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AGA American Gas Association

GAS MEASUREMENT MANUAL

MEASUREMENT OF GAS PROPERTIES

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GAS MEASUREMENT MANUAL
(REVISED)

PART ELEVEN
MEASUREMENT OF GAS PROPERTIES

SECTION 11.1—SPECIFIC GRAVITY DETERMINATION
SECTION 11.2—HEATING VALUE OF GAS DETERMINATION
SECTION 11.3—GAS SAMPLING
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SECTION 11.9—GAS ODORIZATION
SECTION 11.10—WATER VAPOR DETERMINATION

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Part 1 General (XQ1081)
Part 2 Displacement Measurement (XZ0277)
Part 4 Gas Turbine Metering (XQ0684)
Part 5 Other Measurement Methods (XQ0483)
Part 6 Auxiliary Devices (XQ0779)
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Section 11.1
SPECIFIC GRAVITY DETERMINATION

INTRODUCTION

Definition

Specific gravity is a term used to express the ratio of the molecular weight of a gas (or a mixture of gases) to the molecular weight of air. Air is a compound of varying composition. Its molecular weight has been established as 28.9625, as reported in the Table of Physical Properties, A.G.A. Report #3, revised 5/16/85. Where precise specific gravity determinations are made by analytical means, the prevailing composition of air is of no consequence if consistently related to the number 28.9625. Yet, considering technical inability to determine the molecular weight of gas short of analytical fractionation, the ratio of gas density to the density of air under common pressure and temperature conditions is often taken to represent specific gravity. The difference between relative density and relative molecular weight is small, provided, however, that densities are determined at relatively low pressures. Any difference between the two ratios may be attributed to the difference in Ideal Gas Laws deviation at any given common pressure and temperature, if we can assume the composition of reference air at a particular locale approximates a molecular weight of 28.9625. Relative densities may be converted to relative molecular weight (specific gravity) by accounting for the Ideal Gas Laws.

Specific Gravity Relationship to Gas Measurements

Specific gravity is a fundamental aspect of a gas in several gas measuring sectors. In flow metering, the pressure drop across an orifice, flow nozzle, venturi tube, or similar restriction is affected by the molecular weight of the flowing fluid. Also, the relationships that have been found between specific gravity of a gas and its deviation from Ideal Gas Laws account for the preparation of A.G.A.'s *Manual for the Determination of Supercompressibility Factors for Natural Gas* PAR Research Project NX-19*. Similar relationships have also been found between specific gravity and the calorific value of fuel gases and are covered by A.G.A.'s publication Report No. 5, *Fuel Gas Energy Metering*.

Effect of Specific Gravity Errors

Any error in specific gravity determination is very significant, if examined in the light of any one of the several factors affected—F_{gr}, F_{pv}, F_{hgm}, and the heating value of a gas. Yet the overall effect of specific gravity error will be found less than the sum of individual errors, considering the error attributed to a single factor is often offset by compensating errors in other factors tied to a specific gravity index. The effect of specific gravity error on individual factors and combined factors used in orifice meter measurements is illustrated in the following example for a hydrocarbon gas mixture flowing at 1000 psia, at 60°F, under standard gravitational forces of 980.665 cm/sec./sec. (32.174 ft/sec²) at sea level and 45° latitude.

EXAMPLE

	Specific Gravity	Factor F_{gr} (Report #3)	Factor F_{pv} (NX-19)	Factor F_{hgm} (Report #3)	Btu/cf (Report #5)	Combined Factors
Correct	.600	1.2910	1.0834	.9978	1086.9	1516.9
Erroneous	.610	1.2804	1.0872	.9977	1102.6	1531.3
% Error	+1.67	−0.82	+0.35	−0.01	+1.44	+0.95

*This manual has been superseded by A.G.A. Transmission Measurement Committee Report #8. A.G.A. 8 extends the range of contaminants, pressures, and temperatures allowed when it is used to calculated F_{pv}.

If the gas used in the example were other than a pure hydrocarbon mixture, contained diluents would have changed F_{pv} factors, the heating value of the gas, and the combined factors shown. The direction of change depends on the concentration of individual diluents in the gas mixture.

Specific gravity error has a greater effect on displacement metering than will be found with orifice metering, considering that factors F_{gr} and F_{hgm} do not apply to displacement meters and that the effect of the supercompressibility factor is roughly twice as large – $(F_{pv})^2$. All errors arising from specific gravity determinations are additive.

Gas Sampling

Aside from the technique employed in specific gravity determinations, gas sampling practices must be emphasized in the interest of accuracy. Gases diverted to sample bottles or gravitometers should be withdrawn from the center of a flowing stream through a probe whose inlet is near midpoint of the runway cross section. In the absence of a probe or stinger, condensibles in a gas stream will creep along pipewalls to the outlet port and thence into bottles or instruments, in which case a high specific gravity reading may be expected.

Other precautions must be taken where gases contain hydrogen sulfide, carbon dioxide and other constituents which will react with, or be absorbed by, such materials as iron, steel, brass, or rubber. Sampling conduits of aluminum or stainless steel will be found suitable for most gas sampling applications.

DETERMINING SPECIFIC GRAVITY BY LABORATORY METHODS

Direct Weighing

The direct weighing method for finding the specific gravity of a gas represents one of two methods adjudged most accurate although seldom used in practice. Here, an analytical balance is used. Two glass bulbs of matched volume and weight are filled, one with gas and the other with dry air. Both samples must be maintained at equal temperature and pressure. The bulbs are then placed on the balance and weighed. The procedure is repeated, except that the samples are exchanged in the bulbs after thorough purging. Again the weights are observed and recorded, and the average of the two observations is used in determining the weight of each. The ratio of the average weight of the gas sample to the average weight of the air sample is the specific gravity. The procedure of changing sample bulbs has a compensating effect on difference in bulb weight, bulb buoyancy, and slight changes in pressure and temperature. This method is used in laboratories under ideal conditions by skilled technicians using precision instruments; consequently, it does not lend itself to field use.

Gas Analysis

Specific gravity may be determined from a gas analysis obtained by fractional distillation or a mass spectrometer but preferably with a gas chromatograph. Properly conducted, the analysis will provide a quantitative breakdown of the composition from which the specific gravity may be calculated. The specific gravities of the individual components of a gaseous mixture are taken from a reference table, such as is found in A.G.A. Measurement Committee Report No. 3, and multiplied by the mole fraction of each component. The sum of the products is the ideal specific gravity of the gas on a dry basis. If the gas is saturated with water vapor, an adjustment should be made for greater accuracy; however, since this correction is quite small, it is ordinarily disregarded.

Pipeline gas may contain constituents in vapor phase that the chromatograph is not programmed to analyze, such as methanol, amines, glycols, compressor lubricating oils, scrubber oil, and various types of inhibitors. The quality and vapor pressure of these unanalyzed components will affect the calculated specific gravity if the components are in appreciable concentration.

Table 11.1.1 gives an example of specific gravity determination from a fractional gas analysis:

TABLE 11.1.1
Sample Specific Gravity Determination

Compound	**A Compound Mole Fraction (An Example)**	**B Specific Gravity, Pure Compounds (Constants)***	**A×B**
Hydrogen	Nil	.06960	—
Helium	.0001	.13820	.00001
Water Vapor	Nil	.62202	—
Carbon Monoxide	Nil	.96711	—
Nitrogen	.0040	.96723	.00387
Oxygen	Nil	1.10484	—
Hydrogen Sulfide	Nil	1.17669	—
Argon	Nil	1.37930	—
Carbon Dioxide	.0050	1.51955	.00760
Methane	.9312	.55392	.51581
Ethane	.0200	1.03824	.02076
Propane	.0101	1.52256	.01538
Iso-Butane	.0088	2.00684	.01766
N-Butane	.0070	2.00684	.01405
Iso-Pentane	.0069	2.49115	.01719
N-Pentane	.0053	2.49115	.01320
Hexanes (avg.)	.0010	2.97547	.00298
Heptanes (avg.)	.0004	3.45978	.00138
Octanes (avg.)	.0002	3.94410	.00079
Mixture	1.0000		0.63068 (Ideal Specific Gravity, uncorrected for "Z")

*From A.G.A. Report No. 3, Revised 5/16/85. All values are ideal, at 14.73 psia, 60°F.

FIELD METHODS FOR DETERMINING SPECIFIC GRAVITY

Effusion Method

The effusion method is based on the principle that the specific gravity of a gas is equal to the ratio of the square of the time required for a definite volume of gas to pass through a given orifice as compared to the square of time required for an equal volume of air to pass through the same orifice under the same conditions of temperature and pressure. While the theory of this method is sound technically, it is usually associated with Shilling Apparatus, where water is used as a gas drive to expel the gases to atmosphere through a small orifice. Engrained water vapor, condensation about the orifice, and the necessity to use a stop watch to measure time have discredited the method.

Weighing Method (Gravity Balance)

Indirect weighing is used extensively in the natural gas industry, primarily because of the portability of the equipment. The instruments used employ two principles: **Archimedes Principle**, which states that the buoyant force exerted on a body suspended in a fluid is proportional to the density of the fluid, and **Ideal Gas Laws**, which state that the density of a gas is proportional to its absolute pressure at a given temperature. Two types of indirect weighing or gravity balances are used. In the first type (Figure 11.1.1), a balanced condition of the float and counterweight beam is obtained by adjustment of the pressure of the gas or air in the chamber. Equal gas and air densities are used to balance the beam with the assumption that the ratio of gas to air pressure is indicative of the relative density of the two substances following Boyle's Law. With the second type, gas and air chamber pressures are common (usually atmospheric). Relative density is indicated by the difference in the angles of deflection of the beam, comparing the weight of gas to air. Of the two indirect weighing methods, the first type is used most commonly. In either instance, relative densities are found. These relative densities may be converted to ideal specific gravity (molecular weight ratio) by accounting for the ratio of Ideal Gas Laws deviation of gas to that of air. In the absence of precise data relating to Boyle's Law deviation of the gas and air at measured pressures and temperatures, Figure 11.1.2 may be used in conjuction with the first named method.

$$\text{Specific Gravity} = \frac{(Pa \times Tg \times Zg)}{(Pg \times Ta \times Za)}$$

where

P = absolute pressure
T = thermodynamic temperature (Kelvin or Rankine)
Z = Compressibility factor
Subscript g = gas,
Subscript a = air.

In the instance of the second indirect weighing method (where the gas and the air are at equal pressure and temperature and near one atmosphere and 60°F temperature), the Ideal Gas Laws deviation ratio may be expressed as 1.00369 − 0.0101 RD, where RD is relative density. Thus

$$\text{Specific Gravity} = \text{RD}\ (1.00369 - 0.0101\ \text{RD})$$

Auxiliary requirements for making a determination of specific gravity with a gravity balance are a pressure-suction pump, an air drier, a mercury manometer, and a mercurial or aneroid barometer. For field use, a temperature-compensated aneroid barometer is used normally. It should be adjusted to read in inches (or millimeters) of mercury at 32°F. However, it must not be adjusted for elevation or latitude since it must indicate the actual atmospheric pressure at the place of use. An aneroid barometer should be checked frequently against a reference standard mercurial barometer. Indicating silica gel is a practical drying agent for the air drier because it changes color from blue to pink coincident with the absorption of moisture.

When one conducts field determinations with a specific gravity balance, the following precautions should be observed. The instrument should be located where it will be free from vibration and wind currents, and it should be on a firm base and remain level throughout the test. It should be in the test location long enough to attain equilibrium with the ambient temperature before a test is starting; the ambient temperature and the sample temperature should be nearly equal. Sample connections should be purged thoroughly and care should be taken to ensure that no liquid droplets enter the apparatus. To avoid condensation of vapors, the temperature of the balance should be higher than that of the supply gas. Care should be taken to obtain air samples from an uncontaminated source.

The procedure for determining specific gravity with this instrument is as follows. Preferably, the balance is mounted on a tripod or other firm stand then leveled after being connected to the gas supply, the manometer, air drier, and pump. All connections should be checked for leaks against both positive and negative gauge pressures. Next, observe and record the barometer reading. With the suction side of the pump connected to the balance, exhaust the air, then admit air slowly through the drier. Twice again exhaust and refill through the drier. The last refilling operation should be accomplished with the balance beam unlocked, slowly admitting air through the drier until the balance beam reaches the balance or equilibrium position. It must be observed that the beam is in a free equilibrium position, indicated by equal oscillations. Next, lock the beam and read the manometer after tapping it lightly; then, note and record

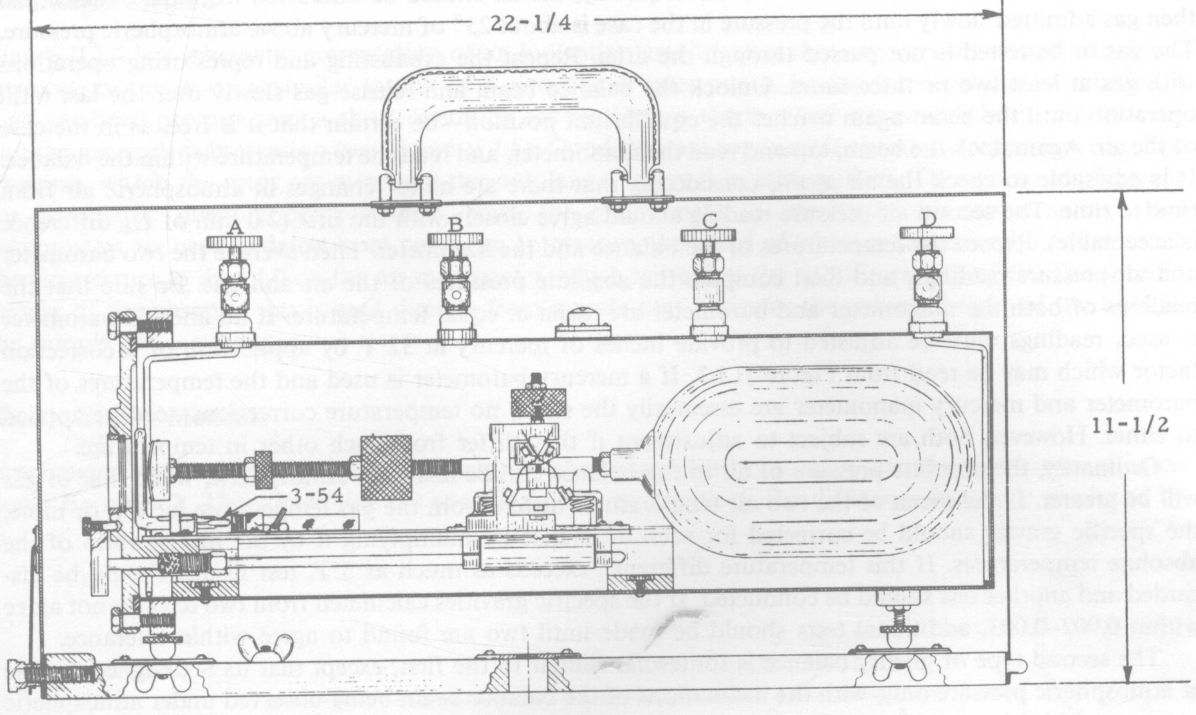

Figure 11.1.1 Portable specific gravity balance.

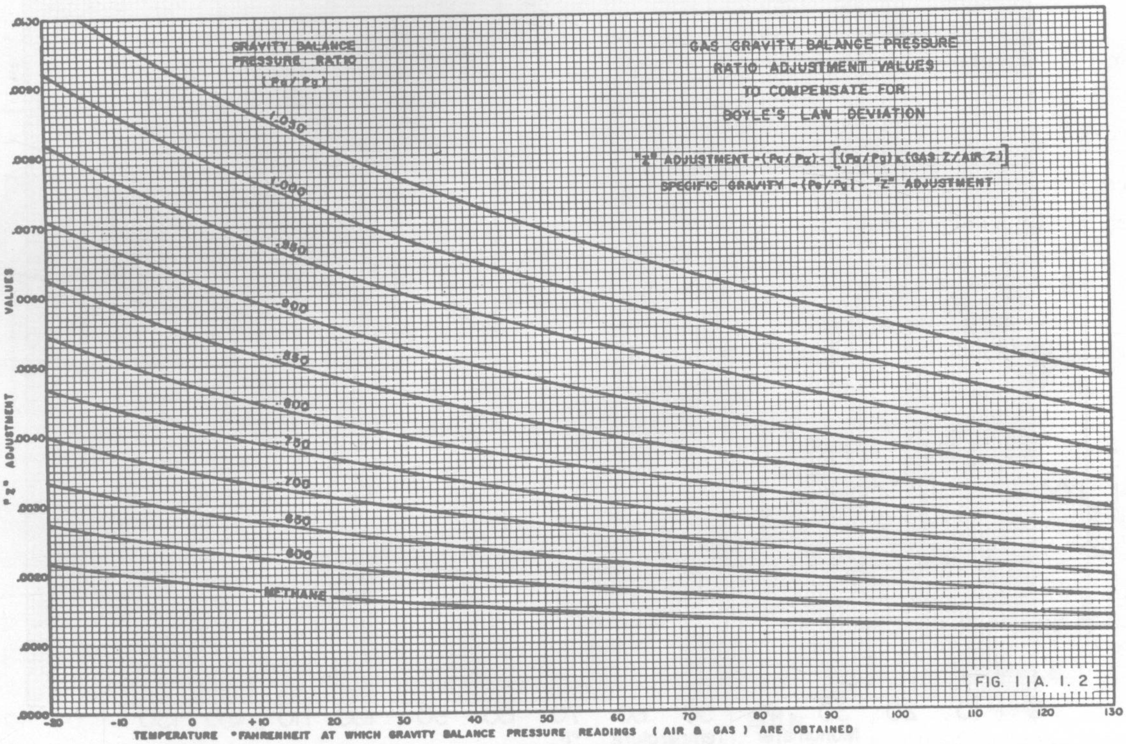

Figure 11.1.2 Gas gravity balance pressure ratio adjustment values to compensate for Doyle's law deviation.

the temperature in the balance chamber. Subsequently, the air should be exhausted from the balance and then gas admitted slowly until the pressure in the case is about 25″ of mercury above atmospheric pressure. The gas to be tested is not passed through the drier. Repeat the exhausting and repressuring operations with gas at least two or three times. Unlock the balance beam and release gas slowly over the last refill operation until the beam again reaches the equilibrium position—be certain that it is free, as in the case of the air. Again, lock the beam, tap and read the manometer, and read the temperature within the balance. It is advisable to check the air again, considering that there are minor changes in atmospheric air from time to time. The second air pressure reading should agree closely with the first (2.0 mm of Hg difference is acceptable). Record the temperatures of the balance and the barometer. Then average the two barometer and air-pressure readings, and then compute the absolute pressures of the air and gas. Be sure that the readings of both the manometer and barometer are taken at equal temperature. If an aneroid barometer is used, readings must be adjusted to provide inches of mercury at 32°F by application of a correction factor which may be read from Figure 11.1.3. If a mercury barometer is used and the temperatures of the barometer and mercury manometer are essentially the same, no temperature corrections need be applied to either. However, both are subject to adjustment if they differ from each other in temperature.

Ordinarily, the absolute pressure of air in the balance will be less than atmospheric, while that of gas will be greater. If the mean of the two air temperatures differs from the gas temperature by 2°F or more, the specific gravity should be corrected for such difference by multiplying it by the inverse ratio of the absolute temperatures. If this temperature difference exceeds as much as 5°F, test results should be discarded and another test should be conducted. If the specific gravities calculated from two tests do not agree within 0.002–0.003, additional tests should be made until two are found to agree within tolerance.

The second type of gravity balance is somewhat similar to the first, except that its is designed for use at atmospheric pressure only, with the inclinations of the balance beam being observed under atmospheric pressure within the weighing chamber.

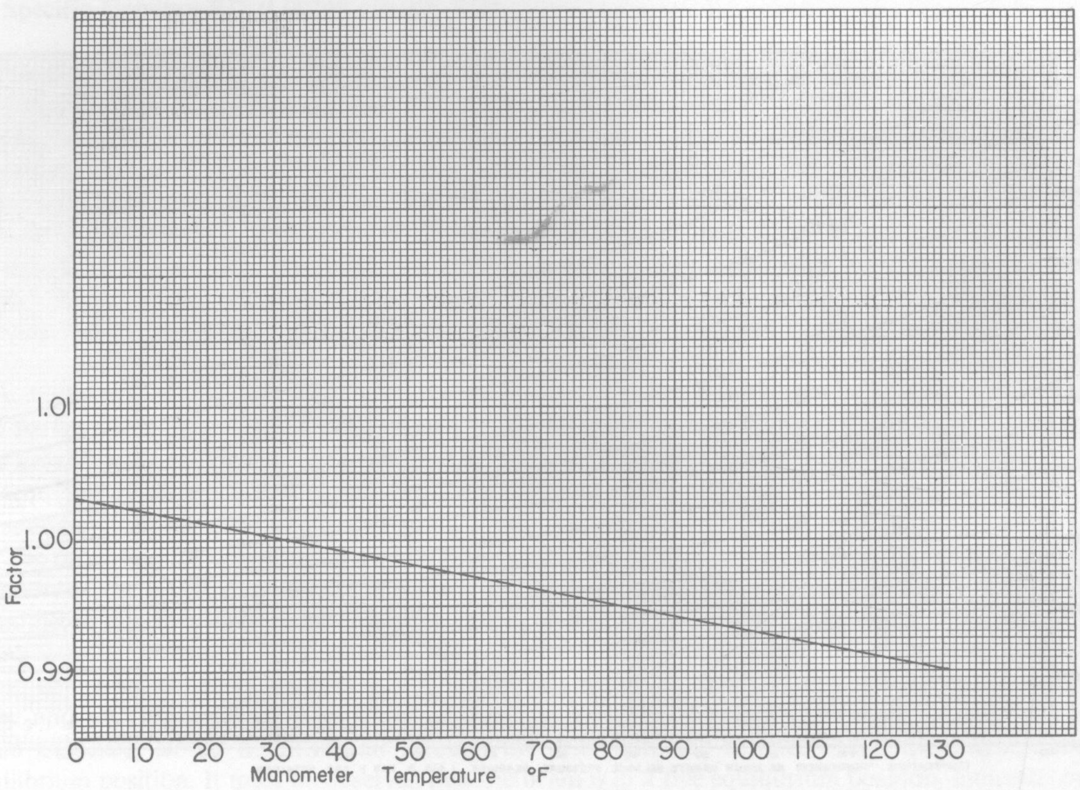

Figure 11.1.3 Factors for converting inches of mercury at manometer temperature to inches of mercury at 32°F.

Centrifugal Method

Figure 11.1.4 is a schematic presentation of an indicating gravitometer that employs centrifuge principles. Its mode of operation is similar to that of a centrifugal water pump, having the capability of creating a high gas head pressure over a short operating radius. Here a single wheel copes with both reference air and the gas under observation (see Figure 11.1.5). Good thermal conductivity insures temperature equality. Pressures within the rotor are measured through lances inserted in inlet orifices. There is no requirement for barometric pressure compensation, since the gravitometer is inherently self-compensating. Two manometers are used to detect head pressures. In practice, the speed of wheel rotation is adjusted to cause the air pressure to read 1.0 on the air manometer, which represents the specific gravity of air. The specific gravity of the observed gas is read directly from a scale that indicates the column height of the fluid in the sample gas manometer.

Kinetic Energy Method

Instruments used to determine specific gravity by the Kinetic Energy method use the kinetic energy equation $KE = mV^2 \div 2$. They determine the specific gravity by means of the difference in torque produced by

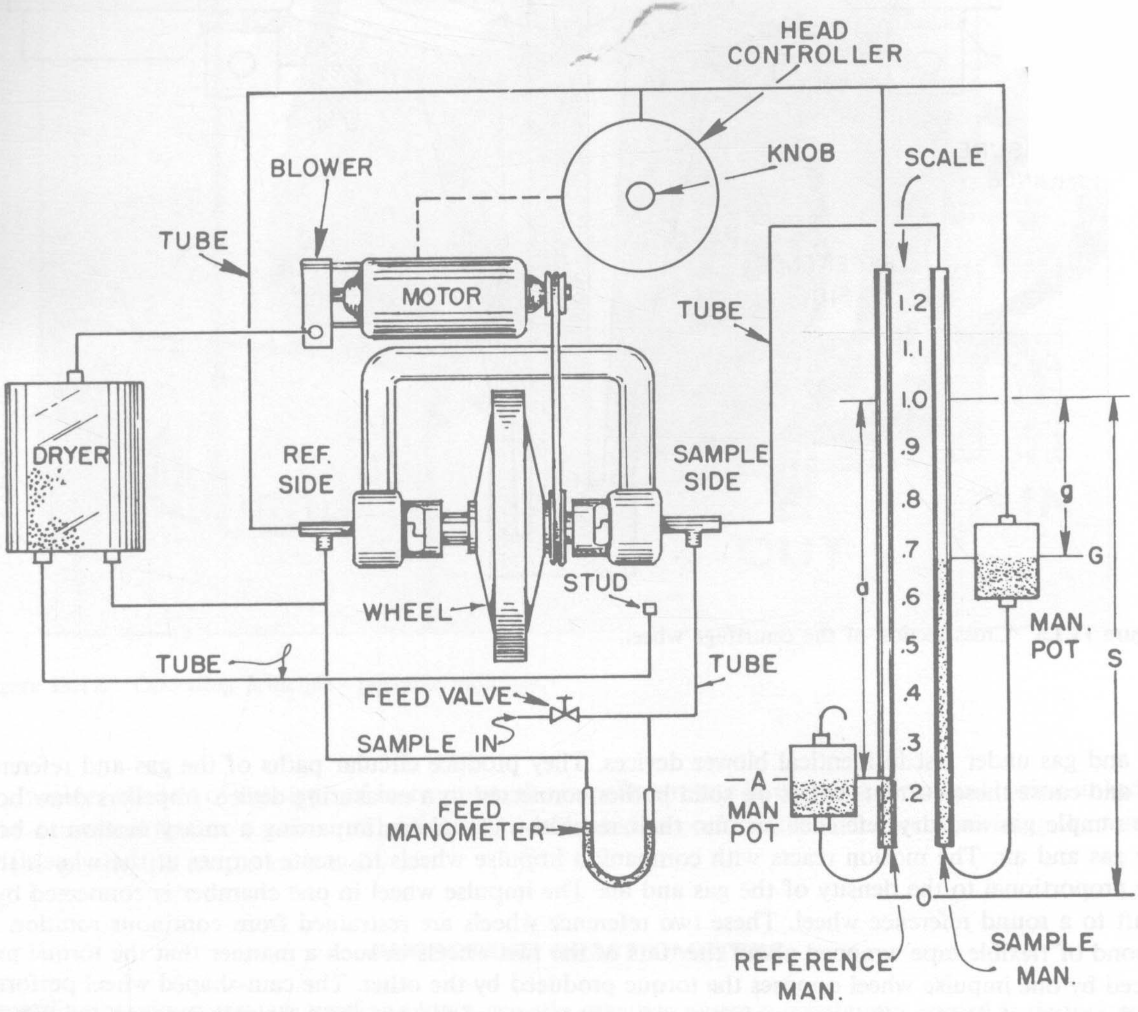

Figure 11.1.4 Schematic of gas centrifuge gravitometer.