measurement Means	Application	Range	Precision	Limitations
1	Micromanometer	Very low press. diff.	0.000–6 in. H_2O	0.0005 in. H_2O	Not readily portable; not easy to use with pulsating pressure
2	Draft gages	Moderately low press. diff.	0.0–10 in. H_2O	0.005 in.–0.05 in. H_2O	Must be leveled carefully; needs calibration
3	Manometer	Medium press. diff.	0–100 in. H_2O or Hg	0.05 in.	Where used with liquid must be compensated for liquid density
4	Swinging-vane type gage	Moderately low press. diff.	0–½ in. 0–20 in. H_2O	5%	Generally usable to atmospheric pressure only
5	Bourdon-tube type	Medium to high press. diff., usually to atmosphere	Any	As high as 0.01 psi or 0.01% of full scale	Must be calibrated; subject to damage due to over press-shock or pulsation
6	Pressure Transducers—strain gage, capacity, potentiometer, crystal, magnet	Remote Reading, responds to rapid changes of pressure	0.05 to 50,000 psi	0.1%	Must be calibrated