SAND2006-3103C

# Pressure Safety Orientation PRS150

## Chapter 2) Pressure Safety Theory

March, 2006

# Pressure Safety Theory


**Chapter 2 / Objective:**

**The student will be introduced to important design relationships and terms and will also be able to understand the basic equations relating pressure, volume,& temperature of gases & liquids.**

**At the end of this section you should be able to:**

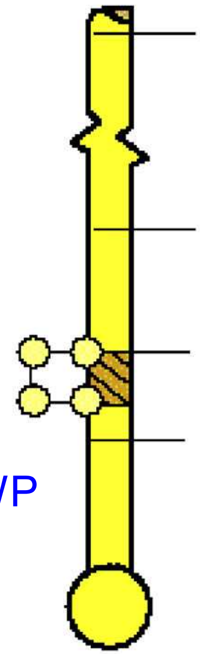
1) Identify the concepts of MAWP, OP, and the relief device set pressure
2) Differentiate between absolute and gauge pressure
3) Recognize the unique properties and hazards of gas vs. liquid pressure systems
4) Recognize the relationships of force, pressure, area, volume, and temperature within a pressure system

* Learning objective # 1

# Pressure Safety Practices

## Key relationships in the proper design of a pressure system

**Material design factor based on design and material allowable stress value**



**Predicted failure**
(rupture or yield)

**Overpressure Test** [1]

**Opening Range of Relief Device**

**MAWP** Maximum Allowable Working Pressure

**Operating Pressure < MAWP** [2]

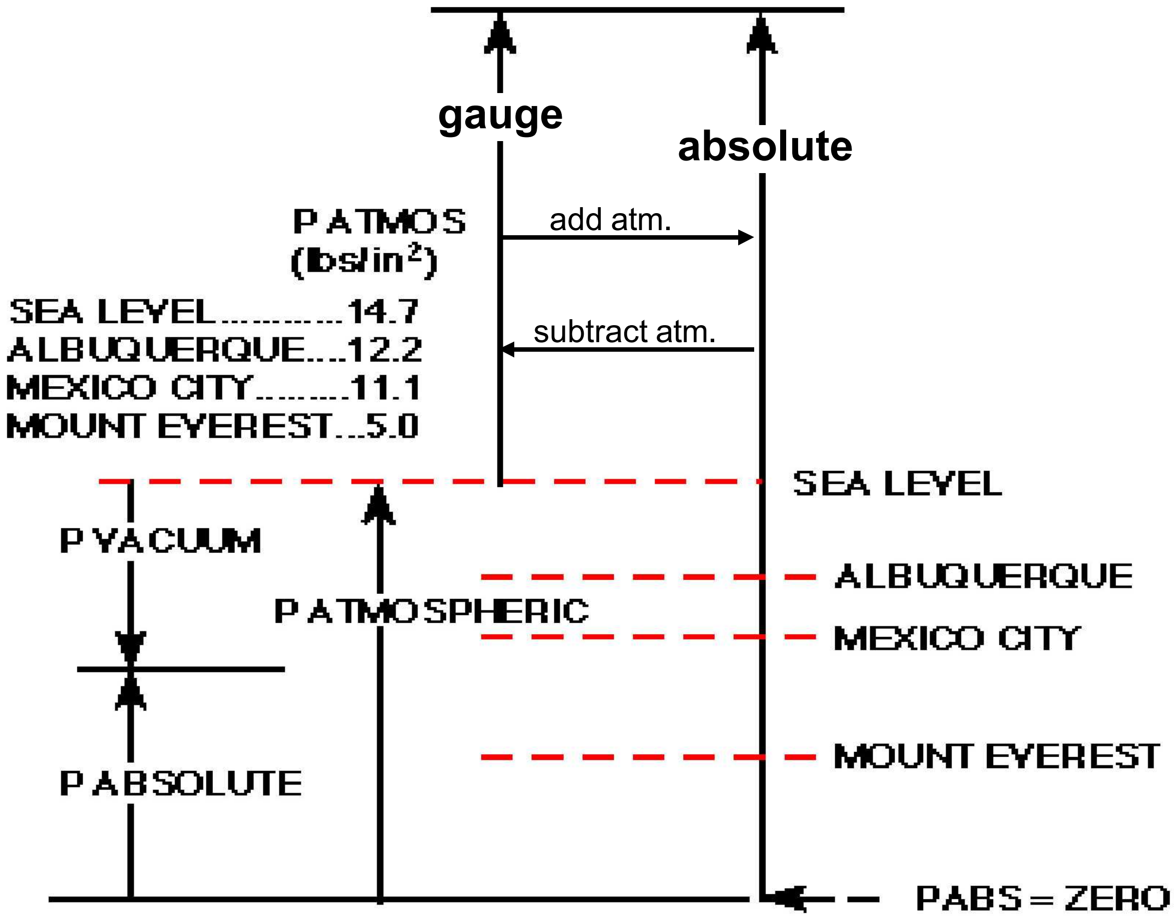
operating pressure < relief device < MAWP

[1] Details on overpressure testing are covered in PRS250 – operators must not conduct overpressure tests

[2] can operate up to MAWP

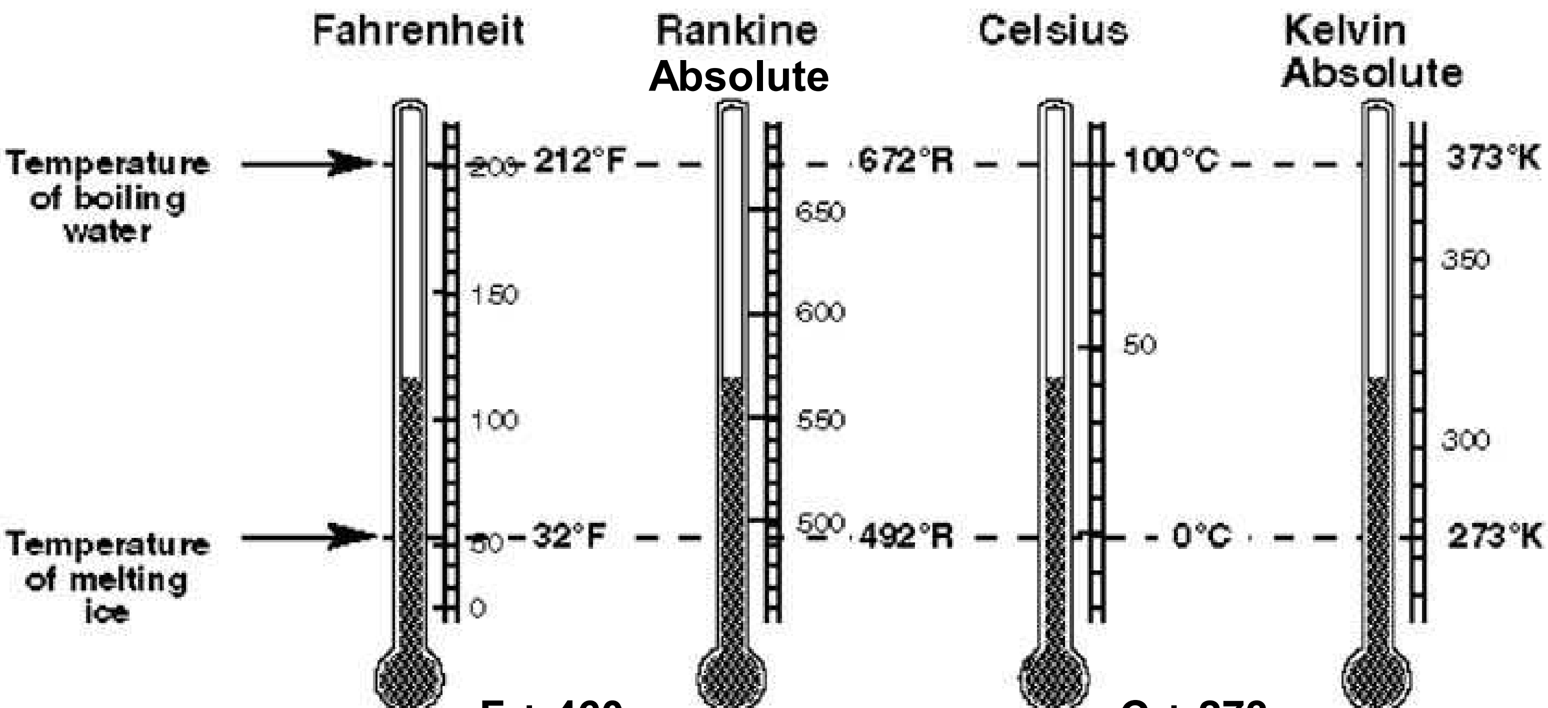
# Summary of Basic Pressure Measurement Relationships

**atmospheric pressure (psi) + gauge pressure (psig) = absolute pressure (psia)**




psig = pounds per square inch gauge
psia = pounds per square inch absolute

# Summary of Basic Temperature Measurement Relationships




F + 460 →

C + 273 →

(F - 32) × (5÷9) →

← C × (9÷5) + 32

# Comparison of Liquids and Gases

**Liquids**

- Both obey Pascal's Law
- Seeks own level w/a free surface
- Relatively incompressible

* Liquid systems can also present significant energy release hazards as well as specific hazards such as hose whipping hazards, jets of hydraulic fluids, etc.

**Gases**

- transmit pressure and motion
- Fills any container regardless of shape
- Highly Compressible

* Gas is compressible and presents a much more hazardous energy release than a liquid in the case of a pressure component failure.

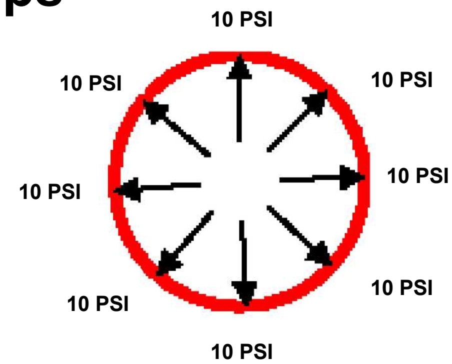
# Basic Pressure Concepts

1) Pressure = Force ÷ Area = lbs per square inch ( psi )

Force = Pressure × Area
Pressure / force devices:
hydraulic jack, barbers chair, compressor

2) Pressure / Volume Temperature Relationships
Ideal Gas Laws

3) Pascal’s Law - pressure in a container is transmitted equally in all directions

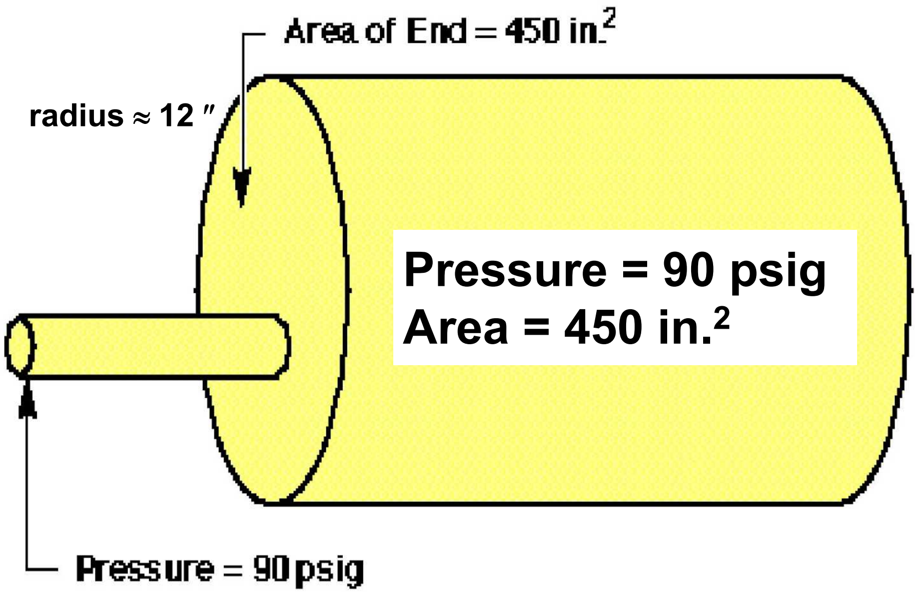



* Pascal’s Law = SNL Pressure Safety Committee symbol

# Force = Pressure × Area

**low pressure ≠ low hazard**

**Find the force on the end of the drum**




**F = P X A**
**= 90 X 450**
**= 40,500 lbs**

**A drum is used to package components at SNL/CA and then shipped to SNL/NM. Upon opening, the drum lid flew off nearly injuring an employee**
**- what happened?**

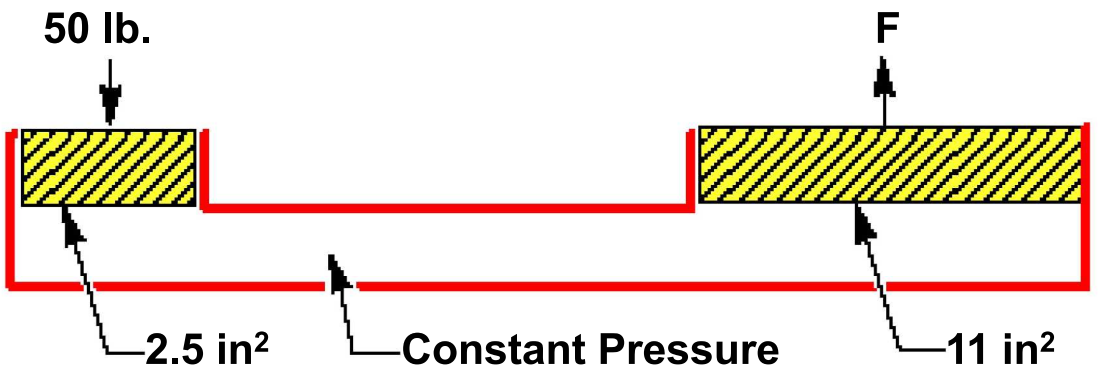
@ SNL/CA, 1 atm. ≈ 14.4 psia
* (drum pressure = 0 psig)

@ SNL/NM, 1 atm. ≈ 12.2 psia
* (drum pressure = 2 psig)
14.4 psia - 12.2 psia = 2.2 psig

F = P × A = 2.2 × 450 = 990 lbs

# Force Amplifier

## - find the upward force exerted by the large piston




**Solution:**

**Left Side**

$P = F/A$

$= 50/2.5$

$= 20$ psi

**Right Side**

$F = P \times A$

$= 20 \times 11$

$= 220$ lb.

# Three Parameters Describe the State of a Fluid

**Pressure**

**Volume**

**Temperature**

**PVT** **data define its "Equation of State"**

**Ideal Gas Law:**

$$PV = nRT$$

where

- P = pressure
- V = volume
- T = temperature
- n = moles of gas
- R = universal gas constant

***Given any two, the third may be determined**

# Gas Laws Relate Pressure, Volume, and Temperature

1) **Boyle's Law**

$$P_1 \times V_1 = P_2 \times V_2$$

2) **Charles' Law**

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \quad \text{or} \quad \frac{V_1}{V_2} = \frac{T_1}{T_2}$$

3) **Ideal Gas Law: PV = nRT**

**(combined gas law)**

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2} = \text{constant}$$

(1) = initial conditions
(2) = secondary conditions

**Safety Concerns :**

**as Temperature↑ , the Pressure↑**

**and as Volume ↓ , the Pressure↑**

Not all gases are "ideal" - Liquefied compressed gases follow a vapor pressure relationship

Sandia National Laboratories

# Pressure Calculations:

At SNL/NM, a vacuum chamber is backfilled with an inert gas to 2 psig. The bake-out heaters are turned on without the system being pumped out - the temperature rises from room temperature (20°C) to 400°C. What is the resultant pressure rise in the system?

**Initial Conditions ( $_1$ )** **Final Conditions ( $_2$ )**

**$P_1$ = 2 psig + 12.2 = 14.2 psia $P_2$ = ? $T_1$ = 20°C + 273 = 293 K $T_2$ = 400°C + 273 = 673 K**

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \xrightarrow[\text{volume}]{\text{constant}} \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

solve for

$$P_2 = \frac{P_1 \times T_2}{T_1} = \frac{14.2 \times 673}{293} = 32.6 \text{ psia}$$

**- 12.2 = 20.4 psig**

**The pressure in the vacuum chamber rises from 2 psig to around 20 psig.**

Consider the force this creates on an 8” vacuum glass viewport?

Area = $\pi r^2 \approx 50$ square inches **F = P x A = 20 x 50 = 1000 lbs force!**

(The pressure could fail the viewport in a violent fashion!)

## Pressure Calculations:

At SNL/NM, a thin-walled stainless steel tube (MAWP = 200 psig) is used in a tube furnace application. The tube is pressurized with helium to 100 psig, sealed off, then heated from room temperature to 650°C. What is the resultant pressure rise in the tube?

**Initial Conditions ( $_1$ )** **Final Conditions ( $_2$ )**

**$P_1$ = 100 psig + 12.2 = 112.2 psia   $P_2$ = ?   $T_1$ = 20°C + 273 = 293 K   $T_2$ = 650°C + 273 = 923 K**

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \xrightarrow[\text{volume}]{\text{constant}} \quad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

solve for

$$P_2 = \frac{P_1 \times T_2}{T_1} = \frac{112.2 \times 923}{293} = 353.4 \text{ psia}$$

**- 12.2 = 341.2 psig**

**The pressure rises from 100 psig to around 341 psig – the MAWP of the tube is clearly exceeded.**

Also keep in mind that as temperature increases, the tensile strength (i.e., the pressure rating) of the tube will decrease.

# Summary of Chapter Objectives

1) Operating pressure < PRV setting < MAWP

2) atmospheric pressure (psi) + gauge pressure (psig)
= absolute pressure (psia)

3) Gas is much more compressible than liquid and represents a much more hazardous energy release in the event of component failure

4) Pressure = Force ÷ Area = lbs / inch$^2$ = psi

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \text{constant}$$

**Safety Concerns :**

as Temperature↑ , the Pressure↑

and as Volume ↓ , the Pressure↑

Sandia National Laboratories