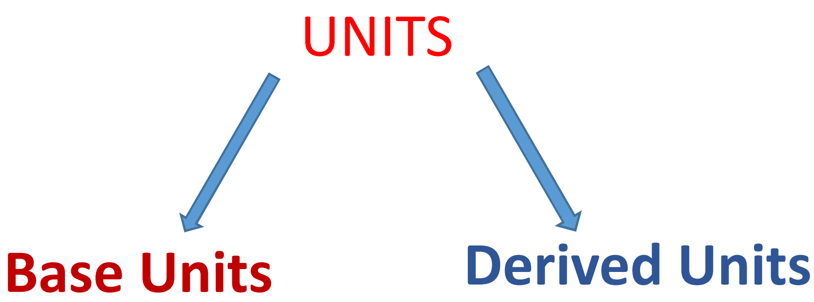
Unit Systems

To measure the magnitudes of quantities measurement units are defined

Engineers specify quantities in two different system of units:

The International System of Units (*Systeme International d'Unites –SI)*

The United States Customary System, USCS)



BASE UNITS

- A base unit is the unit of a fundamental quantity. Base units are independent of one another and they form the core of unit system. They are defined by detailed international agreements.

Base Quantity (common symbol)	SI Base Unit	Abbreviation
Length (l, x, d, h etc.)	Meter	m
Mass (m)	Kilogram	kg
Time (t)	Second	s
Temperature (T)	Kelvin	K
Electric Current (i)	Ampere	A
Amount of substance (n)	Mole	mol
Luminous intensity (I)	Candela	cd

United States Customary System of Units, USCS

- The USCS was originally used in Great Britain, but it is today primarily used in the US. Why does the US stand out against SI? The reasons are complex and involve economics, logistics and culture.
- One of the major distinctions between the SI and USCS is that mass is a base quantity in the SI, whereas force is a base quantity in the USCS. Unit of force in USCS is ‘ pound-force’ with the abbreviation lbf. It is common to use the shorter terminology ‘pound’ and the abbreviation lb.
- Another distinction is that the USCS employs two different dimensions for mass; pound-mass, lbm and the slug (no abbreviation for the slug) (for calculations involving motion, gravitation, momentum, kinetic energy and acceleration the slug is preferred unit. Pound-mass is a more convenient dimension for engineering calculations involving the material, thermal properties of fluids.)

Force: Unit of force is a derived unit

- Newton's 2nd Law for a particle: $F_{net} \propto a \rightarrow F_{net} = ma \ \left[kg\,\frac{m}{s^2}\right]$
- In honor of Newton, instead of saying $\left[kg\,\frac{m}{s^2}\right]$ $we\ say\ Newton, [N]$

1$[kg_f]$: weight of an object of which mass is 1[kg] , customary Turkish Unit for force,
1 $[kg_f]$= g[N],
1[kp]=1 [kgf],
kp: kilopond (German customary force unit)
e.g.: Mass of an object is 50 [kg], calculate the weight of that object at sea level.
W=mg → W= 50[kg]*9.81[m/s^2] $= 490.5[N]$,   W=50$[kg_f]$

Base Units in USCS

Base Quantity **(common symbol)**	USCS Base Unit	Abbreviation
Length (l, x, d, h etc.)	Foot	ft
Force (F)	pound	lb
Time (t)	Second	s
Temperature (T)	Rankine	R
Electric Current (i)	Ampere	A
Amount of substance (n)	Mole	mol
Luminous intensity (I)	Candela	cd

The abbreviation for pound (lb) is taken from the Roman unit of weight, *libra*, and the word pound comes from the Latin *pendere,* meaning to weigh.

Unit Prefixes (Multiples Submultiples of units)

SI PREFIX	SI SYMBOL	SI UNIT CONVERSION FACTOR (STANDARD FORM)	FACTOR (POWER)	FACTOR LANGUAGE
yotta	Y	1 yottametre = 1 000 000 000 000 000 000 000 000 metres	10^{24}	septillion
zetta	Z	1 zettametre = 1 000 000 000 000 000 000 000 metres	10^{21}	sextillion
exa	E	1 exametre = 1 000 000 000 000 000 000 metres	10^{18}	quintillion
peta	P	1 petametre = 1 000 000 000 000 000 metres	10^{15}	quadrillion
tera	T	1 terametre = 1 000 000 000 000 metres	10^{12}	trillion
giga	G	1 gigametre = 1 000 000 000 metres	10^{9}	billion
mega	M	1 megametre = 1 000 000 metres	10^{6}	million
kilo	k	1 kilometre = 1 000 metres	10^{3}	thousand
hecto	h	1 hectometre = 100 metres	10^{2}	hundred
deca	da	1 decametre = 10 metres	10^{1}	ten
		1 metre = 1 metre	$\mathbf{10^{0}}$	**one**
deci	d	1 decimetre = 0.1 metres	10^{-1}	tenth
centi	c	1 centimetre = 0.01 metres	10^{-2}	hundredth
milli	m	1 millimetre = 0.001 metres	10^{-3}	thousandth
micro	µ	1 micrometre = 0.000 001 metres	10^{-6}	millionth
nano	n	1 nanometre = 0.000 000 001 metres	10^{-9}	billionth
pico	p	1 picometre = 0.000 000 000 001 metres	10^{-12}	trillionth
femto	f	1 femtometre = 0.000 000 000 000 001 metres	10^{-15}	quadrillionth
atto	a	1 attometre = 0.000 000 000 000 000 001 metres	10^{-18}	quintillionth
zepto	z	1 zeptometre = 0.000 000 000 000 000 000 001 metres	10^{-21}	sextillionth
yocto	y	1 yoctometre = 0.000 000 000 000 000 000 000 001 metres	10^{-24}	septillionth

$1[lb_f]$=1[slug]1[ft/s^2], (force required to give a mass of one slug an acceleration of one foot per second-square)

Gravitational acceleration, g=32.174 [ft/s^2],

$1[lb_f]$: weight of an object of which mass is $1[lb_m]$

British Force unit: poundal, pdl 1[pdl]=1 $[lb_m]$ * 1 [ft/s^2] (force required to give a mass of one pound an acceleration of one foot per second-square]

$1[lb_f]$=g poundal , e.g:mass of an object is 50 $[lb_m]$ calculate its weight at sea level

W=mg= 50$[lb_m]$ * 32.174 [ft/s^2] $= 1609$ [pdl] $\rightarrow$ 1609/g= 50 $[lb_f]$

1 $[lb_m]$ =0.4536 [kg], 1 slug=32.174 $[lb_m]$

- 1[ft]=12[inch], $1' = 12''$, $1''$=25.4 [mm]
- Yard: 1[yd]=3[ft]
- Mile: 1[mi]= 1.609344 [km]
- Nautical mile: 1[nmi]=1.852[km]

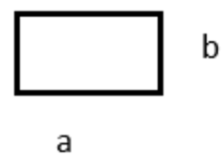
Derived Units

- Combinations or groupings of several different base units. **Derived units are defined interms of the seven base units via a system of quantity equations.** Derived units can not be selected arbitrarily

Some derived units

Density $\equiv \frac{mass}{volume}$, $\rho \equiv \frac{m}{V}$ unit: kg/m^3

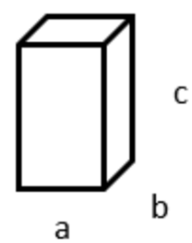
Area $\equiv$ a*b unit: m^2



Volume $\equiv$ a*b*c

Unit: $[m^3]$

1[lt]=1$[dm^3]$



Velocity, V $\equiv \frac{dl}{dt}$ $[\frac{m}{s}]$

Acceleration, a $\equiv \frac{dv}{dt}$ $[\frac{m}{s^2}]$

Force, F_{net}=m a unit: kg m/s^2 →[N]

Specific heat

Thermal energy $\dot{Q} = c\dot{m}\,(\Delta T)$ unit of c: J/(kgK) or J/(kgC^0)

- Conventional area units:

Ar: 1[a]= 100[m^2]   Decar: 1[daa]=10[a]=1000 [m^2]

Dönüm: 1[dönüm]≅ 1[daa],   Hectar: 1[ha]=100[a]=100*100= 10000 [m^2]

Acre: unit of land area used in the imperial and US customary systems.

1[ac]=4046.9 [m^2]

* Nautical speed: knot: 1[knot]=1.852[km/h]

*Conventional Energy Units:

kcal: kilocalorie   1[kcal]=4.184[kJ]

the amount of thermal energy needed to raise the temperature of one kg of water by one Celsius degree at a pressure of one atmosphere

Btu: The British thermal unit is a traditional unit of thermal energy; it is defined as the amount of heat required to raise the temperature of one pound of water by one Fahrenheit degree. 1[Btu]=1.055 [kJ]

"Parts-per" notation The "parts-per" notation is a unit that deals with very small traces of species within a mixture of gases or liquids. Parts-per million [ppm]
A way of expressing very dilute concentrations of substances. Just as per cent means out of a hundred, so parts per million or ppm means out of a million. Usually describes the concentration of something in water or soil. One ppm is equivalent to 1 milligram of something per liter of water (mg/l) or 1 milligram of something per kilogram soil (mg/kg).

- Example: Let's say the air around us contains 20 ppm He (Helium). This means that, if one assumes that a molar basis is being used, for every million moles of air there are 20 moles of Helium.

Temperature Conversion

- $T[°F] = \left(\frac{9}{5}\right) T[°C] + 32$
- T[K]=T[°C] $+ 273.15$
- T[Ra]=T[°F] $+ 459.67$

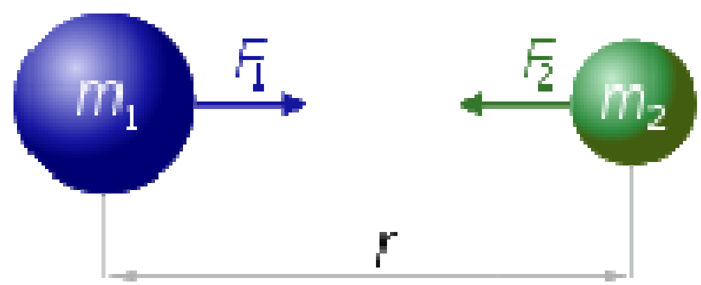
Conversion Formulai

- T[K]=1.8 [Ra] → Conversion Formula: T[R]=1.8$* T[K]$

Newton's law of universal gravitation

- Every particle attracts every other particle in the universe with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. This is a general physical law derived from empirical observations by Isaac Newton.

•*F* is the force between the particles;
•*G* is the gravitational constant (6.674×10^{-11} N · (m/kg)^2);
•m_1 is the first mass;
•m_2 is the second mass;
•*r* is the distance between the centers of the masses.

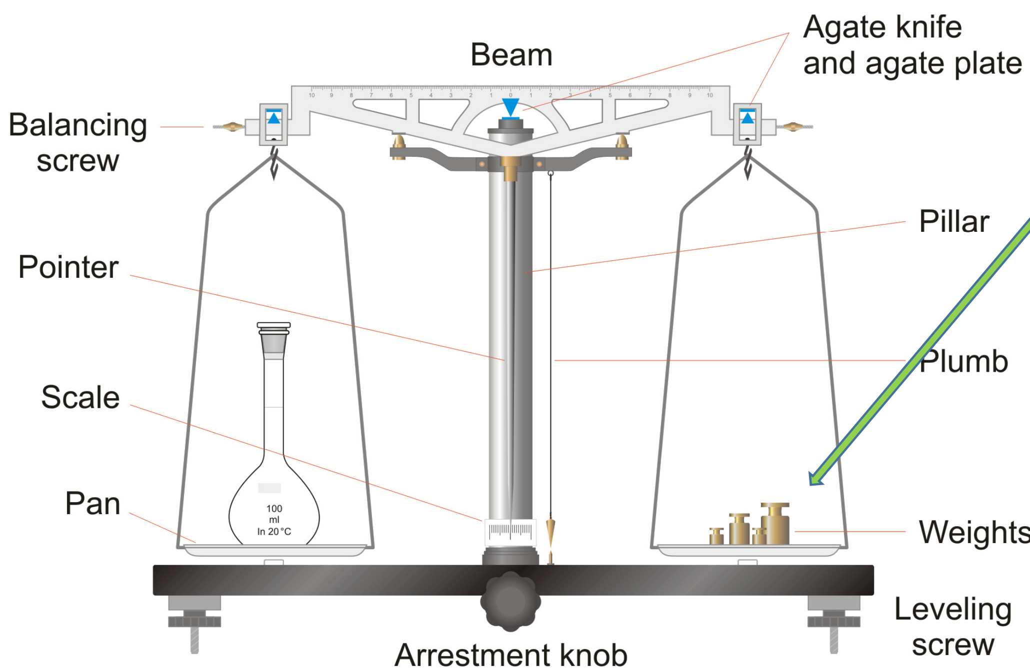


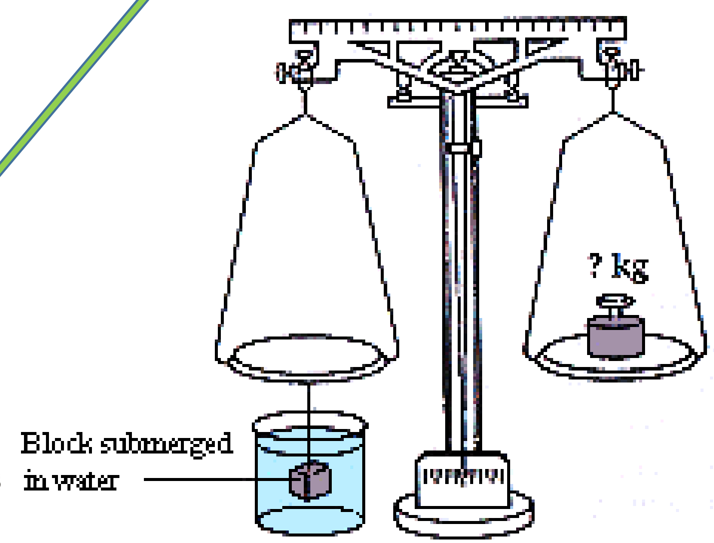
$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

R: Radius of the Earth≅$6.38*10^6$
m_E:mass of the Earth≅$5.98*10^{24}$
W=(Gm_E/R^2) m ⟶ $W = mg$

Balance does not measure mass!

$F = k\Delta L$





Procedure for Drawing a FBD(Free-Body Diagram)

1. Draw outlined shape

   - Isolate object from its surroundings

2. Show all the forces

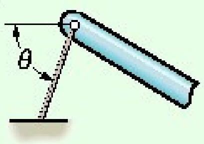
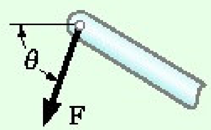
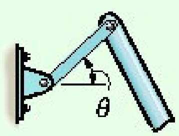
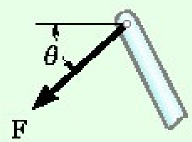
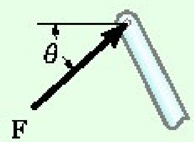
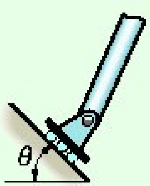
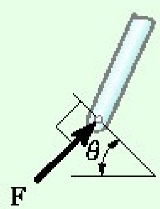
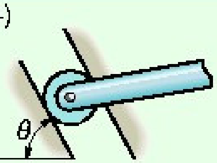
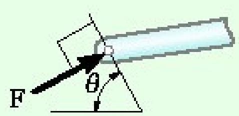
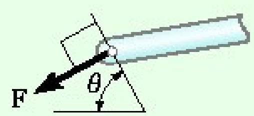
   - Indicate all the forces

3. Identify each forces

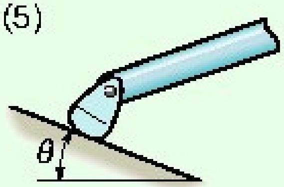
   - Known forces should be labeled with proper magnitude and direction

   - Letters are used to represent magnitude and directions of unknown forces

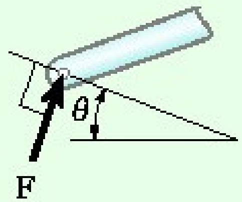
Supports for Rigid Bodies Subjected to Two-Dimensional Force Systems

Types of Connection	Reaction	Number of Unknowns
(1)  cable		One unknown. The reaction is a tension force which acts away from the member in the direction of the cable.
(2)  weightless link	 or 	One unknown. The reaction is a force which acts along the axis of the link.
(3)  roller		One unknown. The reaction is a force which acts perpendicular to the surface at the point of contact.
(4)  roller or pin in confined smooth slot	 or 	One unknown. The reaction is a force which acts perpendicular to the slot.

(5)

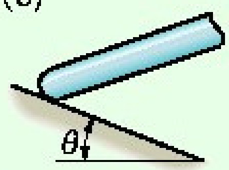


rocker

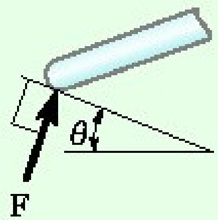


One unknown. The reaction is a force which acts perpendicular to the surface at the point of contact.

(6)

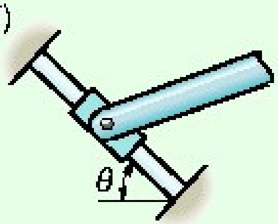


smooth contacting surface

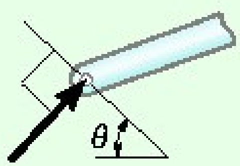


One unknown. The reaction is a force which acts perpendicular to the surface at the point of contact.

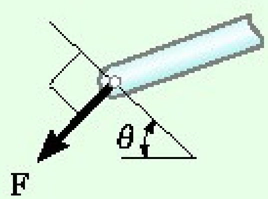
(7)



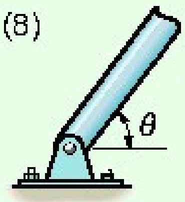
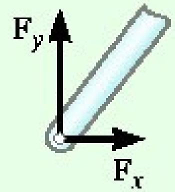
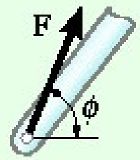
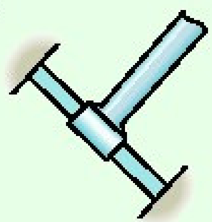
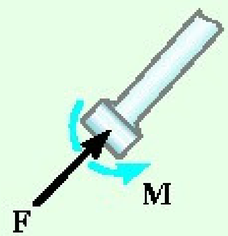
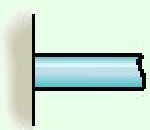
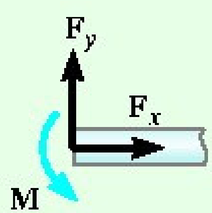
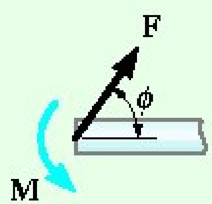
member pin connected to collar on smooth rod



or



One unknown. The reaction is a force which acts perpendicular to the rod.

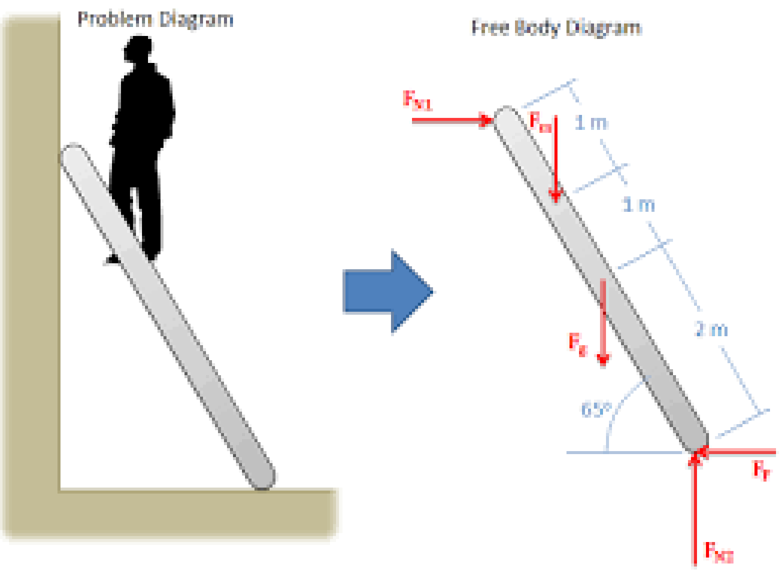
Types of Connection	Reaction	Number of Unknowns
(8)  smooth pin or hinge	 or 	Two unknowns. The reactions are two components of force, or the magnitude and direction ϕ of the resultant force. Note that ϕ and θ are not necessarily equal [usually not, unless the rod shown is a link as in (2)].
(9)  member fixed connected to collar on smooth rod		Two unknowns. The reactions are the couple moment and the force which acts perpendicular to the rod.
(10)  fixed support	 or 	Three unknowns. The reactions are the couple moment and the two force components, or the couple moment and the magnitude and direction ϕ of the resultant force.

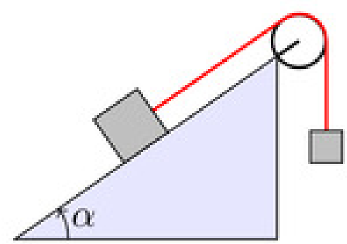
Weight and Center of Gravity

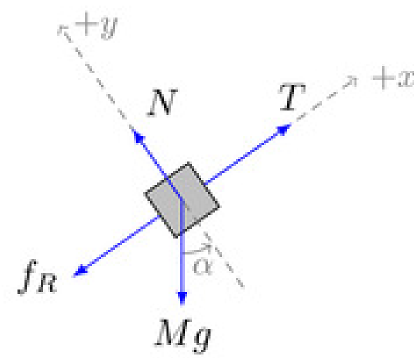
- When a body is subjected to gravity, each particle has a specified weight
- For entire body, consider gravitational forces as a system of parallel forces acting on all particles within the boundary
- The system can be represented by a single resultant force, known as weight $\vec{\mathbf{W}}$ of the body
- Location of the force application is known as the center of gravity

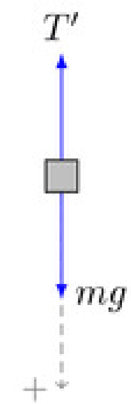
*Center of gravity occurs at the geometric center or centroid for uniform body of homogenous material

Free-Body Diagram









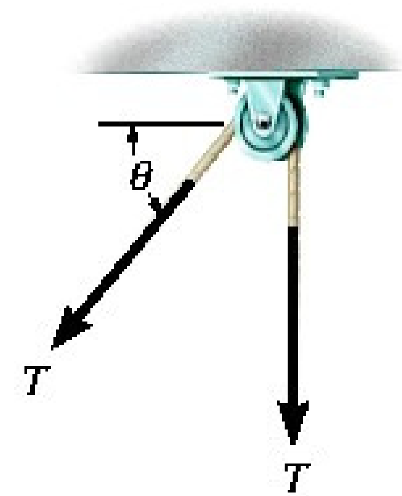
- Cables and Pulley

  - Cables (or cords) are assumed to have negligible weight and they cannot stretch

  - A cable only support tension or pulling force

  - Tension always acts in the direction of the cable

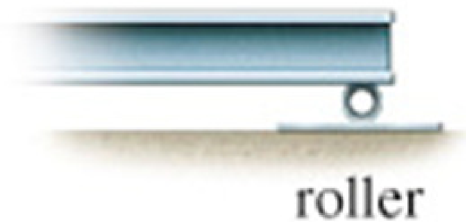
  - Tension force in a continuous cable must have a constant magnitude for equilibrium



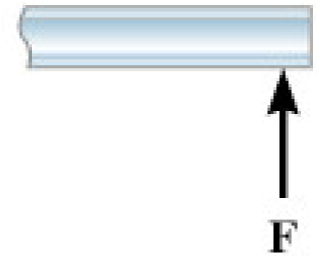
Cable is in tension

- The bucket is held in equilibrium by the cable
- Force in the cable = weight of the bucket
- Isolate the bucket for FBD
- Two forces acting on the bucket, weight **W** and force $\boldsymbol{F_c}$ of the cable
- Resultant of forces = 0

$$\mathbf{W} = \boldsymbol{F_c}$$

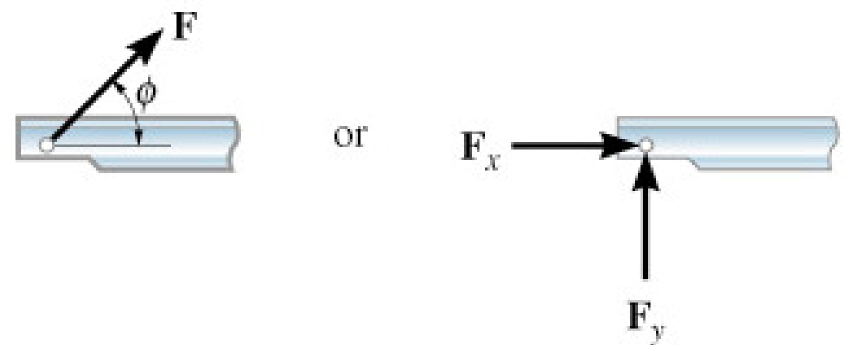


(a)



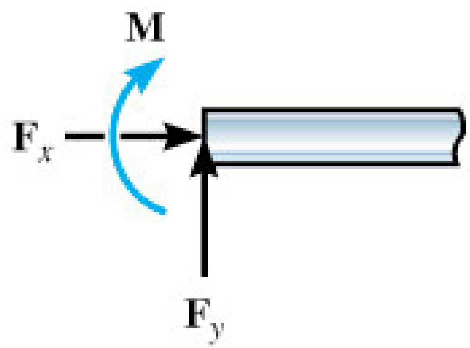
(b)

(a)

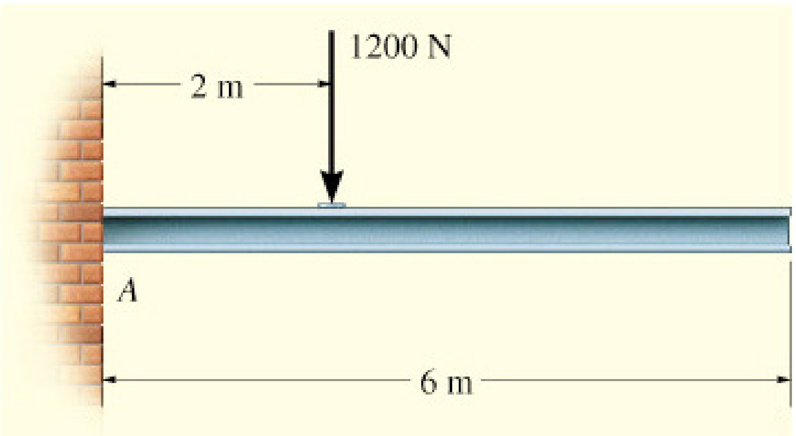


(b) (c)

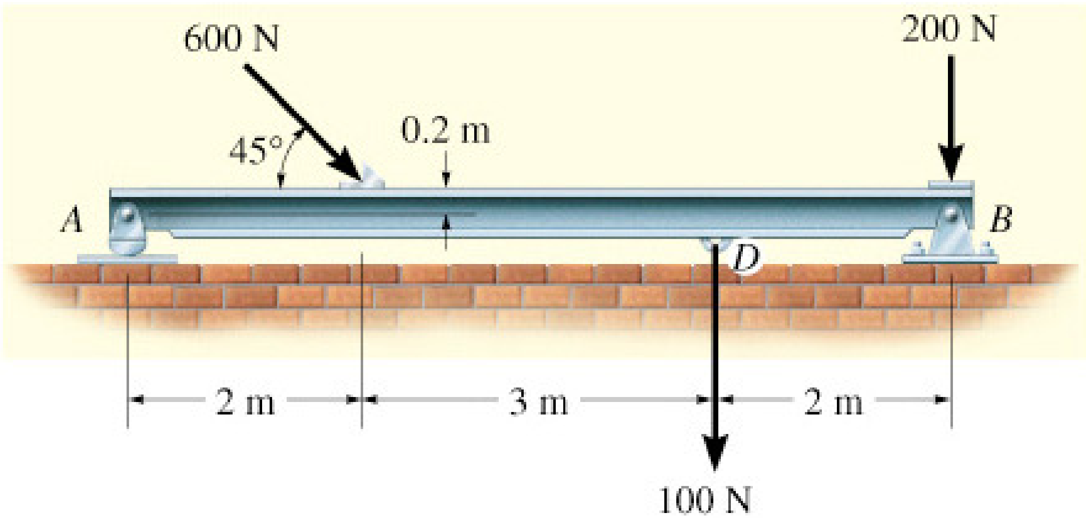
(a)



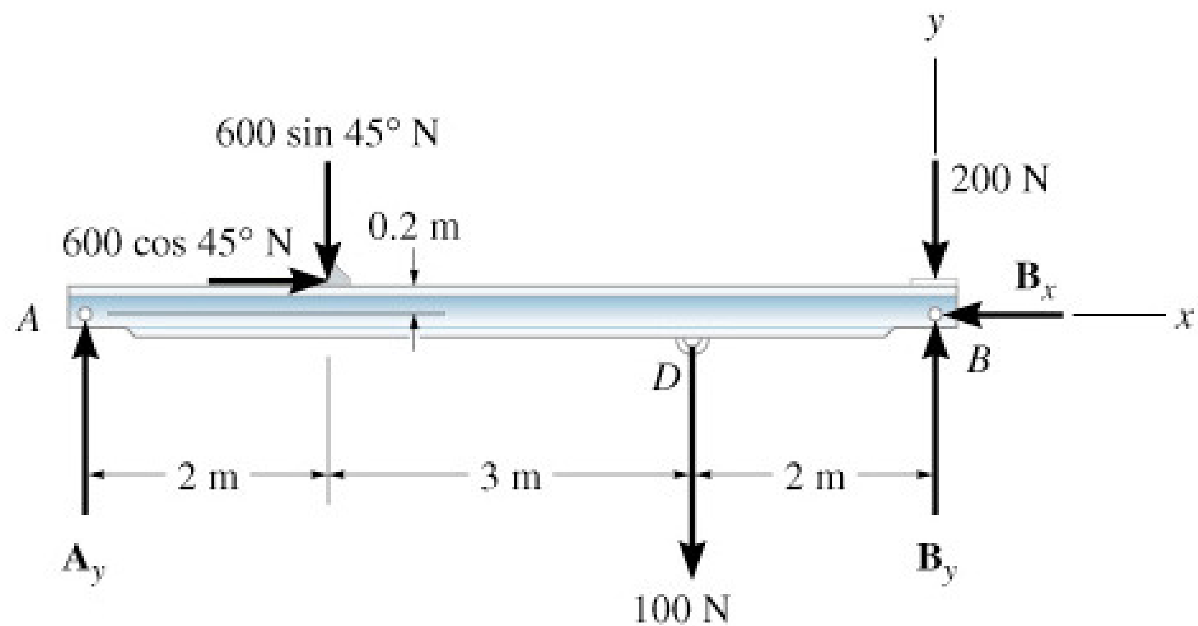
(b)



(a)

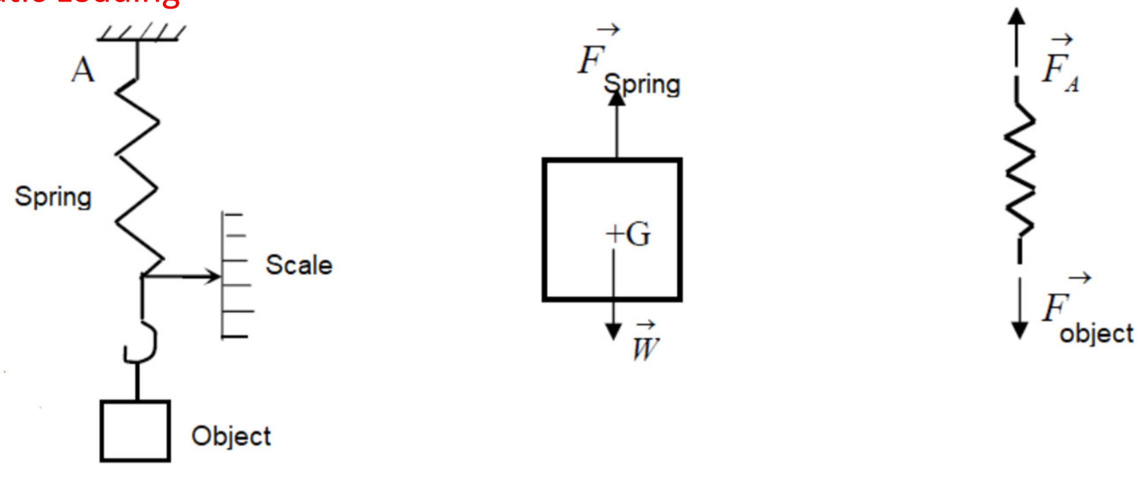

600 N
200 N
45°
0.2 m
A
B
D
2 m
3 m
2 m
100 N

(a)


y
600 sin 45° N
200 N
600 cos 45° N
0.2 m
B_x
x
A
B
D
2 m
3 m
2 m
A_y
B_y
100 N

(b)

Static Loading



(a) (b) (c)

F=$k_{spring}\Delta L$

$$\Delta L = \frac{F_{object}}{k_{spring}} = \frac{F_{spring}}{k_{spring}} = \frac{W}{k_{spring}} = \frac{mg}{k_{spring}}$$

Dynamic Loading

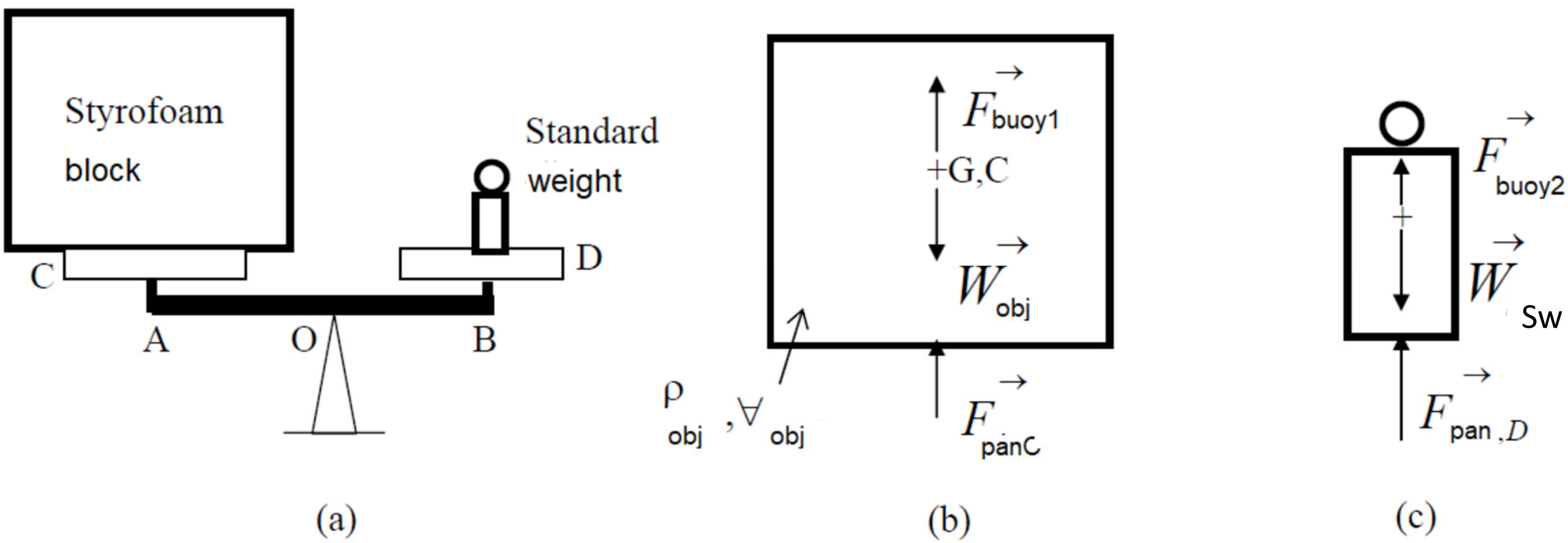
$$\overrightarrow{F_{net}} = m_{obj} * \vec{a}_{G_{obj}}$$

$$F_{spring} = W_{obj} + m_{obj}\ a_{G_{obj}}$$

$$F_A = F_{obj} + m_{spring}\ a_{G_{spring}}$$

$$\Delta L \cong \frac{W_{obj} + m_{obj}\ a_{G\ obj}}{k_{spring}} = \frac{m_{obj}}{k_{spring}}(g + a_{G_{obj}})$$

Equal Arm Scale



$$W_{obj} = W_{Sw} + \rho_{fluid} \, g \, (\forall_{obj} - \forall_{Sw})$$

Unit of Pressure

- Pressure is an expression of force exerted on a surface per unit area. The SI unit of pressure is the Pascal [Pa], equivalent to one newton per meter squared $[\frac{N}{m^2}]$
- Consider an enclosed chamber filled with a gas and surrounded by a vacuum. The pressure exerted on the walls of the chamber by the gas depends on three factors: (1) the amount of gas in the chamber, (2) the temperature of the gas, and (3) the volume of the chamber.

The ideal gas equation

P∀ = mRT ... where R is the specific gas constant $[\frac{kJ}{kgK}]$

R=$\frac{\overline{R}}{M}$ $where$ $\overline{R}$: universal gas constant=8.3143$[\frac{kJ}{kmolK}]$, M: molecular mass $[\frac{\text{kg}}{\text{kMol}}]$

m: mass [kg], T: Absolute temprature [K], P: pressure[kPa]

∀: volume $[m^3]$

Real Gas

Generalized Compressibility Chart

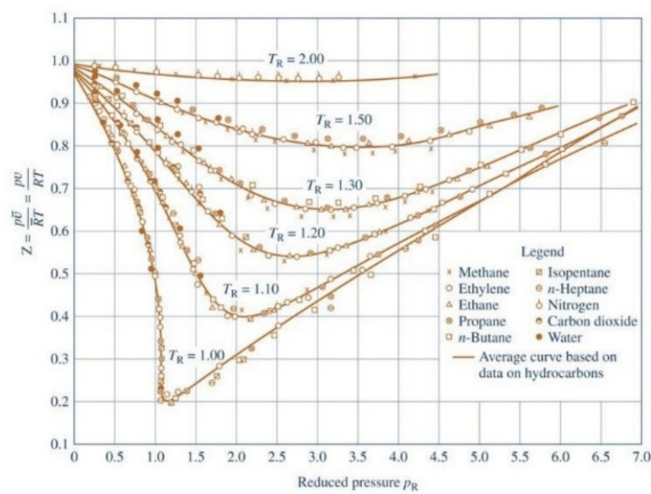
- In this chart, the compressibility factor, Z, is plotted versus the ***reduced pressure***, p_R, and ***reduced temperature*** T_R, where

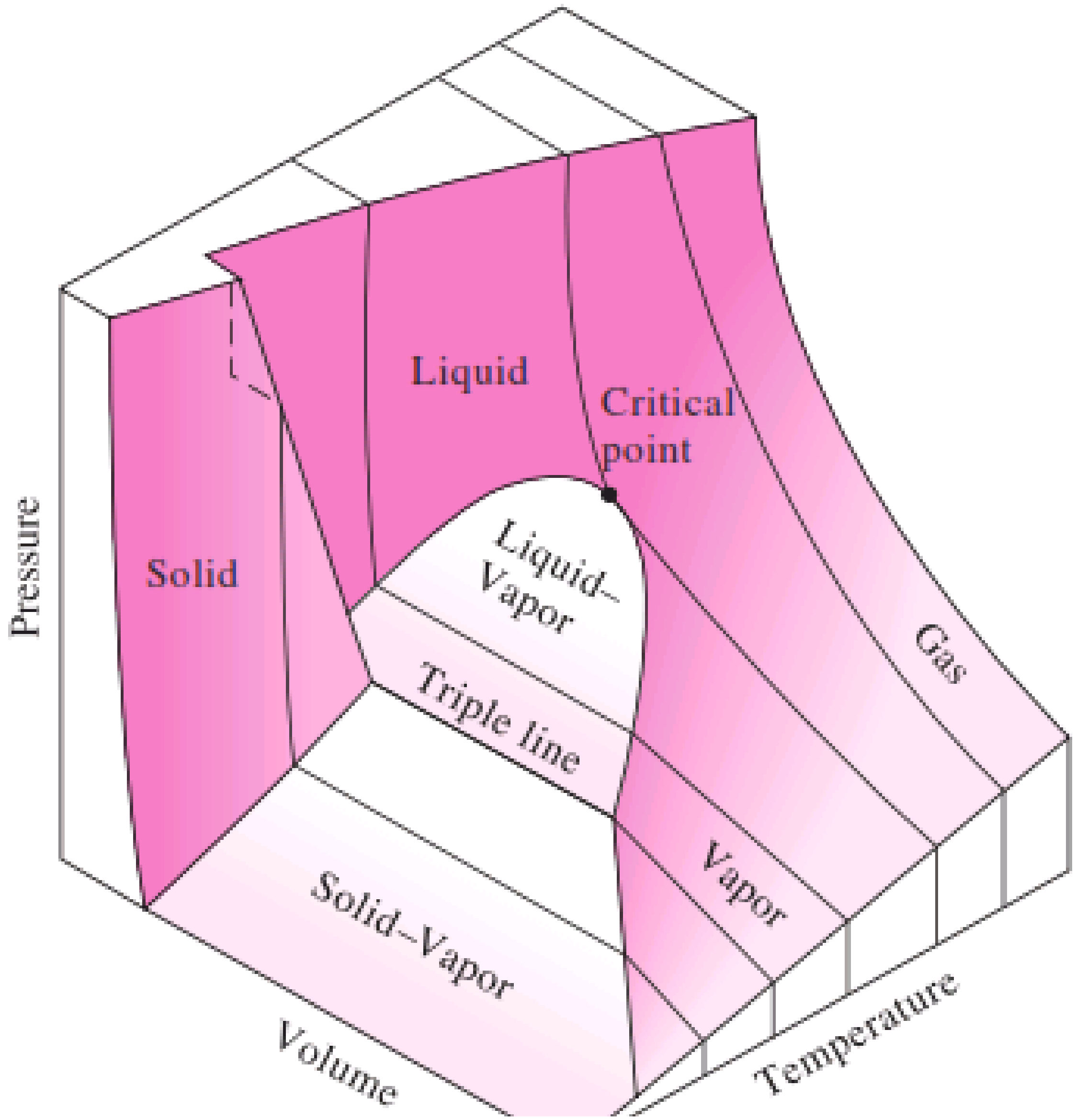
$$Z = \frac{p\bar{v}}{\bar{R}T} \qquad p_R = p/p_c \qquad T_R = T/T_c$$

$\bar{R}$ is the universal gas constant

$$\bar{R} = \begin{cases} 8.314 \text{ kJ/kmol·K} \\ 1.986 \text{ Btu/lbmol·°R} \\ 1545 \text{ ft·lbf/lbmol·°R} \end{cases}$$

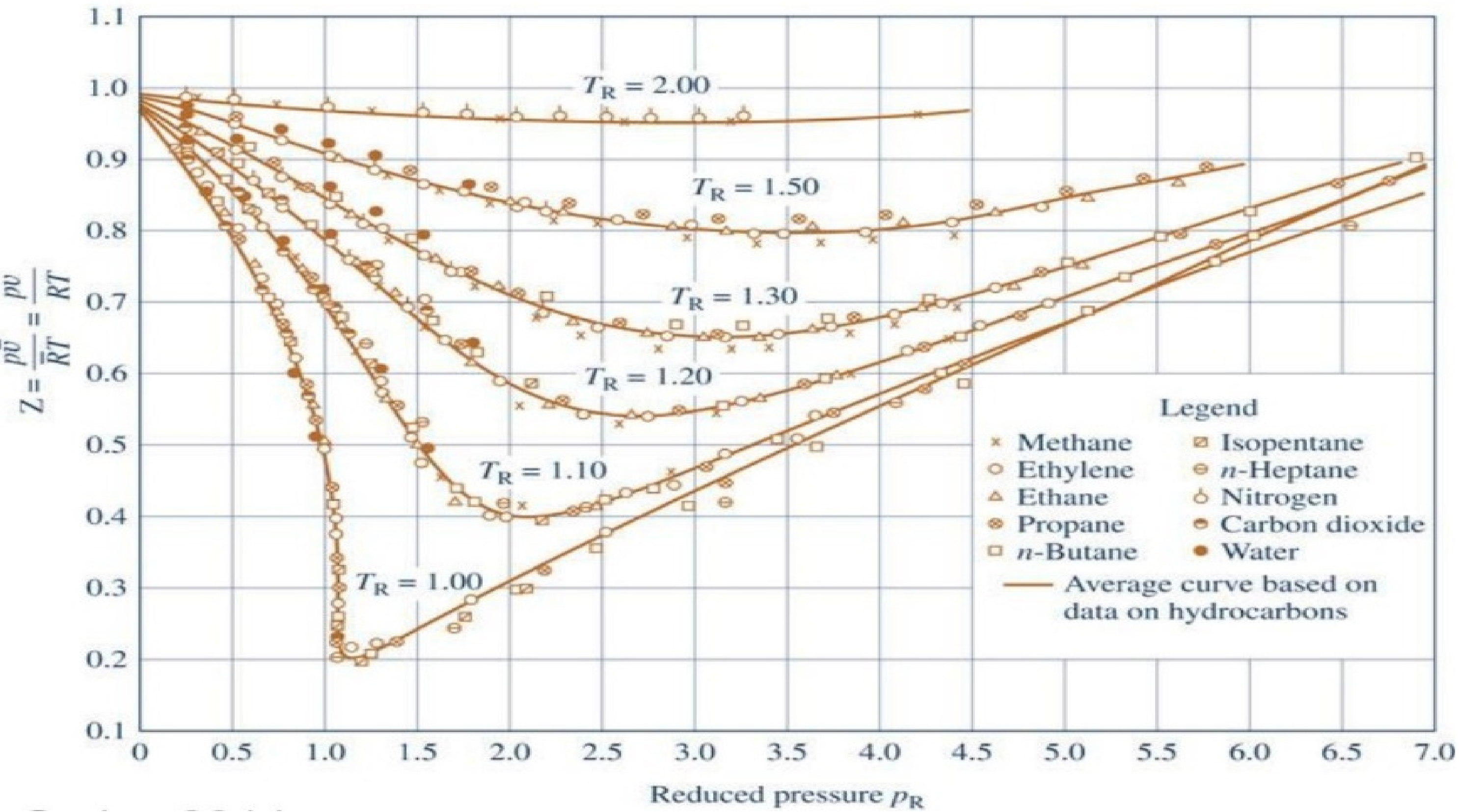
The symbols p_c and T_c denote the temperature and pressure at the critical point for the particular gas under consideration.

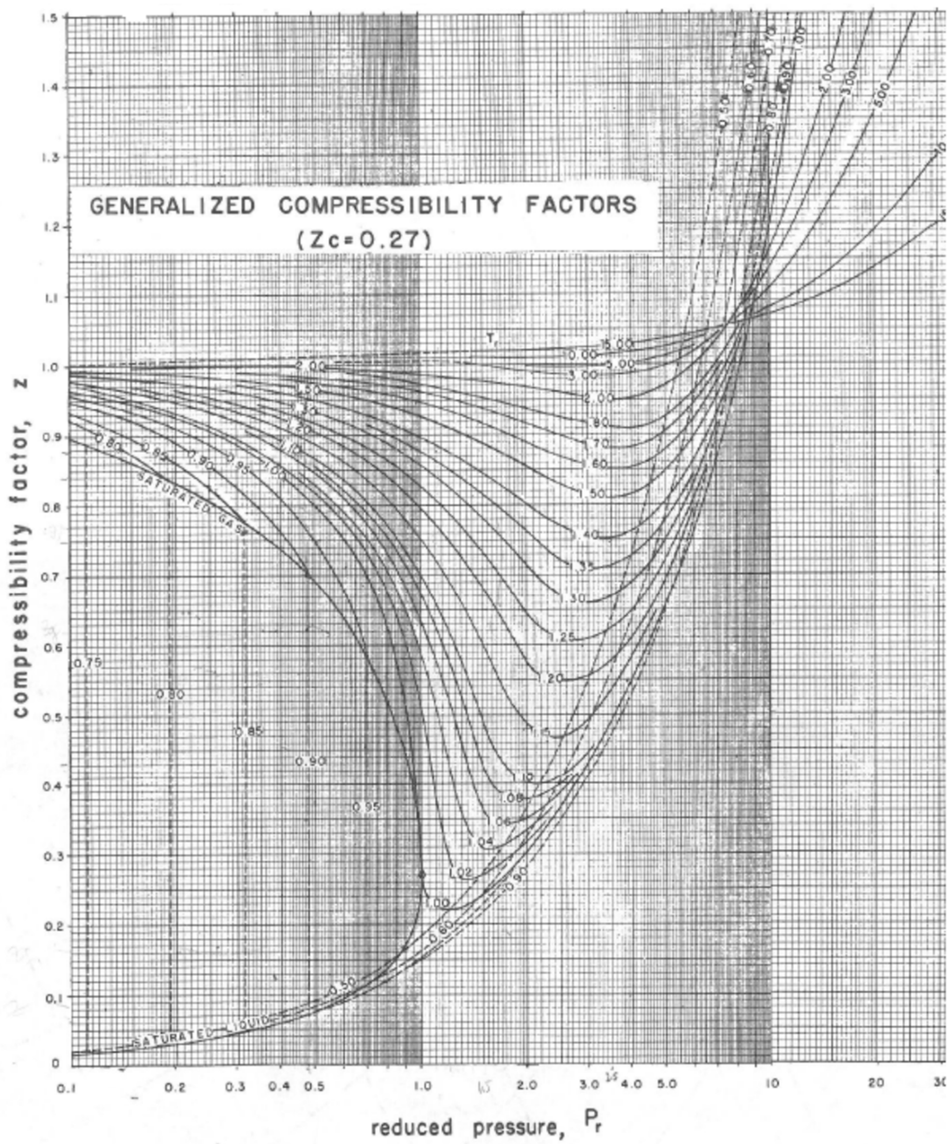



Liquid
Critical point
Solid
Liquid–Vapor
Triple line
Gas
Vapor
Solid–Vapor
Pressure
Volume
Temperature

Generalized Compressibility Chart

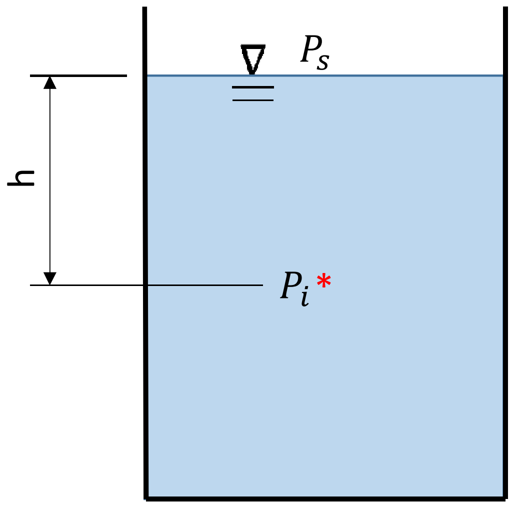
► The p-$\overline{v}$-T relation for 10 common gases is shown in the generalized compressibility chart.





Generalized compressibility chart.

Hydro-static Pressure:



$$P_i = P_s + \rho_l g h$$

where; P_i: Pressure in liquid at point i

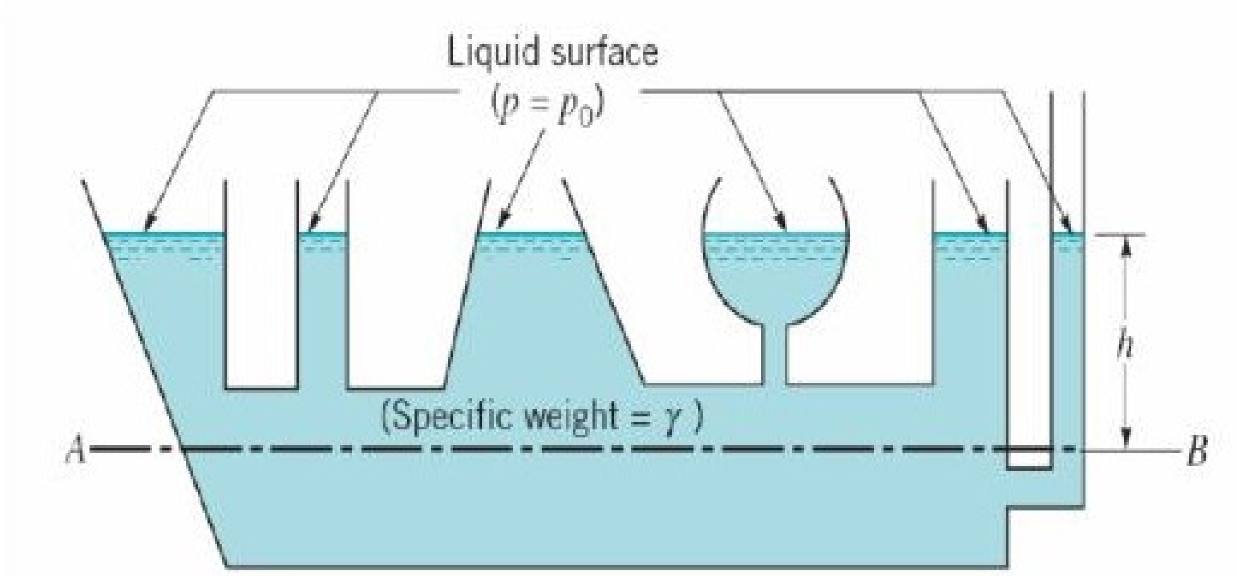
P_s: *Pressure at the free surface*

ρ_l: *Density of liquid*

g: Gravitational acceleration

h: location dimension for point i relative to the free surface in the vertical direction

Fluid Equilibrium



Pressure is the same at all points along the line AB irrespective of height

Fluid equilibrium in a container of arbitrary shape

- Unit of pressure in USCS:

$[\frac{lb_f}{ft^2}]$ more common unit: [psi] means $[\frac{lb_f}{inch^2}]$

1[psi]= 6.89476 [kPa]

- Other common units of pressure:

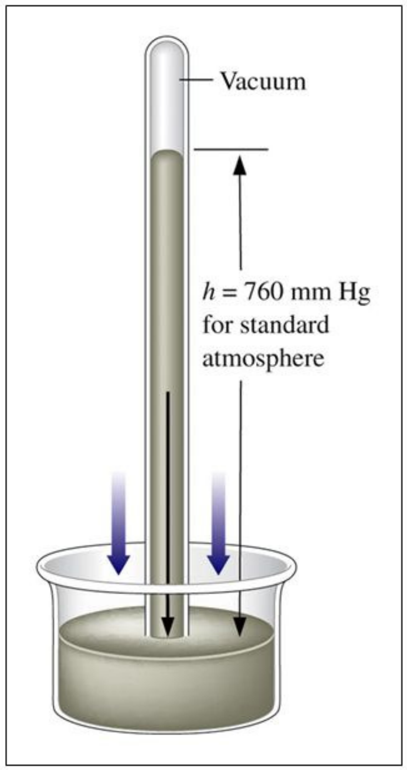
Bar: 1[bar]=100[kPa]

Atmosphere: 1[atm]=101.325[kPa]

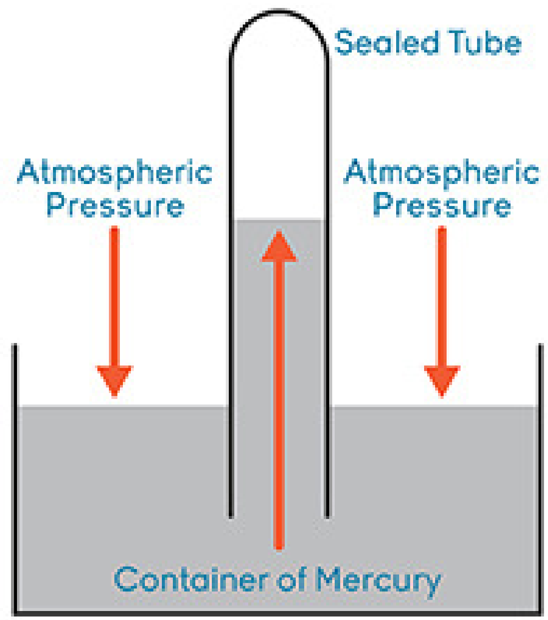
Technical Atmosphere: 1[at]≡ $\left[\frac{kg_f}{cm^2}\right]$
1[at]=98.067[kPa]=0.98067[bar]

One mmHg is the pressure exerted by a 1 mm vertical column of mercury (Hg) at 0 degree Celsius. One mmHg is virtually equal to 1 torr, which is defined as 1/760 of 1 atmosphere (atm) pressure (i.e., 1 atm = 760 mmHg).

Torricelli's Barometer

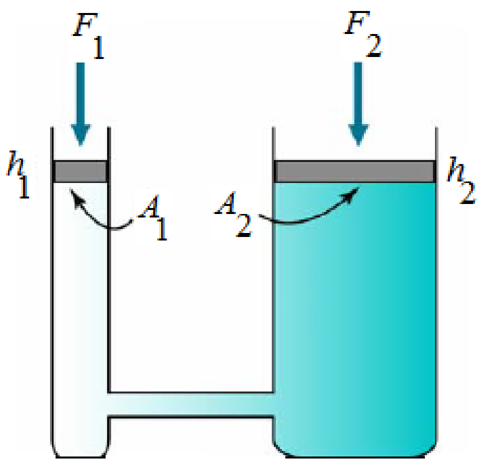


1



Pascal's Principle

Mechanical Advantage $\equiv \frac{F_{output}}{F_{input}}$



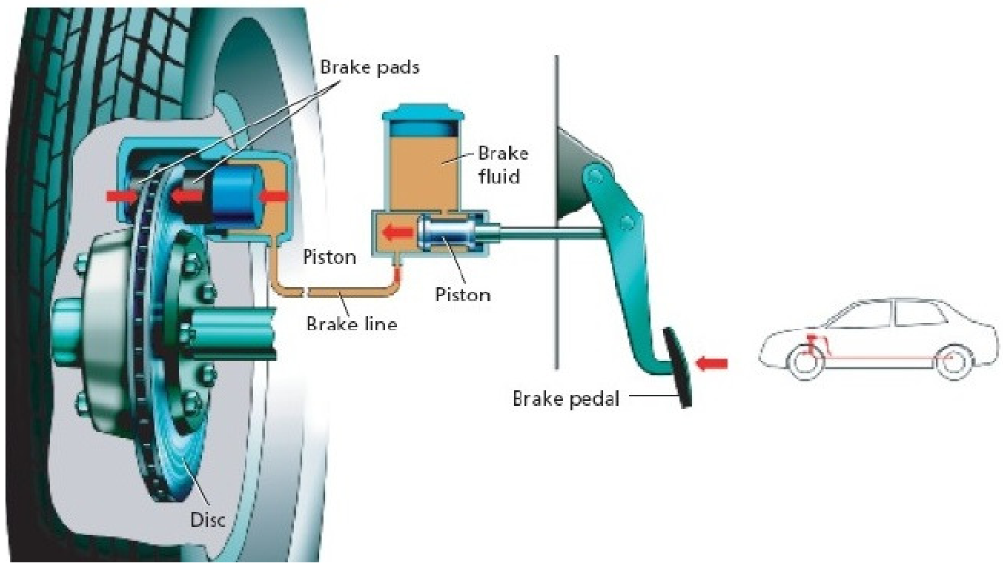
$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$MA = \frac{A_2}{A_1}$$

F_1 = Force exerted on the small piston
A_1 = area of the small piston
F_2 = Force exerted on the big piston
A_2 = area of the big piston

Hydraulic Press / Lift

Car Breaks



- Absolute pressure

Absolute pressure is referred to the vacuum of free space (zero pressure)

* Gage pressure

Gage pressure is measured relative to the ambient pressure. If ambient is atmospher, changes of the atmospheric pressure due to weather conditions or altitude directly influence the output of a gage pressure sensor. A gage pressure higher than ambient pressure is referred to as positive pressure. If the measured pressure is below atmospheric pressure it is called negative or vacuum gage pressure.

*Differential pressure

Differential pressure is the difference between any two pressures p1 and p2

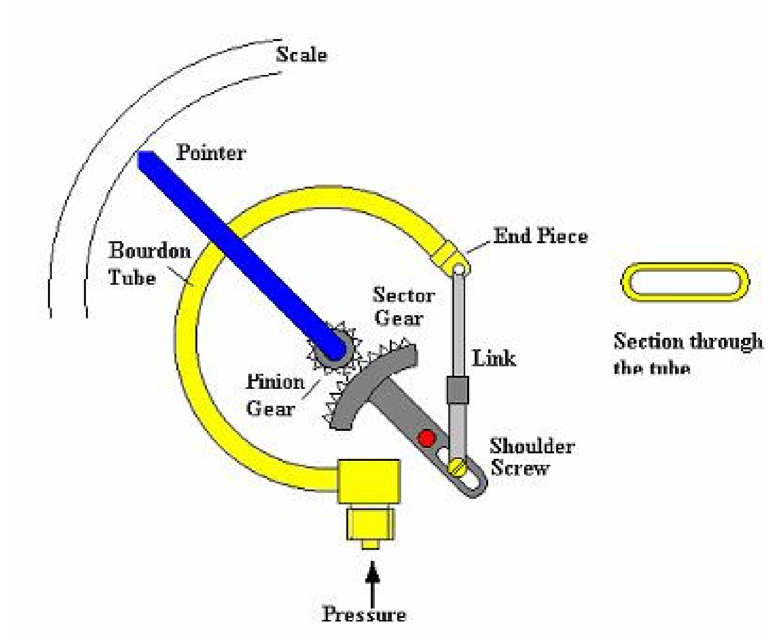
- Pressure gages measure pressure relative to the pressure of their ambient

e.g. Car tire inflation pressure=40[psi]

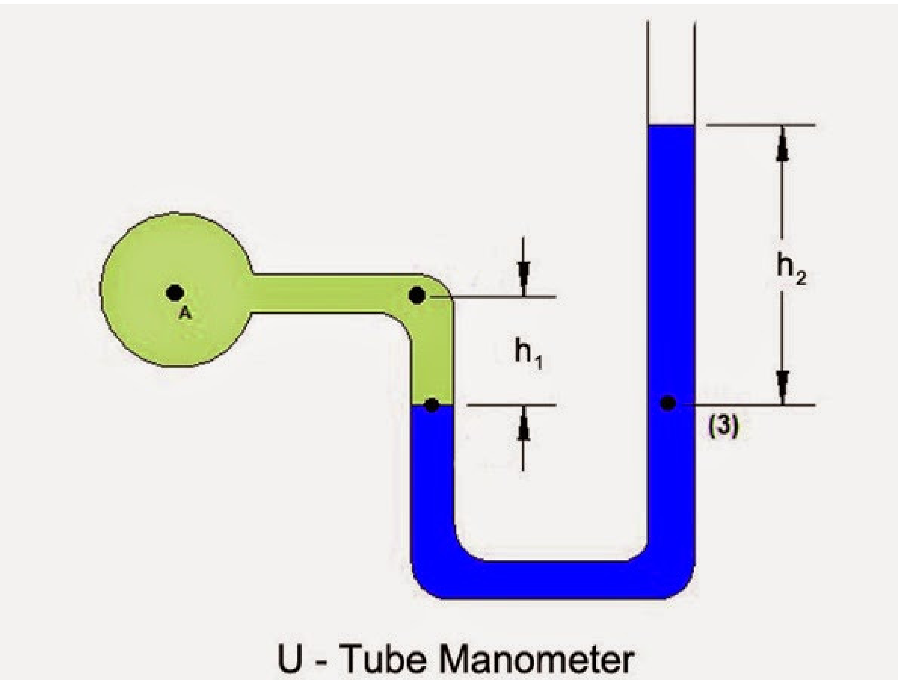
means the inside pressure- atmospheric pressure is 40[psi]

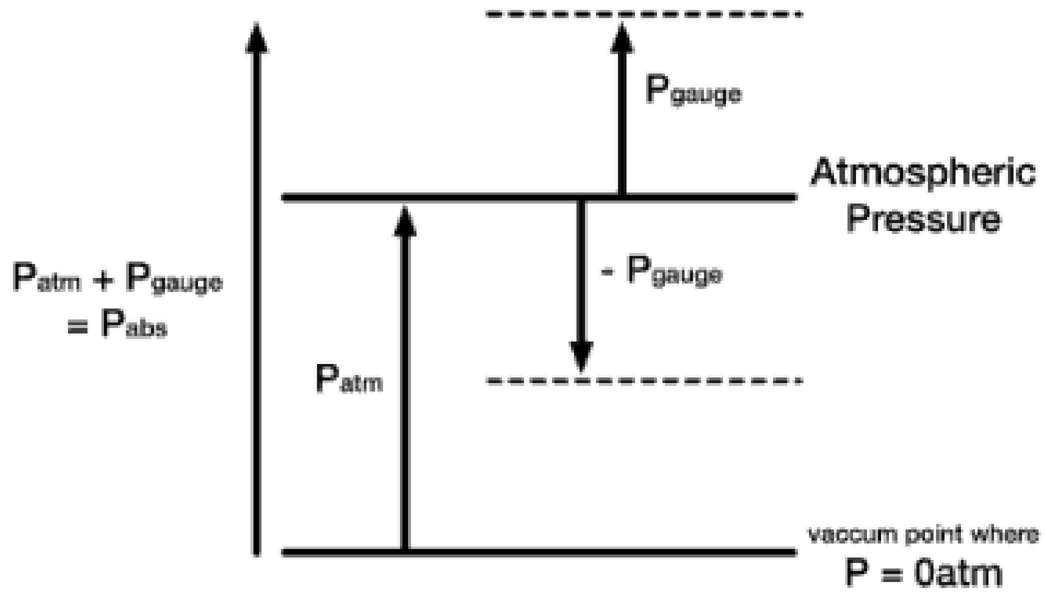
Absolute pressure of the compressed air inside of the tire=$P_{gage} + P_{atm}$

40[psi]=6.895*40=276[kPa]→ absolute pressure=276+101=377[kPa]



Bourdon Gage


A
h_1
h_2
(3)
U - Tube Manometer


P_{gauge}
Atmospheric Pressure
$P_{atm} + P_{gauge}$ = P_{abs}
- P_{gauge}
P_{atm}
vaccum point where
P = 0atm

Atü, Atu, Ata