CHAPTER 1

1.1 (a) The weight of a person is 175 pounds which is equivalent to 778 Newtons.

$$175 lbf \ * \ \frac{4.4482N}{1lbf} = 778 \text{ Newtons}$$

(b) The magnetic force of 1,200 dynes is equivalent to 0.0027 pounds or 0.012 Newtons.

$$1200 dyn \ * \ \frac{10^{-5} N}{1dyn} = 0.012 \text{ Newtons}$$

$$1200 dyn \ * \ \frac{10^{-5} N}{1dyn} \ * \ \frac{1lbf}{4.4482N} = 0.0027 \text{ pounds}$$

(c) The force exerted by the spring is 10 Newtons which is equivalent to 1,000,000 dynes or 2.248 pounds

$$10N \ * \ \frac{1dyn}{10^{-5} N} = 1{,}000{,}000 \text{ dyne}$$

$$10N \ * \ \frac{1lbf}{4.4482N} = 2.248 \text{ pounds}$$

1.2 (a) The tire pressure is 30 psig which is equivalent to 2.069 bars or 2.041 atm.
Note: 1 psig is considered to be = 1 psi

$$30 psig \ * \ \frac{1atm}{14.696 psi} = 2.041 \text{ atm}$$

$$30 psig \ * \ \frac{6.895kPa}{1psi} \ * \ \frac{1bar}{100kPa} = 2.069 \text{ bars}$$

(b) The compressed air at 10 bars is equivalent to 145 psig or 9.87 atm or 295.3 inches of mercury or 102 meters of water

$$10bars \ * \ \frac{100kPa}{1bar} \ * \ \frac{1psi}{6.895kPa} = 145 \text{ psi}$$

$$10bars \ * \ \frac{100kPa}{1bar} \ * \ \frac{1psi}{6.895kPa} \ * \ \frac{1atm}{14.696 psi} = 9.87 \text{ atm}$$

$$10bars \ * \ \frac{100kPa}{1bar} \ * \ \frac{1psi}{6.895kPa} \ * \ \frac{1atm}{14.696 psi} \ * \ \frac{76cmHG}{1atm} \ * \ \frac{1in}{2.54cm} = 295.3 \text{ in of Hg}$$

$$10bars \ * \ \frac{100kPa}{1bar} \ * \ \frac{1psi}{6.895kPa} \ * \ \frac{1atm}{14.696 psi} \ * \ \frac{1033.2cmWater}{1atm} \ * \ \frac{1m}{100cm} = 102 \text{ meters water}$$

(c) 50 cm of water is equivalent to 0.0490 bars or 0.711 psi or 1.45 inches of mercury

$$50cmWater \ * \ \frac{1atm}{1033.2cmWater} \ * \ \frac{101.325kPa}{1atm} \ * \ \frac{1bar}{100kPa} = 0.0490 \text{ bars}$$

$$50cmWater \ * \ \frac{1atm}{1033.2cmWater} \ * \ \frac{101.325kPa}{1atm} \ * \ \frac{1psi}{6.895kPa} \ * = 0.711 \text{ psi}$$

$$50cmWater \ * \ \frac{1atm}{1033.2cmWater} \ * \ \frac{76cmHG}{1atm} \ * \ \frac{1in}{2.54cm} = 1.45 \text{ in of Hg}$$

1.3 (a) The household energy use of 750 kWh is equivalent to 2,559,241.71 Btu or 645,007 kCal or 2,700,000,000 joules

$$750kWh * \frac{3600kJ}{1kWh} * \frac{1000J}{1kJ} * \frac{1Btu}{1055J} = 2{,}559{,}241.71 \text{ Btu}$$

$$750kWh * \frac{3600kJ}{1kWh} * \frac{1000J}{1kJ} * \frac{1cal}{4.186J} * \frac{1kcal}{1000cal} = 645{,}007 \text{ kcal}$$

$$750kWh * \frac{3600kJ}{1kWh} * \frac{1000J}{1kJ} = 2{,}700{,}000{,}000 \text{ J}$$

(b) The gas water heater uses 50,000 Btu or 52,750,000 joules or 12,601.5 kcal or 38,908,386 ft.lbf

$$50000Btu * \frac{1055J}{1Btu} = 52{,}750{,}000 \text{ joules}$$

$$50000Btu * \frac{1055J}{1Btu} * \frac{1cal}{4.186J} * \frac{1kcal}{1000cal} = 12{,}601.5 \text{ kcal}$$

$$50000Btu * \frac{1\,ft.lbf}{0.00128507Btu} = 38{,}908{,}386 \text{ ft.lbf}$$

(c) The amount of heat required is 250 kCal which is equivalent to 992 Btu or 250,000 Cal or 1,046,500 joules

$$250kcal * \frac{1000cal}{1kcal} * \frac{4.186J}{1cal} * \frac{1Btu}{1055J} = 992 \text{ Btu}$$

$$250kcal * \frac{1000cal}{1kcal} = 250{,}000 \text{ cal}$$

$$250kcal * \frac{1000cal}{1kcal} * \frac{4.186J}{1cal} = 1{,}046{,}500 \text{ J}$$

1.4 **(a)** The automobile rating of 150 hp is equivalent to 112 kW or 82,500 ft.lbf/sec or 106.02 Btu/sec

$$150hp * \frac{745.7W}{1hp} * \frac{1kW}{1000W} = 112 \text{ kW}$$

$$150hp * \frac{550\frac{ft.lbf}{s}}{1hp} = 82{,}500 \text{ ft.lbf/sec}$$

$$150hp * \frac{745.7W}{1hp} * \frac{1\frac{Btu}{s}}{1055.04W} = 106.02 \text{ Btu/sec}$$

(b) The truck rating of 400 kW is equivalent to 536 hp or 295,025 ft.lbf/sec or 379 Btu/sec

$$400kW * \frac{1000W}{1kW} * \frac{1hp}{745.7W} = 536 \text{ hp}$$

$$400kW * \frac{1000W}{1kW} * \frac{1hp}{745.7W} * \frac{550\frac{ft.lbf}{s}}{1hp} = 295{,}025 \text{ ft.lbf/sec}$$

$$400kW * \frac{1000W}{1kW} * \frac{1\frac{Btu}{s}}{1055.04W} = 379 \text{ Btu/sec}$$

(c) The water heater rating of 40,000 Btu/hr is equivalent to 11.72 kW

$$40000\frac{Btu}{hr} * \frac{0.293W}{1\frac{Btu}{hr}} * \frac{1kW}{1000W} = 11.72 \text{ kW}$$

1.5 **(a)** 50 ºF is equivalent to 10 ºC

$(\frac{5}{9})(50 - 32) = 10$ ºC

(b) 150 ºC is equivalent to 302 ºF

$(\frac{9}{5})(150\ ^{o}C) + 32 = 302$ ºF

(c) The water temperature increase of 40 ºC is equivalent to a change of 40 K or 72 ºF or 72 ºR

$(40\ ^{o}C) * \frac{1°K}{1°C} = 40\ K$

$(40\ ^{o}C) * \frac{1.8°F}{1°C} = 72\ ^{o}F$

$(40\ ^{o}C) * \frac{1.8°R}{1°C} = 72\ ^{o}R$

(d) The air temperature change of 30 ºF is equivalent to a change of 16.7 K or 16.7 ºC or 30 ºR

$(30\ ^{o}F) * \frac{0.556°K}{1°F} = 16.7\ K$

$(30\ ^{o}F) * \frac{0.556°C}{1°F} = 16.7\ ^{o}C$

$(30\ ^{o}F) * \frac{1°R}{1°F} = 30\ ^{o}R$

1.6 (a) 4 gallons is equivalent to 15.1 liter or 15,142 cm^3 or 0.535 ft^3

$$4gal * \frac{0.0037854m^3}{1gal} * \frac{1Liter}{10^{-3}m^3} = 15.1 \text{ liter}$$

$$4gal * \frac{0.0037854m^3}{1gal} * \frac{1cm^3}{10^{-6}m^3} = 15{,}142 \text{ cm}^3$$

$$4gal * \frac{0.0037854}{1gal} * \frac{1ft^3}{0.02832m^3} = 0.535 \text{ ft}^3$$

(b) 10 liters is equivalent to 2.64 gallons or 10,000 cm^3 or 0.353 ft^3

$$10Liter * \frac{10^{-3}m^3}{1liter} * \frac{1gal}{0.0037854m^3} = 2.64 \text{ gallons}$$

$$10Liter * \frac{10^{-3}m^3}{1liter} * \frac{1cm^3}{10^{-6}m^3} = 10{,}000 \text{ cm}^3$$

$$10Liter * \frac{10^{-3}m^3}{1liter} * \frac{1ft^3}{0.02832m^3} = 0.353 \text{ ft}^3$$

(c) 5 ft^3 is equivalent to 37.4 gallons or 141,600 cm^3 or 142 liters

$$5ft^3 * \frac{1gal}{0.13368ft^3} = 37.4 \text{ gallons}$$

$$5ft^3 * \frac{0.02832m^3}{1ft^3} * \frac{1cm^3}{10^{-6}m^3} = 141{,}600 \text{ cm}^3$$

$$5ft^3 * \frac{0.02832m^3}{1ft^3} * \frac{1liter}{10^{-3}m^3} = 142 \text{ liters}$$

1.7 The air gas constant of 53.34 ft.lbf/lbm.ºR is equivalent to 0.0685 Btu/lbm.ºR or 287 joules/kg.K or 0.0686 kcal/kg.K

$$53.34\frac{ft.lbf}{lbm^\circ R} * \frac{0.00128507Btu}{1ft.lbf} = 0.0685 \text{ Btu/lbm.ºR}$$

$$53.34\frac{ft.lbf}{lbm^\circ R} * \frac{0.00128507Btu}{1ft.lbf} * \frac{1055J}{1Btu} * \frac{1lbm}{0.4536kg} * \frac{1^\circ R}{\frac{5}{9}{}^\circ K} = 287 \text{ J/kg.K}$$

$$53.34\frac{ft.lbf}{lbm^\circ R} * \frac{0.00128507Btu}{1ft.lbf} * \frac{1055J}{1Btu} * \frac{1cal}{4.186J} * \frac{1kcal}{1000cal} * \frac{1lbm}{0.4536kg} * \frac{1^\circ R}{\frac{5}{9}{}^\circ K} =$$

$$0.0685\frac{kcal}{kg^\circ K}$$

1.8 The universal gas constant is 1.986 Btu/lb mole.ºR which is equivalent to 1.986 kCal.kg mole.K or 1,545 ft.lbf/lb mole.ºR or 8,314 joules/kg mole.K

$$1.986\frac{Btu}{lbmole°R} * \frac{1055J}{1Btu} * \frac{1cal}{4.186J} * \frac{1kcal}{1000cal} * \frac{1lbm}{0.4536kg} * \frac{1°R}{\frac{5}{9}°K}$$ = 1.986 kCal.kg mole.K

$$1.986\frac{Btu}{lbmole°R} * \frac{1\,ft.lbf}{0.00128507Btu}$$ = 1,545 ft.lbf/lb mole.ºR

$$1.986\frac{Btu}{lbmole°R} * \frac{1055J}{1Btu} * \frac{1lbm}{0.4536kg} * \frac{1°R}{\frac{5}{9}°K}$$ = 8,314 J/kg mole.K

1.9 The thermal conductivity is 200 W/m.ºC or 116 Btu/hr/ft/ºF or 0.048 kcal/sec.m.ºC

$$200\frac{W}{m°C} * \frac{1\frac{Btu}{hr.ft.°F}}{1.7307\frac{W}{m°C}}$$ = 116 Btu/hr/ft/ºF

$$200\frac{W}{m°C} * \frac{1\frac{Btu}{s}}{1055.04W} * \frac{1055J}{1Btu} * \frac{1cal}{4.186J} * \frac{1kcal}{1000cal}$$ = 0.048 kcal/sec.m.ºC

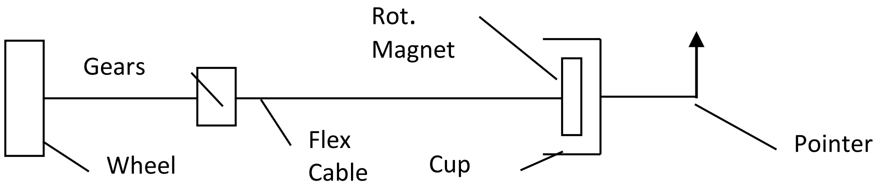
1.10 The thermal conductivity is 50 Btu/hr.ft.ºF or 86.54 W/m.ºC or 20.7 Cal/sec.m.ºC

$$50\frac{Btu}{hr.ft°F} * \frac{1.7307\frac{W}{m°C}}{1\frac{Btu}{hr.ft°F}}$$ = 86.54 W/m.ºC

$$50\frac{Btu}{hr.ft°F} * \frac{1.7307\frac{W}{m°C}}{1\frac{Btu}{hr.ft°F}} * \frac{1\frac{Btu}{s}}{1055.04W} * \frac{1055J}{1Btu} * \frac{1cal}{4.186J}$$ = 20.7 cal/sec.m.ºC

CHAPTER 2

2.1 **(a)** The mechanical speedometer measures vehicle speed by measuring the angular velocity of the wheels. The angular velocity of the wheels (through some gears) causes a flexible cable to rotate. This cable causes a magnet to rotate inside a metal cup creating a circumferential drag on the cup (a torque). The drag is sensed by allowing the cup to rotate less than a complete turn against the resistance of a torsional spring. The cup is connected to a pointer which can be compared to a stationary scale.



The sensing element is the magnet rotating inside the metal cup creating drag. The signal modification system is the system that allows the cup to rotate against a torsional spring. The indicator is the comparison of the pointer to a stationary scale.
(b) The fuel level inside a fuel tank is measured with a mechanical float which follows the surface of the fuel (see Ch. 10). The position of the float is sensed with a connected arm which rotates a rotary variable resistor (angular potentiometer, see Ch. 8). The resistance of the variable resistor is sensed by passing applying a voltage to the resistor and measuring the current with an electromechanical gage. The sensing element is the float. The signal modification system consists of the angular potentiometer and the indicator is the electromechanical gage.
(c) Most of these devices use a variable resistance device called a thermistor. The resistance of the thermistor is a strong function of it's temperature. The resistance is sensed by passing applying a voltage to the device and sensing the current, which will be a function of temperature. The current is then converted to a digital form which is then output to the display. In this case, the thermistor is the sensing device. The signal modification system is quite complicated including the creation of the current and the conversion to digital form. Finally, the indicator is the liquid crystal display.

2.2 True Value = 0.5000 inches

Determination of Bias Error.

First, the average of readings must be calculated:

Average of Readings =

$$(0.4821+0.4824+0.4821+0.4821+0.4820+0.4822+0.4821+0.4822+0.4820+0.4822)/10$$

$$=0.48214$$

$$=0.4821 in$$

Bias Error = Average of Readings -True Value

$$=0.4821-0.5000$$

$$=-0.01786$$

$$=-0.0179\ in$$

Determination of Maximum Precision Error:

$$\text{Maximum Precision Error} = \begin{pmatrix}\text{Largest difference between a single} \\ \text{reading and the Average of Readings}\end{pmatrix}$$

$$=0.4824-0.4821$$

$$=0.0003\ in$$

2.3 Readings:

20.2, 20.2, 20.6, 20.0, 20.4, 20.2, 20.0, 20.6, 20.0, 20.2 (lb)

First determine the average of the reading:

Average W = 20.2 lb

For bias error,

Bias Error = Average Value -True Value

= 20.24-20.0

= 0.2 lb

For maximum precision error, we need the reading with the greatest deviation from the average reading (20.6 lb). Therefore,

Maximum Precision Error = 20.6 -20.2 = 0.4 lb

2.4 (a) Intrusive; The thermometer causes a loading error.

(b) Non-intrusive; The photography does not affect the speed of the bullet at any time.

(c) Non-intrusive; Optical thermal radiation device would yield a non-intrusive measurement as long as it is insulated from the furnace.

(d) Non-intrusive; The speed of the car is unaffected by waves measured by the radar gun.

2.5 **(a)** A single conducting wire induces a small magnetic field around itself and if it is alternating current, will induce an alternating magnetic in the clamp on ammeter. The clamp on ammeter will have a negligible effect on the current in the wire and for all practical purposes is non-intrusive.
(b) The orifice meter (see Ch.10) measures fluid flowrate by obstructing the flow in pipe and measuring the resultant pressure drop. The pressure drop is significant and this device is intrusive.
(c) This device passes a beam of infrared radiation through the gases which absorb some of the radiation (see Ch. 10). This measurement has no effect on the composition of the gases and negligible effect on the gas temperature. It is non-intrusive.
(d) This device measures rotational speed by shining a pulsing light on a mark on the shaft and adjusting the pulsing rate until the mark appears stationary (see Ch. 8). The light has negligible effect on the rotation of the shaft and is non-intrusive.

2.6 **(a)** Bias Error; The output will consistently deviate from the true value.
(b) Precision Error; The speedometer output shows data scatter.
(c) If the difference is consistent with time, then it is a bias error - either of calibration or spatial error. If the difference varies with time, it is precision.

2.7 **(a)** In most cases, this error will by systematic since repeated measurements at the same time will produce the same error. However, if measurements are made over a long period of time and the temperature varies randomly, the error will be random.
(b) This error will be the same each time the measurement is made by the same person with the same procedure and hence is systematic. However, if the measurement is made by several people using different procedures, it may appear to be random.
(c) This error will be the same each time the measurement is made and is always systematic.

2.8 **(a)** This error is usually considered systematic if the readings are all made at the same ambient temperature. However, if the readings are taken over a period of time and the ambient temperature varies randomly, then the error will appear random.
(b) This is always random since the fields normally vary in a random manner.
(c) Since this is a malfunction, it is not predictable in occurrence so it would be considered random.

2.9 **(a)** This error is usually considered random even if the readings are all made at the same conditions since corn-growing conditions are highly dependent on various factors.
(b) The deterioration of asphalt/concrete in a highway is a combination of factors that needs further analysis since the same-grade concrete will deteriorate at a same rate which gives a systematic error, but given the various conditions at which the different portions of the highway is exposed to the elements, each section will have a random error.
(c) The variation of height of the same type of tree in an orchard qualifies as a random error since the height of each tree is highly dependent various growth factors.
(d) The variation of drying time of concrete columns of a highway is subjected to both systematic and random error; only if the drying conditions are constant for all columns and the concrete grade is uniform throughout the highway will the error be limited to systematic.

2.10 **(a)** The variation in access for a popular website would usually be considered a random error since it is dependent on unknown factors.
(b) The variation in average access per day of a popular website would also be considered a random error since it is due to uncontrollable factors.
(c) The variation in the rider-ship of a bus or train line would usually be considered a random error since it is dependent on unknown factors.
(d) The variation in the rider-ship of a bus or train would also be considered a random error since it is due to uncontrollable factors.

2.11 Resolution or readability does not necessarily give any information about accuracy so we cannot make any statement about accuracy. However, the digital device can be read to only 1 part in 999 of the full scale reading. It may be possible to interpolate between divisions on the analog device giving an effective resolution that is better.

2.12 The span is 50 - 0 = 50 m/s.

2.13 **(a)** The span is 50 - 5 = 45 psig
(b) 70 cm vacuum is taken to be 70 cm of mercury which is equivalent to 93 kPa. Thus, the span is 200 - 93 = 107 kPa
(c) The span is 150 - 10 = 140 kPa

2.14 Device (D) would be the best. Device (C) is really the closest in its range. However, measurement errors might cause device (C) to be over range for some measurements producing meaningless results.

2.15 Manufacturer Accuracy = ±2.0% of full scale
= ±0.02(30V)
= ±0.6V
% uncertainty of accuracy = ± (0.6V/5V)(100) = ±12%
The resolution of the device is 0.1 Volts. With a reading of 5V,
% uncertainty of resolution = (0.1V/5V)(100) = 2% (or ±1%)

2.16 **(a)** The maximum reading for each range will be 2.999, 29.99, 299.9 and 2999. and the resolution uncertainty will be 1 in the least significant digit. So the resolution uncertainty will be 0.001V,).01V, 0.1V and 1V for the three ranges. This could also be viewed as ±0.0005V, ±0.005V,±0.05V and ±0.5V
(b) The uncertainties will be 2% of full scale. This is .02*3 for the lowest scale or ±0.06V. Similarly for the higher ranges, the uncertainties will be ±0.6V, ±6V and ±60V.
(c) The resolution uncertainty is negligible compared to the accuracy. Hence we can use the results of part (b). For the 30 V range the relative uncertainy will be 0.06/25 = ±2.4%. For the higher ranges, the uncertainties are ±24% and ±240%.

2.17 Since the device reads 0.5 psi when it should read zero, it has a zero offset of 0.5 psi which will affect all readings. Zero offset is not a component of accuracy. The accuracy specification of 0.2% of full scale gives an uncertainty of $\pm 0.002 \times 50 = \pm 0.1$ psi. This means that we can have an expected error in any reading of 0.5 ± 0.1 psi. For an applied pressure of 20 psi, the reading would be expected to be in the range 20.4 to 20.6 psi.
We can reduce the expected error by either adjusting the zero (if possible) or by subtracting 0.5 psi from each reading. It may be possible to reduce the error due to the accuracy specification by a calibration of the gage.

2.18 With 2V reading when leads are shorted together,

Error 1 = 2V

Error 2 = ±4%(100) = ±4V

⇒ Maximum Total Error = +6/-2V = (6V/80V)(100) = +7.5%

With 0V reading when leads are shorted together,

Error = ±4%(100) = ±4V

⇒ Maximum Percent Error = ±(4V/80V)(100) = ±5%

2.19 The range of both temperature gages will allow the intended 300 C measurement. The uncertainty for each of the two gages is 2% of its span; this gives an uncertainty of 8 C and 18 C for the temperature gage with the smaller and larger span respectively. Thus, the temperature gage with range of 100 C to 500 C should be selected since there is smaller uncertainty.

2.20 The sensitivity is Δoutput/Δinput. This is (125-5)/1000-100) = 0.1333 mV/kPa.

2.21 The sensitivity is Δoutput/Δinput. This is (150-10)/100-10) = 1.556 mV/psi

2.22 The relationship between pressure and temperature is given by:

$$PV = mRT$$

$$P = \frac{mRT}{V}$$

The sensitivity is given by:

$$\frac{dP}{dT} = \frac{mR}{V} = \frac{P_i}{T_i} \;; R, m, and\ V\ cons\tan t$$

⇒ We see the sensitivity $\frac{dP}{dT}$ is proportional to the initial pressure and is changed when the initial filling pressure is changed.

2.23 (a) The sensitivity from A to C is not a constant and gets smaller from A to C.
(b) If a high degree of sensitivity is required, use A-B. For most purposes, B-C would not be recommended due to the sensitivity approaching zero at C.

2.24 Usually, the maximum output increases proportionally with increasing range so the sensitivity will be unchanged.

2.25 Installing an amplifier will increase the sensitivity.

2.26 **(a)** For this device, the output is ΔP and the input is Q. So the sensitivity is simply the derivative of ΔP with respect to Q. Solving for ΔP we get:

$$\Delta P = \left(\frac{Q}{C}\right)^2 \quad \text{then} \quad \frac{d\Delta P}{dQ} = \frac{2Q}{C^2}$$

(b) The sensitivity increases with flowrate and with pressure drop.

(c) This device is best for values of ΔP which are high relative to the design value. At 10% of the design Q, the pressure drop will be only 1% of the design pressure drop.

2.27 Ideal sensitivity = 0.1 cm/N
Input span = 200 N

⇒ Ideal output span = Input span × Ideal Sensitivity
= 200N × 0.1cm/N
= 20 cm

Actual sensitivity = 0.105 cm/N
⇒Actual output span = Input span × Actual sensitivity
= 200N × 0.105cm/N
=21 cm

$$\Rightarrow \text{\%error of output span} = \frac{\text{Actual} - \text{Ideal}}{\text{Ideal}}(100)$$

$$= \frac{21-20}{20}(100)$$

$$= 5\%$$