MENG2520 Pneumatics and Hydraulics

Module 5 – Pneumatic Properties

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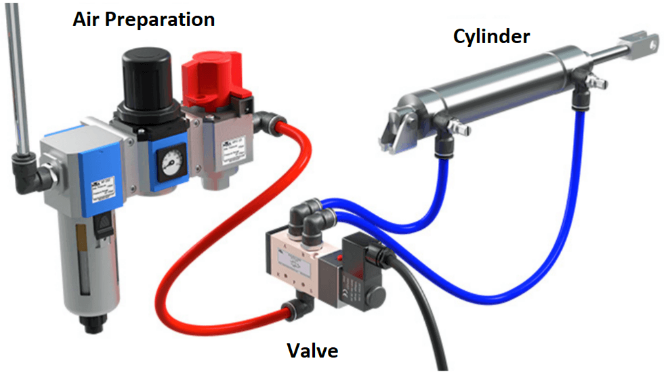
Pneumatic Systems and Properties

This is the beginning of the study of Pneumatic Fluid Power

In this Module we will study

- **The components of a pneumatic system**
- **Properties of air and temperature**
- **Gas laws**
- **Flow rates and compressor selection**

13.1 Pneumatics vs Hydraulics



https://instrumentationtools.com/wp-content/uploads/2021/06/Basic-pneumatic-system.png

In a pneumatc system, **AIR** is the fluid, or medium, which is used to transmit power

Air is safe
can be used in an environment that may be explosive
Leakage does not produce contaminants of present any significant hazard

Air is readily available – it *is* the atmosphere

Air is light compared to oil hance a lower inertia reducing (or eliminating) the problems when accelerating and decelerating actuators and when suddenly opening and closing valves.

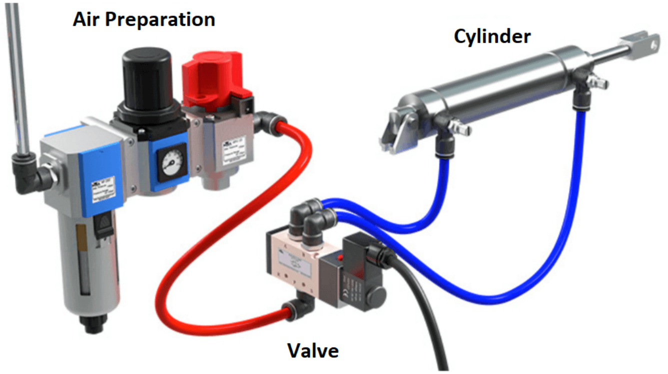
Air is less viscous – results in less frictional pressure and power losses

Air can vent directly into the surrounding environment whereas oils must be preserved in a closed-loop, no-leak system (the atmosphere *is* the tank)

Air is cheap - pneumatic systems tend to be lower-cost than hydraulic systems

13.1 Pneumatics vs Hydraulics

In a pneumatc system, **<u>AIR</u>** is the fluid, or medium, which is used to transmit power



https://instrumentationtools.com/wp-content/uploads/2021/06/Basic-pneumatic-system.png

<u>HOWEVER</u>

<u>Air is compressible</u> – it is difficult (if not impossible) to
- obtain precise, controlled actuator velocities with pneumatic systems.
- obtain precise positioning control
- smooth and consistent actuator travel under varying loads

<u>Air is used in low power applications</u> – it takes a large amount of energy to compress air beyond about 250 psi, furthermore the low pressures reduce explosion dangers involved if components such as air tanks should rupture

Recall:

$$Force(lbs) = pressure\left(\frac{lbs}{in^2}\right) \times Area(in^2)$$

$$F = p \times A$$

13.1 Pneumatic System

Air Compressor – reduces volume of atmospheric air and hence increases its pressure

Air Dryer – reduces moisture from air after compression

Air Tank – stores compressed air and acts an 'infinite' supply for the systems

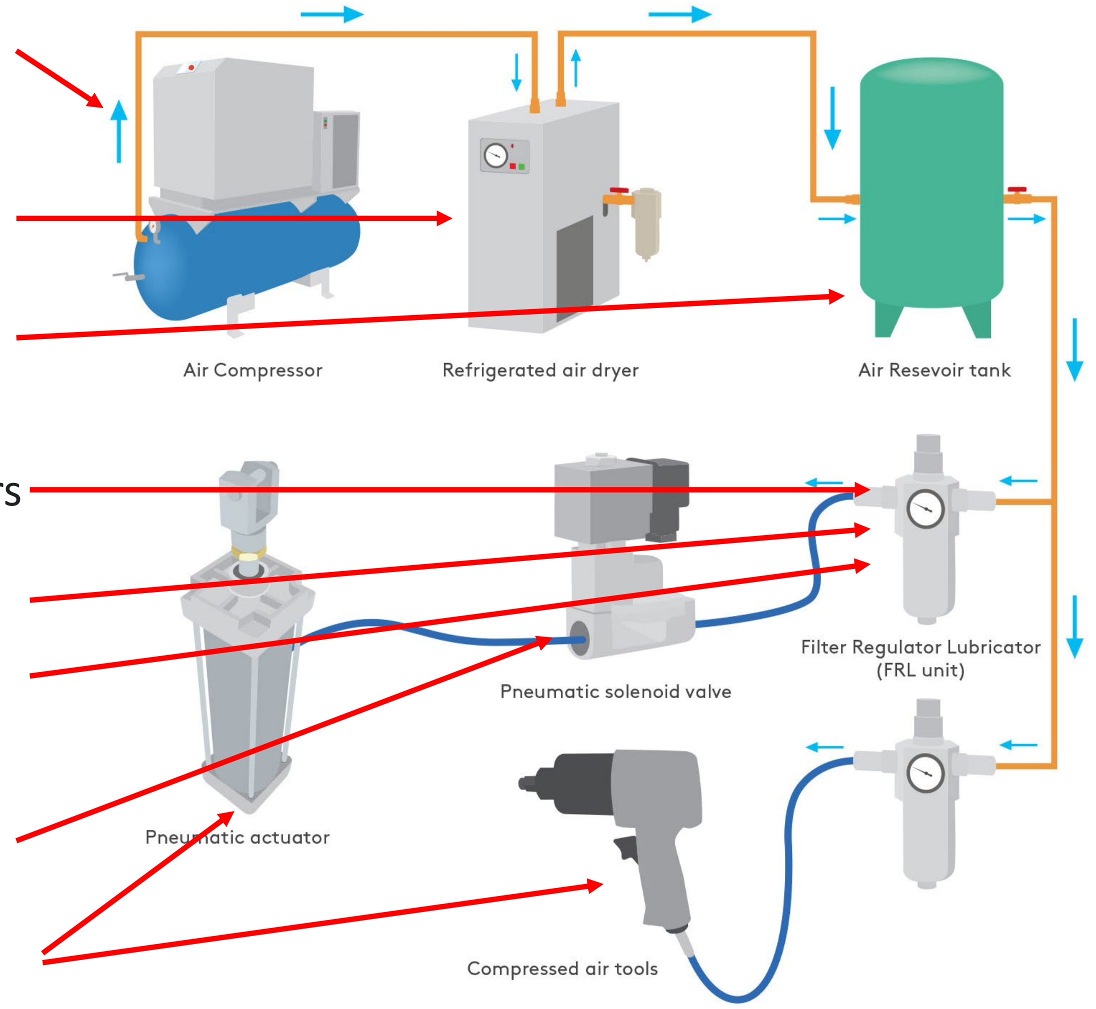
Filter – removes contaminants that can damage DCVs and actuators

Regulator – reduces the pressure to the actuator

Lubricator – adds a fine mist of oil for lubricating the DCV and actuator's moving parts

Valve – controls the direction and movement of the air

Actuator – converts the pneumatic power into mechanical power



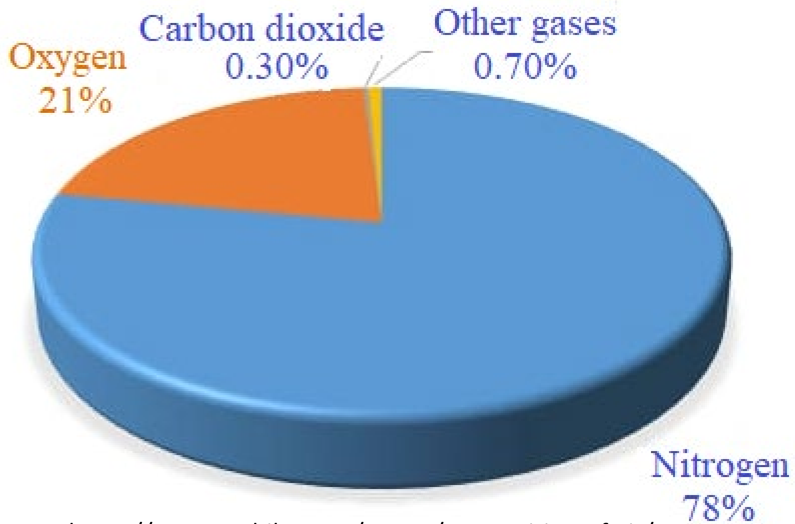
https://www.essentracomponents.com/en-gb/news/guides/hydraulics-versus-pneumatics

13.2 Properties of Air

Air is a composition of various gases and is present everywhere in our atmosphere.

Air also includes water vapours, otherwise known as humidity

Air can also include contaminants such as dust, soot, or other polluting gases



https://www.embibe.com/exams/composition-of-air/

https://ychef.files.bbci.co.uk/976x549/p06zbdgm.jpg

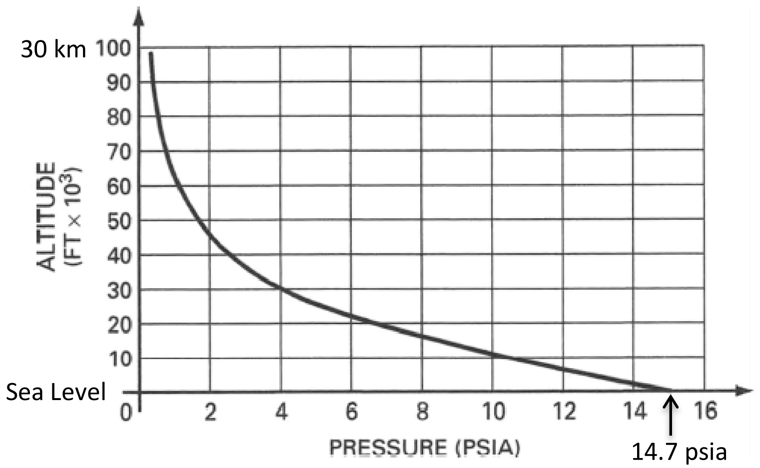
13.2 Properties of Air

Earth is surrounded by a blanket of air called the atmosphere which extends from the surface of the earth up to the edges of the exosphere.

Because air has weight, the atmosphere exerts a pressure at any point due to the column of air above that point.

The reference point is sea level, where the atmosphere exerts a pressure of **14.7 psia (101 kPa abs)**, and drops off rapidly with altitude

https://www.tutorialspoint.com/general_knowledge/images/troposphere.jpg



13.2 Standard Air

<u>Free Air</u> is considered to be air at *actual* atmospheric conditions.

Since atmospheric pressure and temperature vary from day to day, the characteristics of free air vary accordingly.

<u>Standard Air</u> is air which is used in the calculation of pneumatic systems

The most used standard for air comes from the “Compressed Air & Gas Institute (CAGI)” and the “American Society of Mechanical Engineers (ASME):

Standard air or (STP: Standard Temperature and Pressure) has the following attributes:

Pressure: 14.7 psia 101.3 kPa abs
Temperature: 68 degF,, 20 deg C
Relative Humidity: 36%

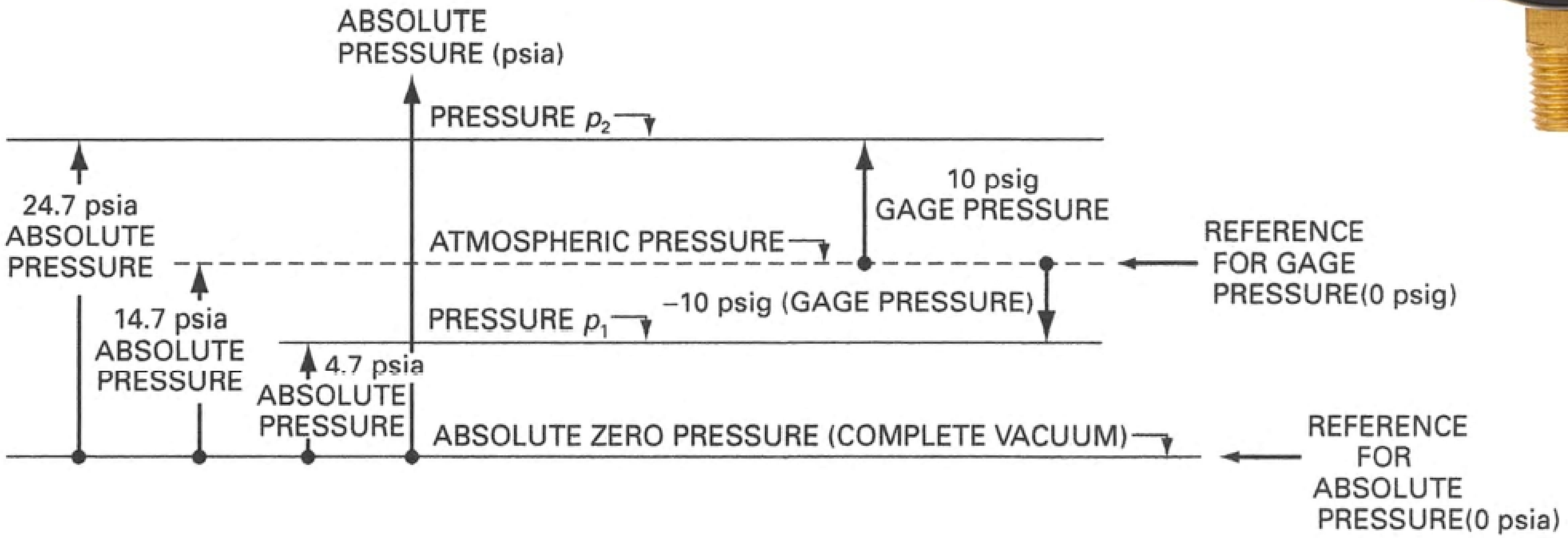
<u>Compressed Air</u> is air that has been compressed, resulting in higher density and pressures than **<u>Standard Air</u>**

13.2 Gauge and Absolute Pressure

<u>Pressure gauges</u> measure the pressure of a vessel ***relative*** to atmospheric pressure

Absolute pressure = gauge pressure + atmospheric pressure

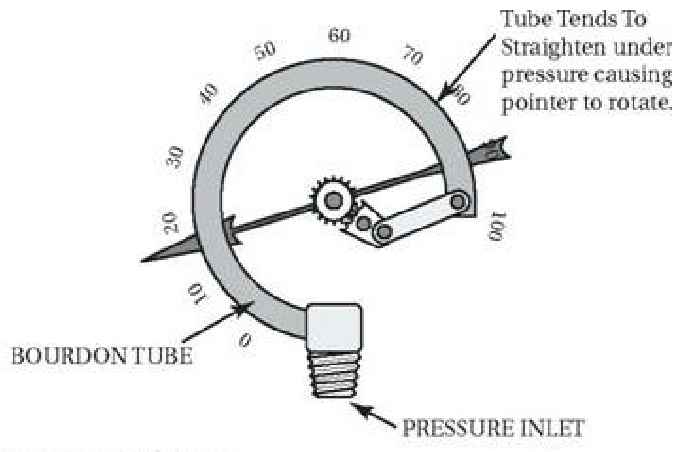
$$p_{abs} = p_{gauge} + p_{atm}$$



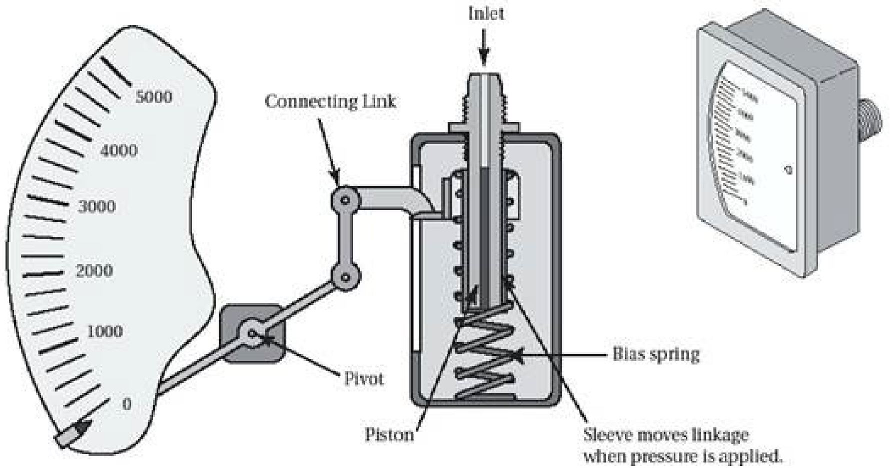
13.2 Pressure Measurement

There are 2 types of pressure gages that are commonly used in pneumatic systems:

Bourdon tube gages are 0.1% to 3% accurate. They are used in laboratories and in systems where accurate pressure determination is important.
Under 500 psig.



Pneumatic Plunger gauges are used for very high pneumatic pressure. 500 to 5000- psig.
For example: pneumatic Jack Hammers driven from large truck mounted compressors you see behind construction trucks.



https://www.hwhcorp.com/ml57000-012-ch1.html

13.2 Pressure Units

Unit	unitsymbol	corresponds to	Country/Region
Pascal	Pa	1 bar = 100,000 Pa	-
Bar	bar	1 bar = 1 bar	Western Europe
Kilopascal	kPa	1 bar = 100 kPa	Australia
Megapascal	MPa	1 bar = 0.1 MPa	China
Pound per square inch	psi	1 bar = 14.5 psi	North America
Kilogram per square centimetres	kg/cm^2 or $kg(f)/cm^2$	1 bar = 1.02 kg/cm^2	India, Korea
Inch of mercury column	inHg	1 bar = 29.53 inHg	North America

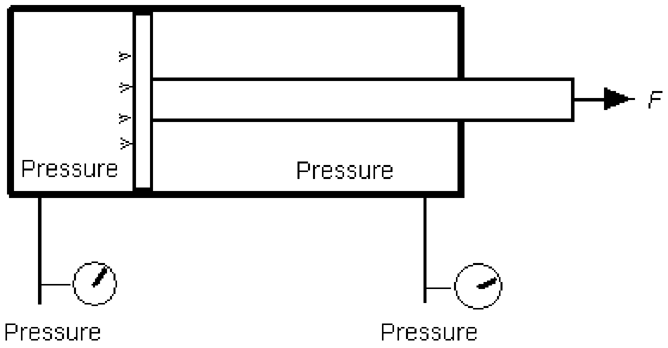
https://blog.wika.com/knowhow/international-pressure-units/

13.2 Pressure and Force

It is the **Pressure** of the air in a pneumatic system that results in force, and thus movement of actuators to do useful work

Pressure is applied uniformly and perpendicular to all the surfaces within the pressurized system, resulting in a force applied uniformly and perpendicular to all the surfaces within the pressurized system

Pressure (hence force) applied to the moving surface(s) of a cylinder or motor will result in that surface moving, hence performing useful mechanical work.



$$Force(lbs) = pressure\left(\frac{lbs}{in^2}\right) \times Area(in^2)$$

$$Force(N) = pressure(Pascals) \times Area(m^2)$$

$$F = p \times A$$

13.2 Temperature and Absolute Temperature

Temperature measured in a given scale (C or F) is *relative* to Absolute Zero

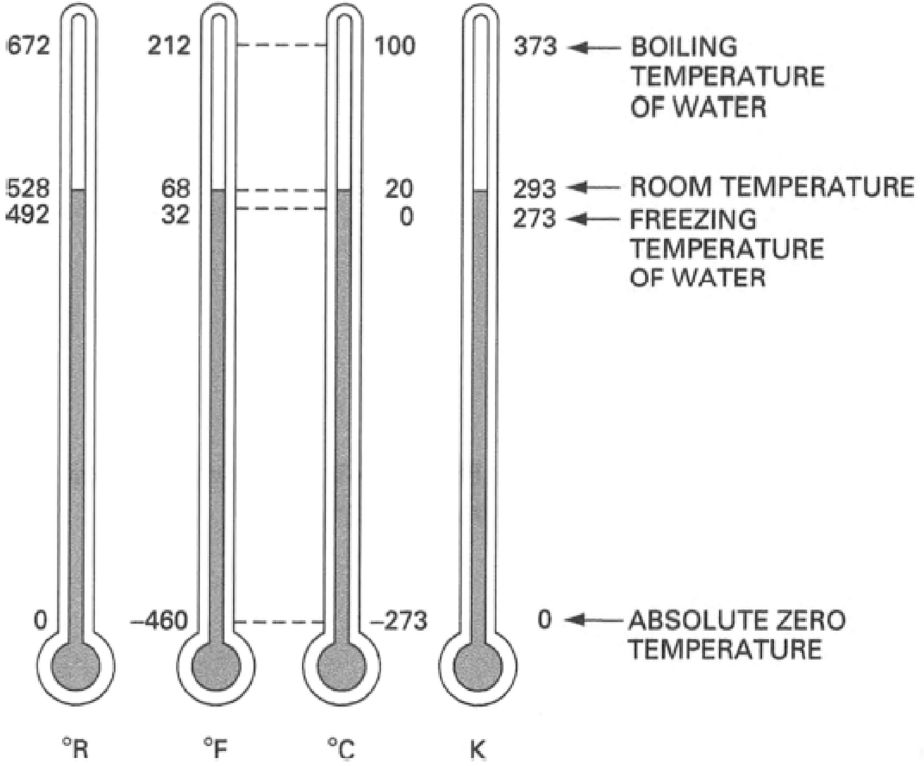
Absolute Zero is the temperature at which all molecular motion ceases to exist and the volume and pressure of a gas theoretically become zero.

Absolute temperature = measured temperature + absolute zero temp

$$t_{abs} = t_{measured} + |t_{abs\ zero}|$$

If using imperial degrees F then $|t_{abs\ zero}|$= 460 and t_{abs} is in Rankine (°R)

If using metric degrees C then $|t_{abs\ zero}|$= 273 and t_{abs} is in Kelvin (K)



13.3 The Perfect Gas Laws

The Perfect Gas Laws determine the interactions of pressure, volume, and temperature of a gas.

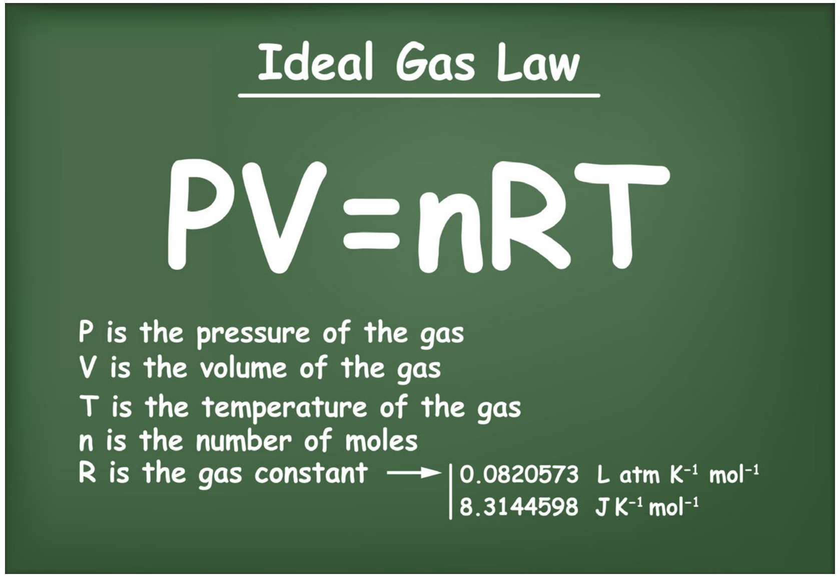
Boyle's Law defines the relationship between volume and pressure

Charles' Law defines the relationship between volume and temperature

Guy-Lussac's Law defines the relationship between pressure and temperature

General Gas Law combines these three

For these calculations, you MUST use *absolute pressure* and *absolute temperature*



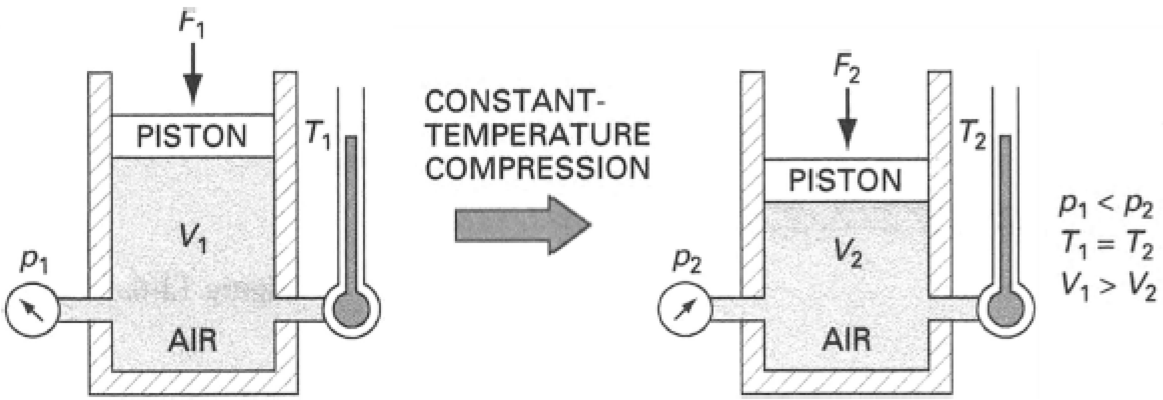
https://www.embibe.com/exams/ideal-gas-equation/

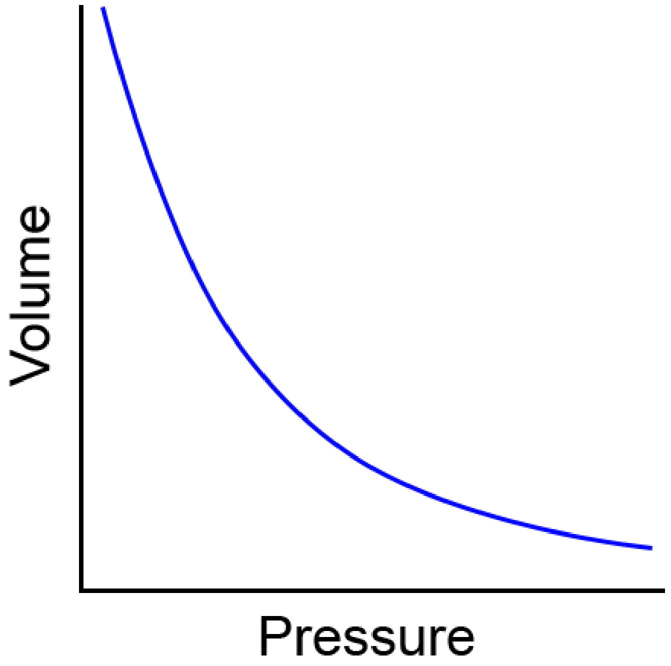
13.3 Boyle's Law

Boyle's Law defines the relationship between volume and pressure

$$\frac{V_1}{V_2} = \frac{p_2}{p_1}$$

Volume is inversely proportional to Pressure, if Temperature remains constant





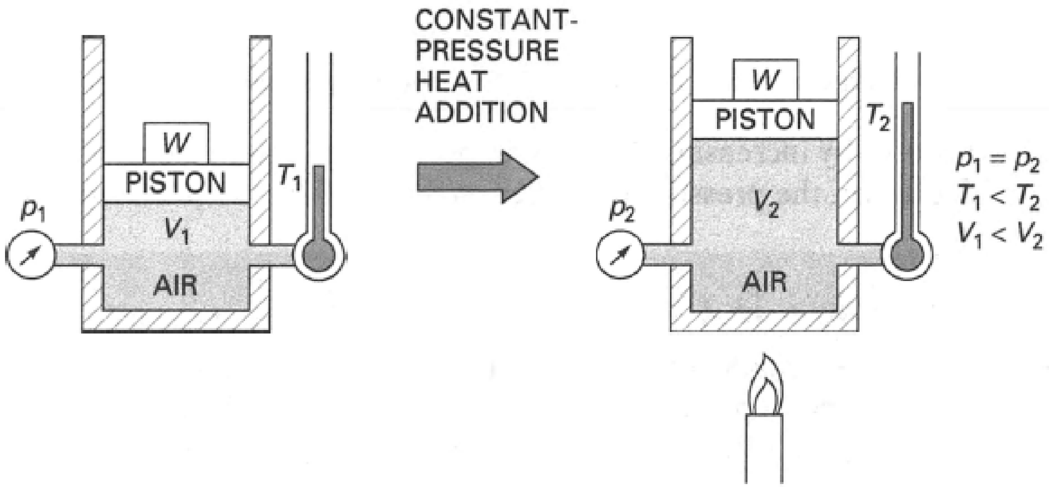
https://study.com/

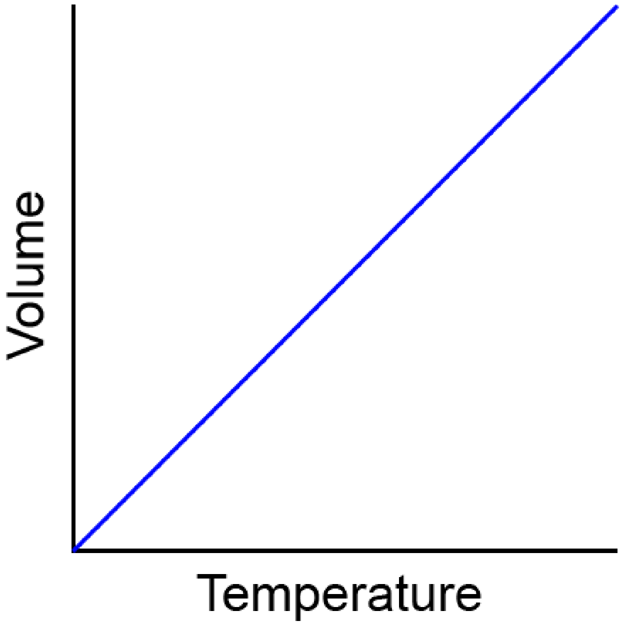
13.3 Charles' Law

Charles' Law defines the relationship between volume and temperature

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Volume is <u>directly</u> proportional to Temperature, if Pressure remains constant





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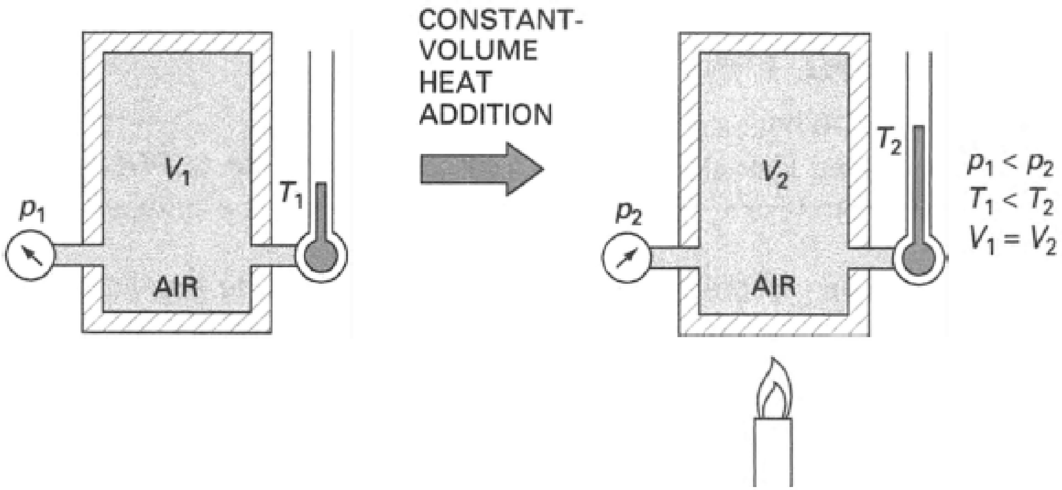
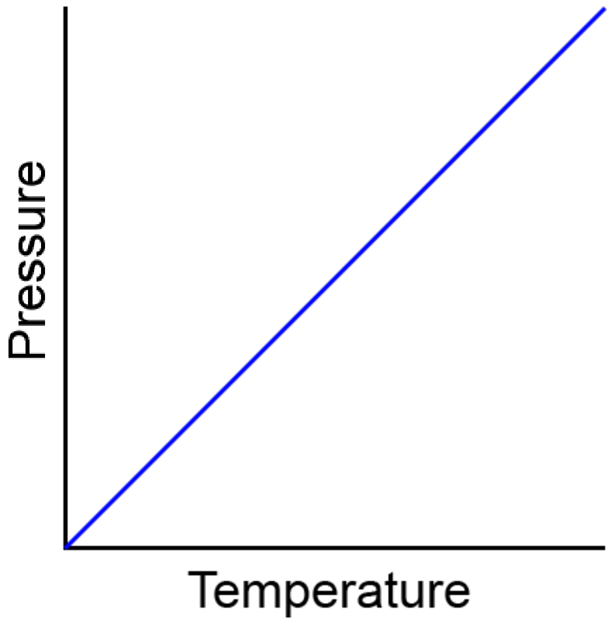
13.3 Guy-Lussac's Law

Guy-Lussac's Law defines the relationship between pressure and temperature

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}$$

Pressure is directly proportional to Temperature, if Volume remains constant





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13.3 General Gas Law

General Gas Law combines the three Laws and defines the relationship between volume, pressure and temperature

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

With this General Gas Law, we can predict the effect on the system when one of these variables changes

And it is because of the compressibility of air and the resulting Gas Laws that makes pneumatic system design fundamentally different than hydraulic systems.

Hydraulic vs Pneumatic System Design

Hydraulic System Design

Based on required force, size the cylinder and operating pressure P(psi), and set Pressure Relief Valve

Based upon the maximum cylinder speed, determine the flow rate, Q(GPM)

Based on GPM determine volumetric displacement of pump, v_d

Based on v_d and P displacement determine power and select prime mover

Pneumatic System Design

Based on required force, size the cylinder and operating pressure P(psi), and set Pressure Regulator

Based upon the cylinder cycle time (including dwell), determine the flow rate, Q(CFM)

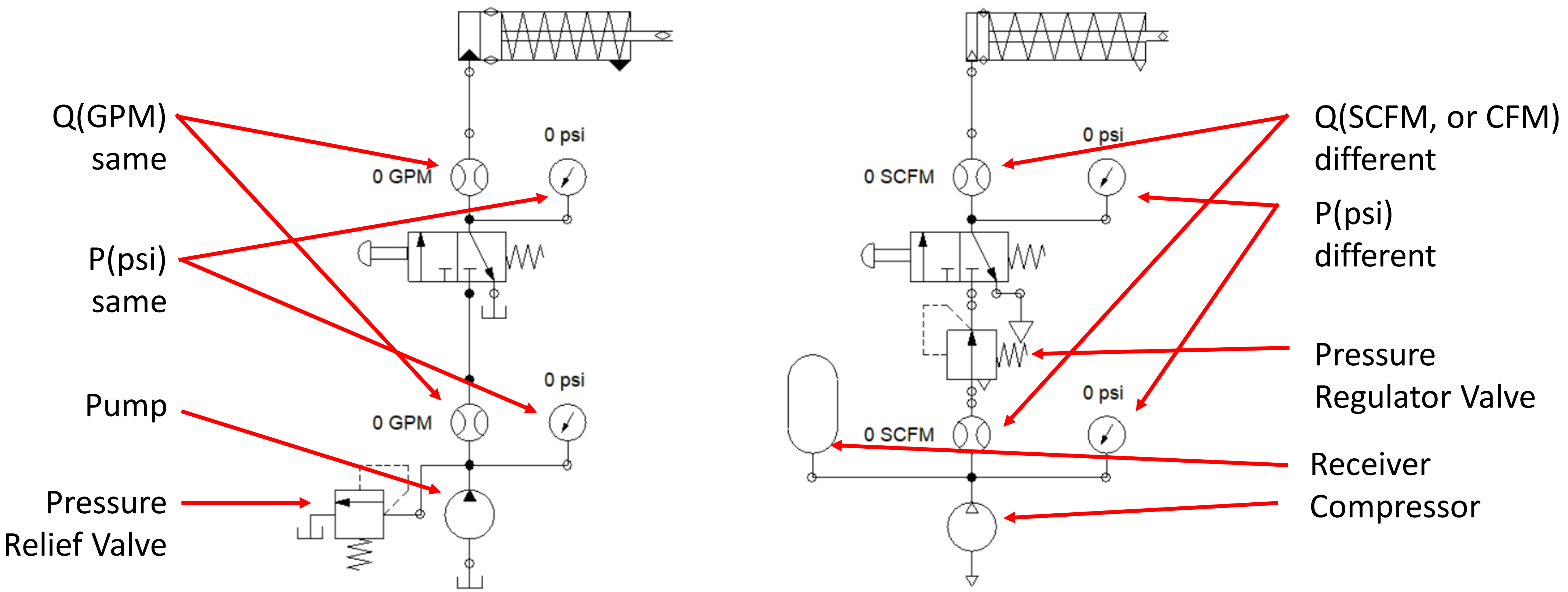
Based on CFM determine capacity of compressor, in CFM at the required P

Based on CFM and P determine power and select prime mover

Although they appear similar, the fact that air is compressible and flow rate is dependent upon pressure, unlike oil, the design approach is very different

Pressures and flow rates will change throughout the pneumatic circuit

Hydraulic vs Pneumatic System Design

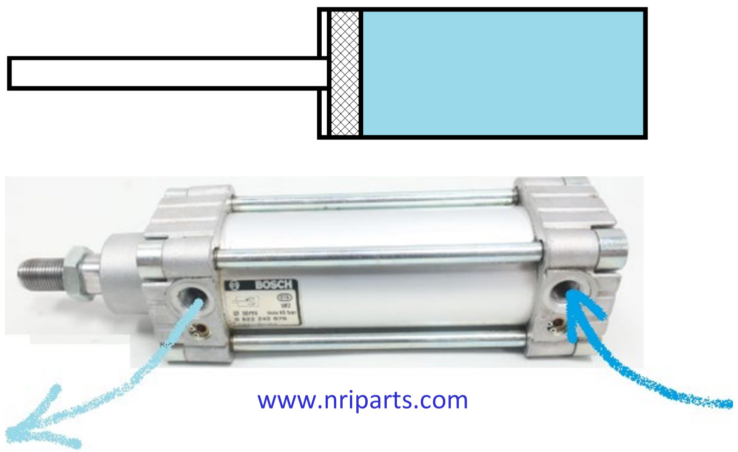


Flow Rate (Q)

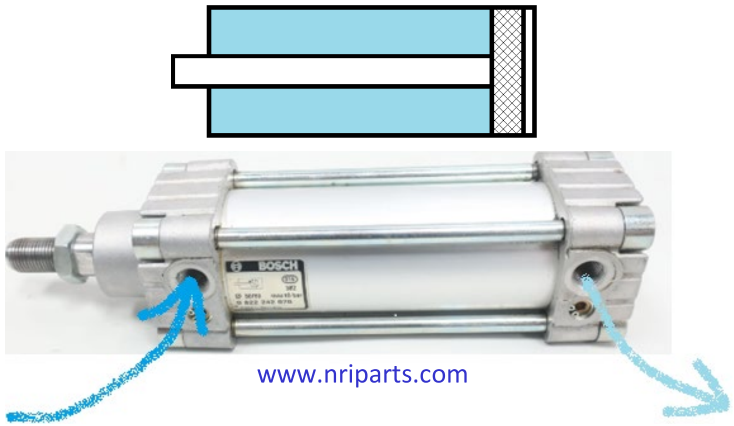
The flow rate (Q) of an actuator is the total displacement of the actuator in ft^3 for each minute of its operation.

CFM means Cubic Feet Per Minute, (ft3/min) – for Pressurized air

SCFM means Standard Cubic Feet Per Minute, (ft3/min) – for Standard air



Q to extend
CFM or SCFM



Q in to retract
CFM or SCFM

Flow Rate (Q)

Two things must be considered to find the required flow rate of air (CFM) delivered to a cylinder or set of cylinders:

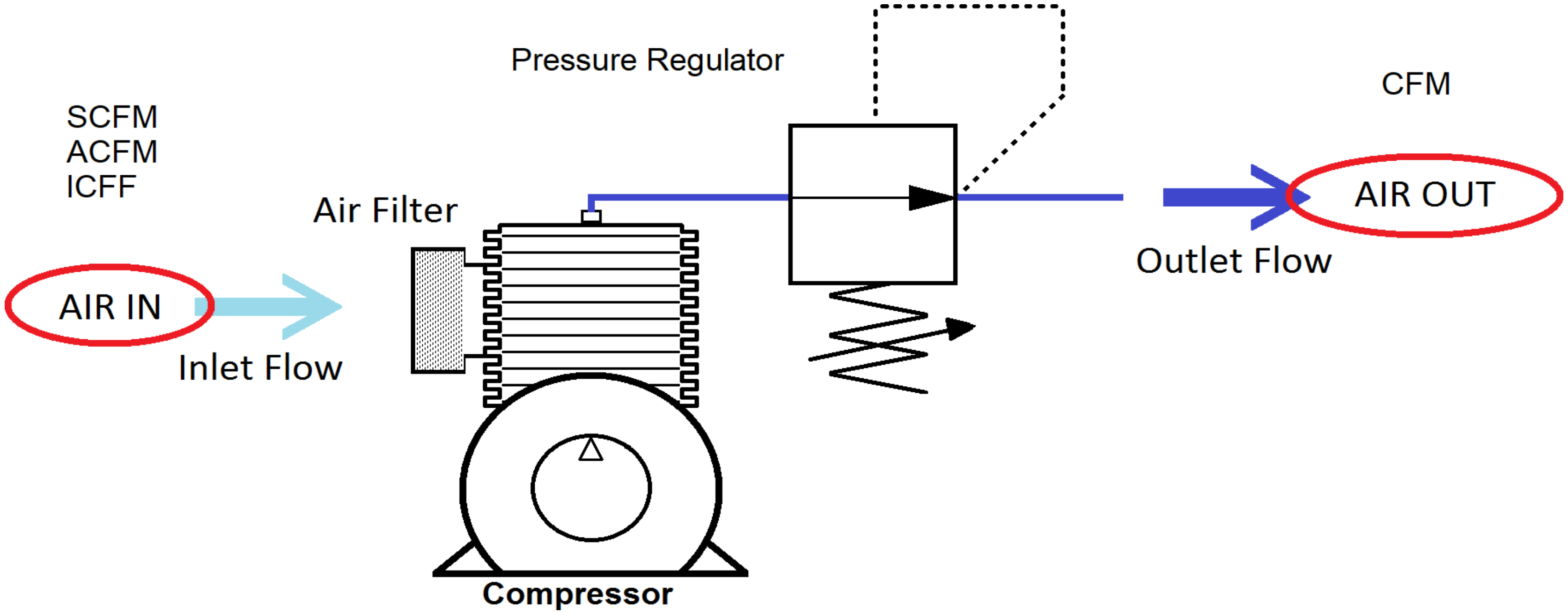
1) The number of cycles (*n*) per minute of the cylinder(s), *n/min*

   A cycle is considered an extend/retract sequence which then repeats

2) The displacement required to complete one extend/retract cycle of the cylinder(s), D_T

$$Q(CFM) = D_T(in^3) \times \frac{n}{t(min)} \div 1728\left(\frac{in^3}{ft^3}\right)$$

Flow Rate (Q)



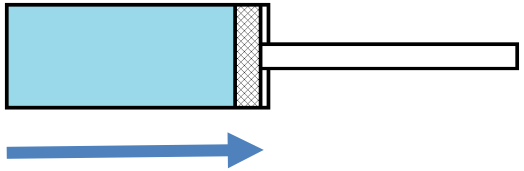
The units of flow rate Q for a pressurized system is measured in CFM

The units of flow rate Q of free-air into a compressor, before pressurization, is measured in SCFM

Compressors are rated in <u>CFM</u> and <u>Pressure</u>

Actuator Displacement, D_T

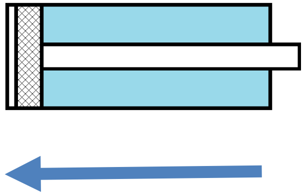
Extension Displacement: $\mathbf{D_E}$



$$D_E(in^3) = stroke\_length(in) \times A_E(in^2)$$

$$D_E(in^3) = stroke\_length(in) \times \frac{\pi}{4} D_{piston}^2(in^2)$$

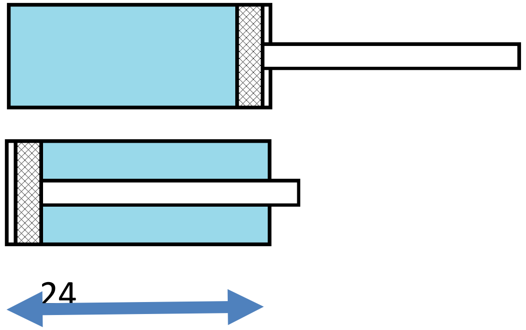
Retraction Displacement: $\mathbf{D_R}$



$$D_R(in^3) = stroke\_length(in) \times A_R(in^2)$$

$$D_R(in^3) = stroke\_length(in) \times \frac{\pi}{4}(D_{piston}^2 - D_{rod}^2)(in^2)$$

Total Displacement: $\mathbf{D_T}$



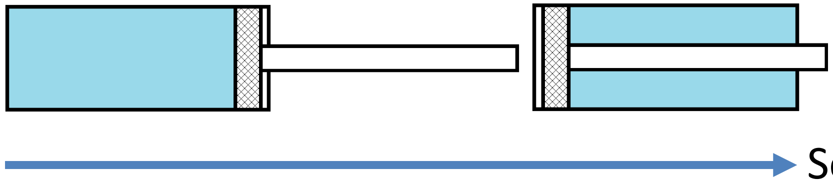
$$D_T(in^3) = D_E(in^3) + D_R(in^3)$$

$$D_R(in^3) = stroke\_length(in) \times \frac{\pi}{4}(2 \times D_{piston}^2 - D_{rod}^2)(in^2)$$

Number of Cycles per Minute

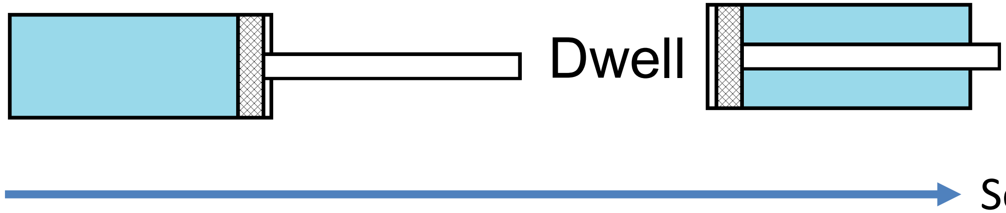
Determine the time (sec) to complete one cycle (cycle)

$$\frac{n}{min} = \frac{1}{\frac{sec}{cycle} \times \frac{1min}{60\ sec}}$$



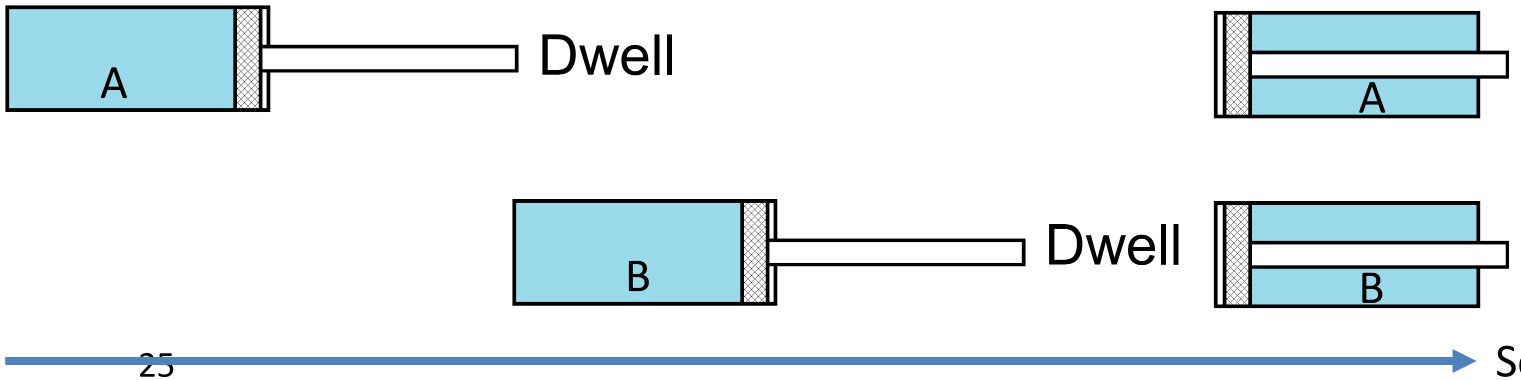
Sec/cycle

For a single continuously cycling cylinder, determine in seconds how long one extend and retract cycle is



Sec/cycle

For a single cycling cylinder with dwell time, determine in seconds how long one extend and retract cycle is including dwell time



Sec/cycle

For multiple cylinders, determine in seconds how long a complete sequence is including any dwell times

Pressure Requirements

The pressure required at the cylinder is derived from the forces required to do the necessary work of the cylinder.

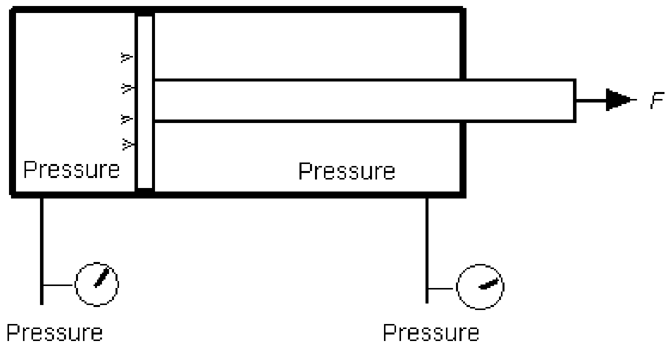
Recall

$$Force(lbs) = pressure\left(\frac{lbs}{in^2}\right) \times Area(in^2)$$

$$Force(N) = pressure(Pascals) \times Area(m^2)$$

$$F = p \times A$$

With this relationship, a system operating pressure and cylinder size can be selected



Compressor Selection

Compressors have rated flow rates (CFM) at a given system pressure (psi).

Recall the Gas Law $\frac{p_1}{p_2} = \frac{V_2}{V_1}$

As the compressor increases the pressure P of the air, the volume V decreases thus resulting in a lower CFM

The flow rate rating of a compressor is in CFM at a certain Pressure

This is how much *pressurized air* it can *deliver* while running at full CFM (No idle time)

Compressor Rating Example
135 CFM @ 60 psi
75 CFM @ 80 psi
30 CFM @ 100 psi

https://images.homedepot.ca/productimages/p_1000681001.jpg?product-images=l

Chapter Reading

Chapter 13

13.1-13.3