# Prototyping in Mechanical Engineering

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# Class 4: Fluids and Thermo

## Movie Break!

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# Today's Agenda

- ~~Movie Break!~~
- Intro to Fluids and Thermodynamics
- Fluid Dynamics
- Thermodynamics
- Resources for Design

# Intro to Fluids and Thermodynamics

# Introduction

- Why are fluids and thermodynamics often taught together?
  - Thermo in stationary bodies is well known
  - Fluids complicate thermo
  - Pressure, temperature, and heat show up in both
  - Applications often overlap
- Today's class:
  - More theory than practical knowledge

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# Fluid - Definition

- Material that conforms to its container
  - Liquid
    - Incompressible
    - Viscous
  - Gas
    - Compressible
    - Inviscid

# Terms & Properties

- Pressure – force per area
- Temperature
- Heat – thermal energy
- Volume
  - Compressibility
- Entropy – disorder, but also thermal energy *not* available for work
- Enthalpy – product of P and V, energy available for work
- Viscosity – material property
  - Temperature dependent

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- Fluid Dynamics
- Thermodynamics
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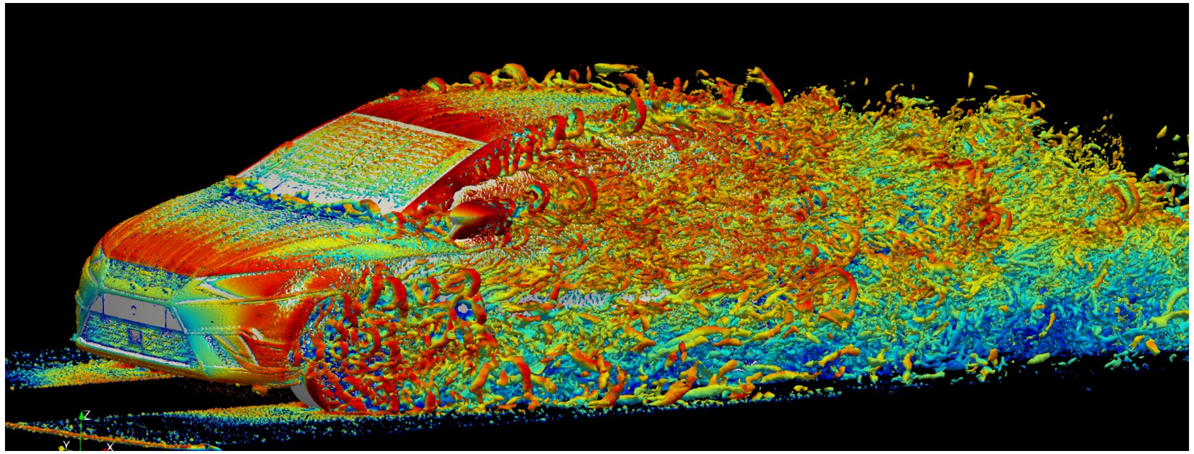
# Fluid Dynamics

# Fluid Dynamics

- The Big Three: Pressure, Volume, and Temperature
- Flow Field Diagrams
- No Slip Condition
- Laminar and turbulent flow
- Drag
- Conservation of Mass & Conservation of Energy
- Fluid Circuits
- Bernoulli Effect
- Lift



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# Pressure

- Force per area
  - **Pa**, bar, torr, psi, atm
- Design for pressure:
  - Cylinders and sphere
  - Avoid corners
  - High pressure is harder than vacuum
- Vacuum
  - Millitor (mtorr)
  - Microtorr (high vac)
  - Mean Free Path (ultra high vac)

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# Volume

- **Liter**, mL, cc
- Variable volume
  - Cylinders
    - Syringes
    - Pistons
  - Bladders / Balloons
  - Bellows


# Temperature

- Measure of molecular kinetic energy
  - **Celsius**, Fahrenheit, Kelvin, Rankine
- Changed by heat flow
- Endothermic / exothermic processes
- Determines speed of sound in a gas

# The Big Three

$$PV = nRT$$

Amount	Constant

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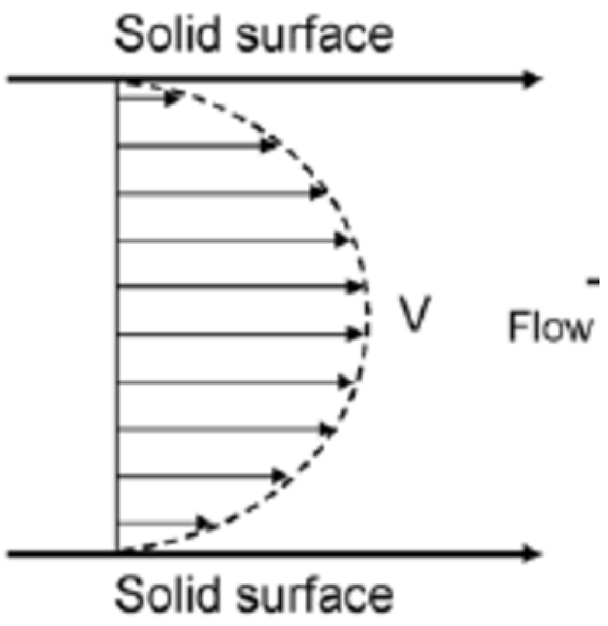
# The Big Three

$$\Delta PV = \Delta T$$

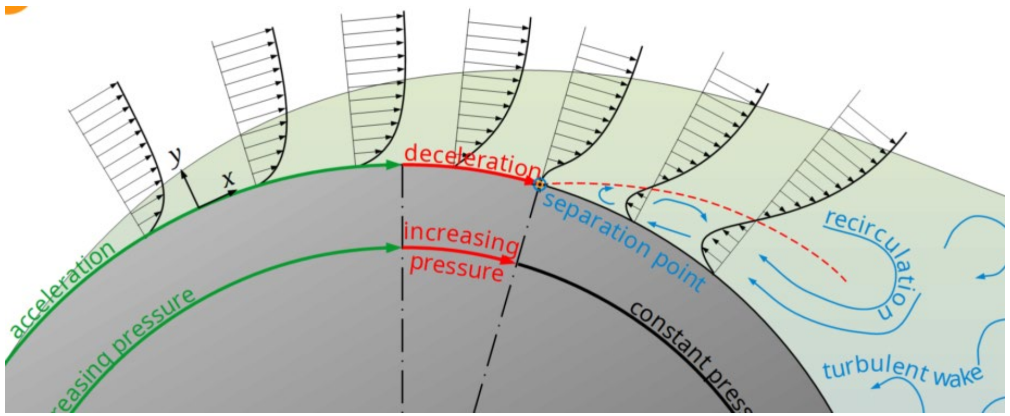
# The Big Three

$$\frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1}$$

# Flow Fields




Velocity profile without slip



# No Slip Condition

**Fluid in contact with a surface does not move with respect to the surface**

# Movie Break!

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# Laminar and Turbulent Flow

- Laminar flow
  - Smooth, predictable, mathematical
  - Viscous flow dominates
  - Re < 2300 (pipe flow)
- Turbulent flow
  - ‘choppy’, chaotic, difficult math
  - Inertial flow dominates
  - Re > 2900 (pipe flow)
- Reynold’s Number:

$$Re = \frac{\rho u L}{\mu}$$

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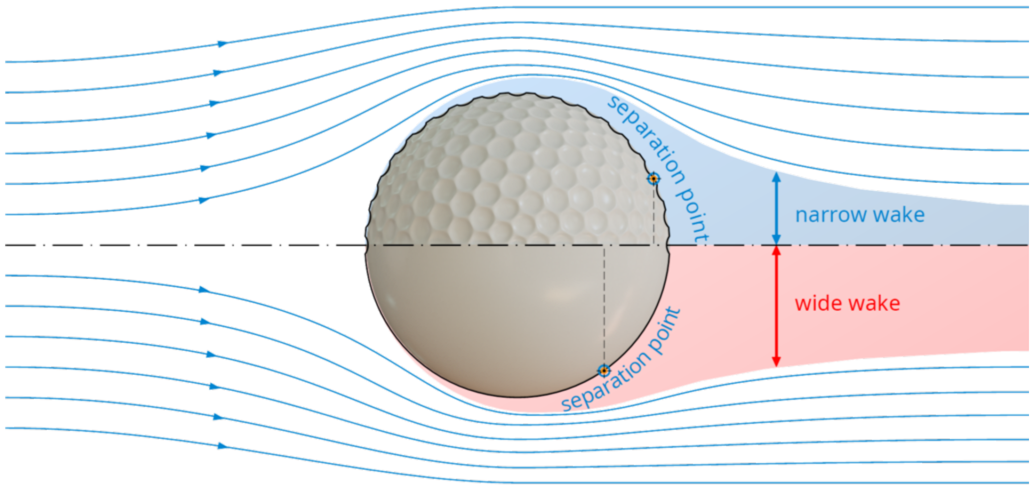
# Movie Break!

# Drag

- Skin Drag
  - Based on the no-slip condition and fluid viscosity
- Pressure Drag
  - Based on pressure differences in the flow field
- Sportsballs
  - Turbulent flow separation

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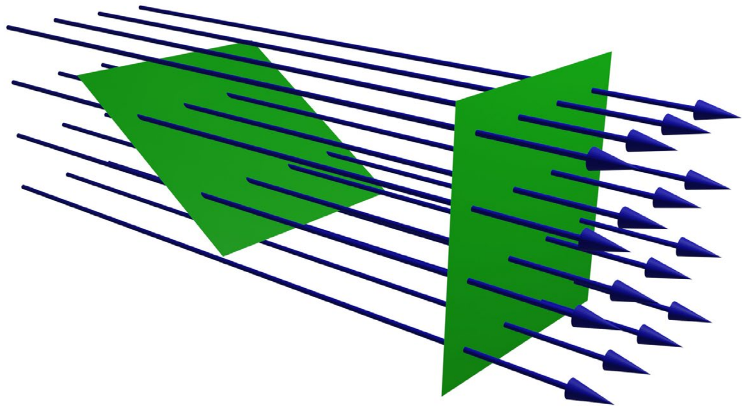
# Conservation

- Mass
  - Flow that goes into a system comes out of it
  - Flux: Flow through a known area
- Energy
  - Energy that goes in to a system comes out of it



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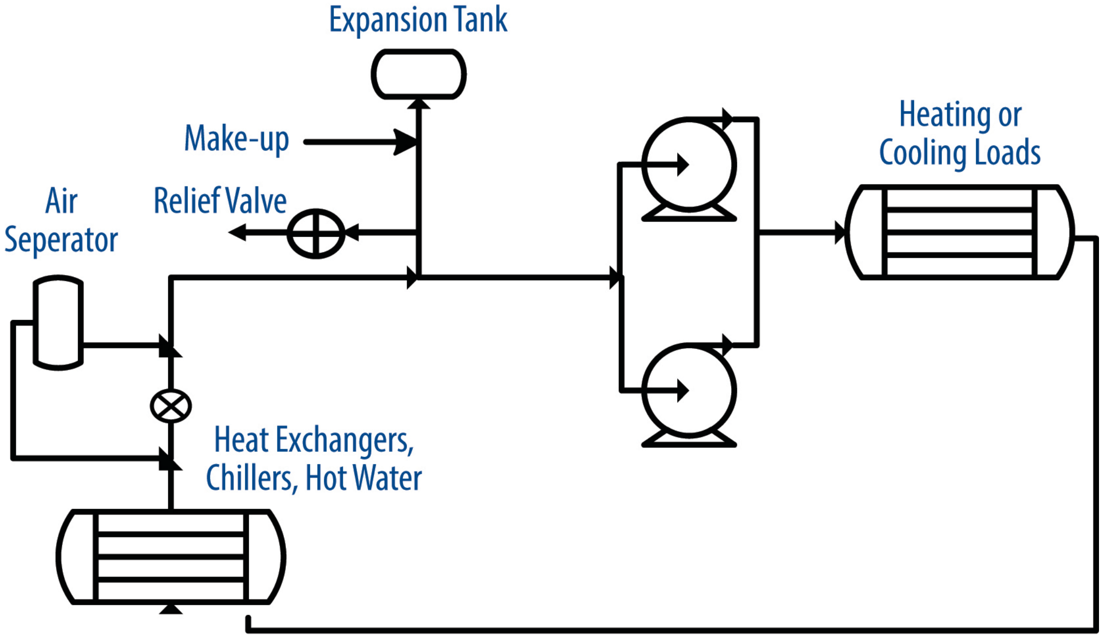
# Closed systems

- Circulating systems
  - Mass (thus flow rate) through the system stays constant
  - Temperature, pressure, work, heat, etc. may not be constant

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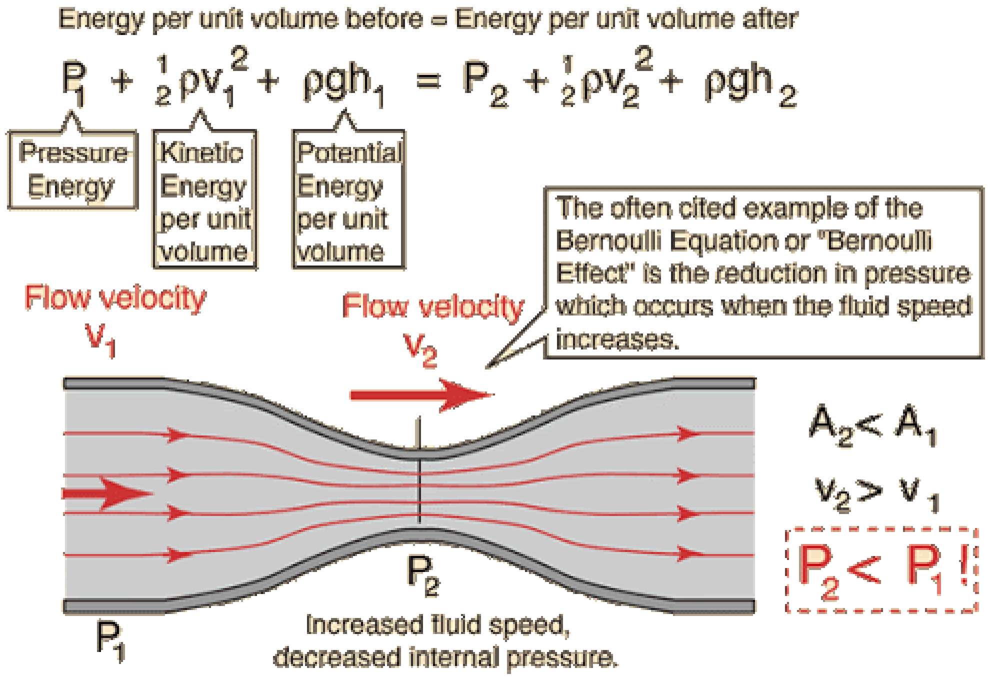
# Bernoulli Principle

- Increasing fluid velocity *decreases* fluid pressure!

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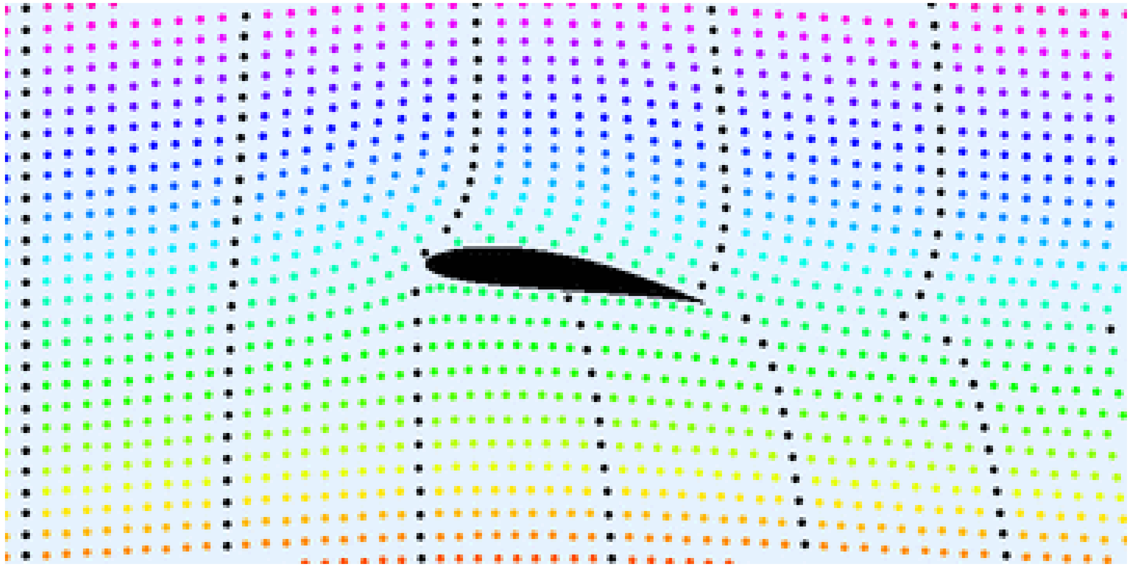
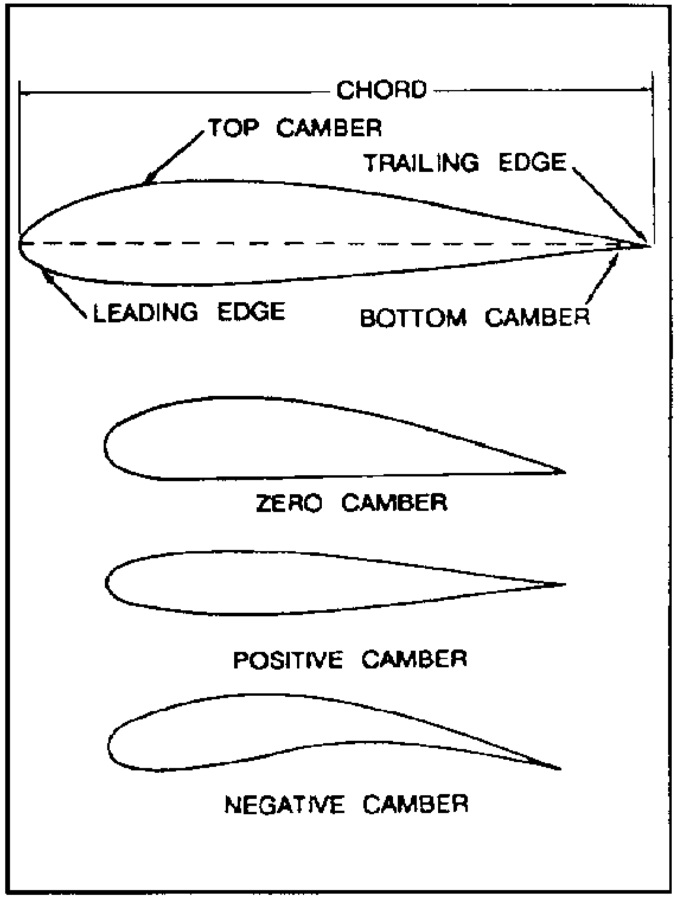
# Lift

- Redirecting flow

**AND**

- Bernoulli's principle



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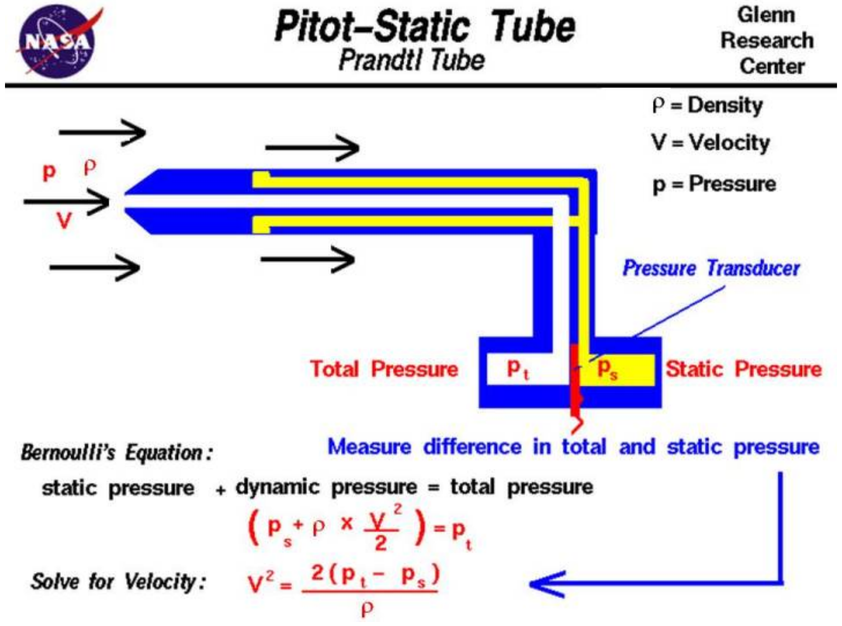
# Applications

- Pitot Tube:



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- ~~Intro to Fluids and Thermodynamics~~
- ~~Fluid Dynamics~~
- Thermodynamics
- Resources for Design

# Thermodynamics

# Thermodynamics

- Heat Transfer
  - Radiation
  - Conduction
  - Convection
- Heat that "does work"
- State Changes
- Psychrometrics
- Refrigeration
- ~~Combustion~~

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# Radiation

- Electromagnetic emission
  - Usually IR, but at higher temperatures, visible
- All matter emits it
  - Flow from higher temperature to lower
  - Absolute units

$$(T_a - T_b)^4$$

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# Conduction

- Math
  - "The Heat Equation" (when transient)

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{e}=\rho c_p\frac{\partial T}{\partial t}$$

  - Linear with $\Delta T$ (in steady-state)
- Semantically: Between or within solid objects

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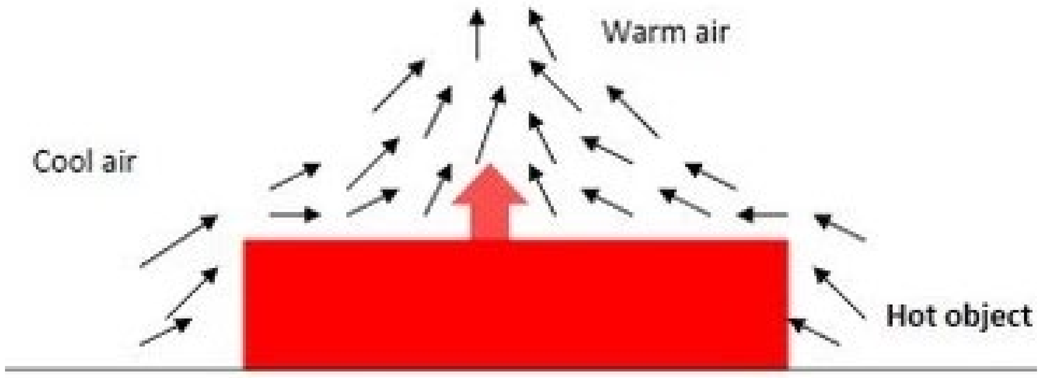
# Convection

- Conduction to a fluid
- Natural convection
  - Density driven
- Forced convection



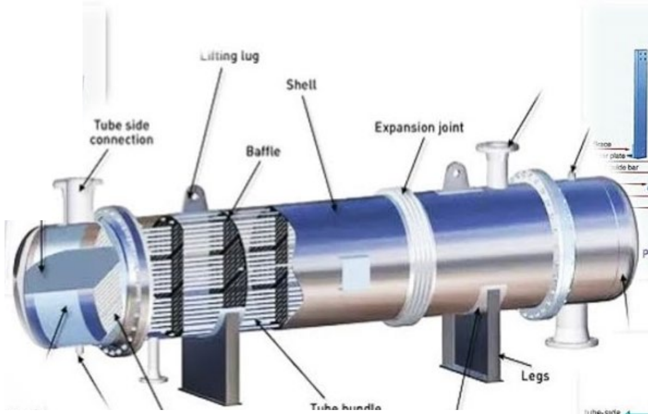

- Dimensionless Numbers: Rayleigh, Prandtl, Nusselt, etc.
  - Predicts forced vs. natural convection and other factors
- More mathematically difficult than conduction!

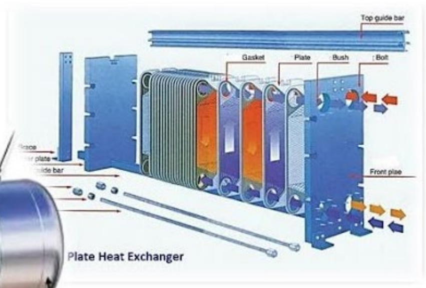
# Design for Convection

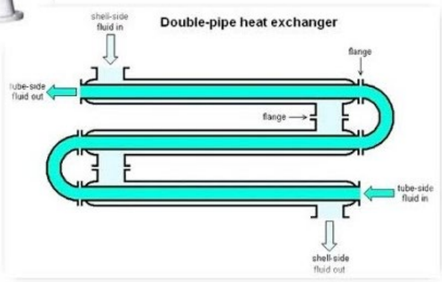
- Surface area
  - Fins
  - Multiple loops
- Flow
  - Forcing additional volume of fluid through helps convection, but is also more difficult
  - Set up natural flow to help
  - Anticipate flow direction and work with it

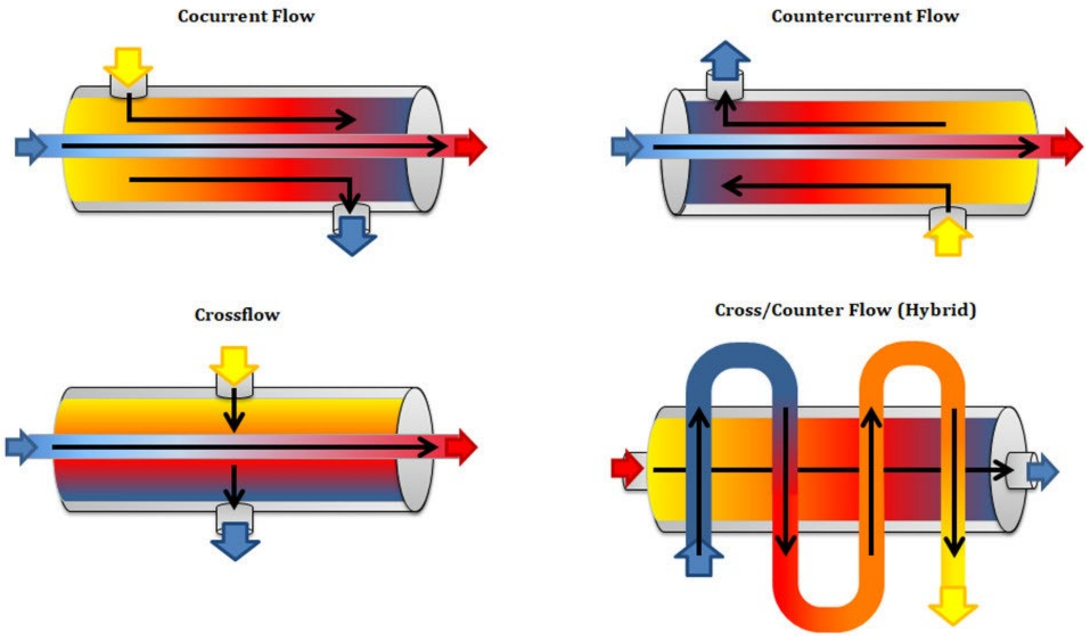
# Heat Exchangers

- Countercurrent and cross/counter are most efficient

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# Heat that does work

- Convert Enthalpy to Work
- Combustion
  - Chemical potential energy converts to thermodynamic energy
  - Otto and Diesel Cycles
- Turbines
  - Rankine Cycle
  - Very high efficiency
  - Typically industrial-scale

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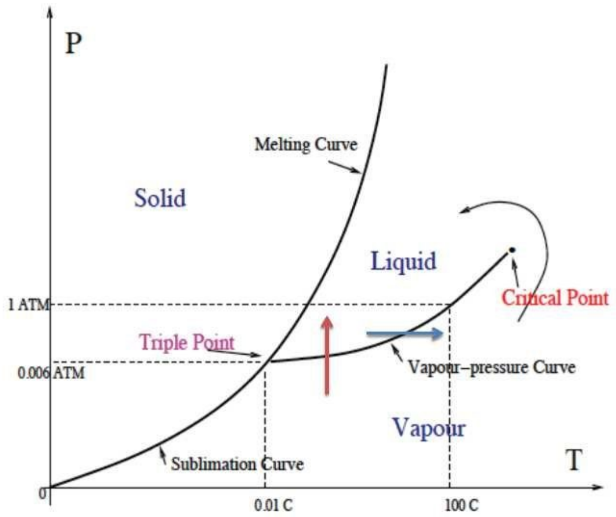
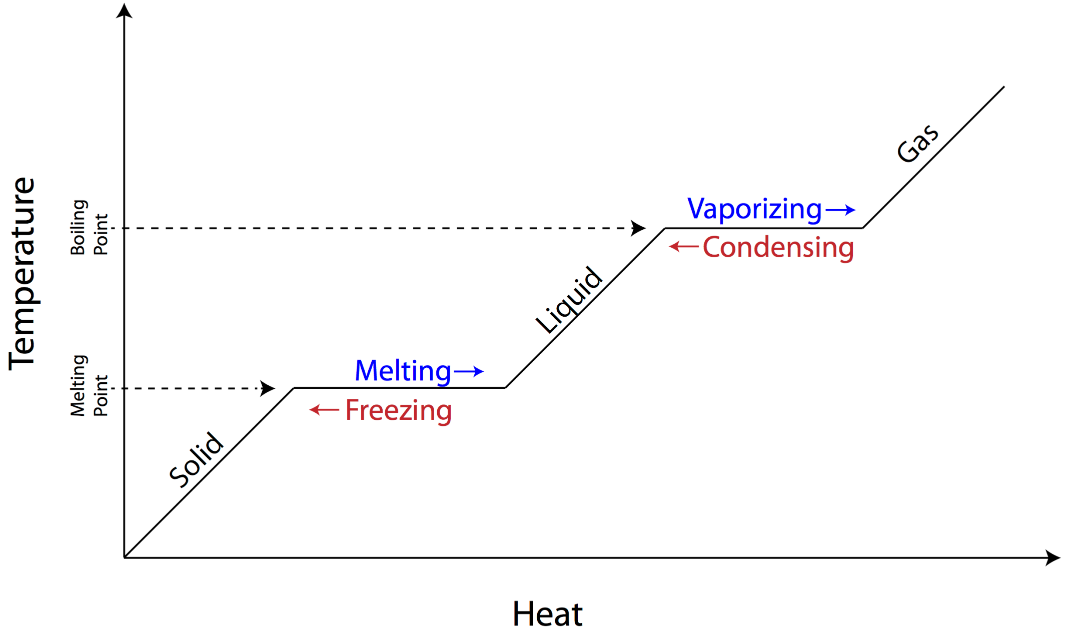
# State Changes

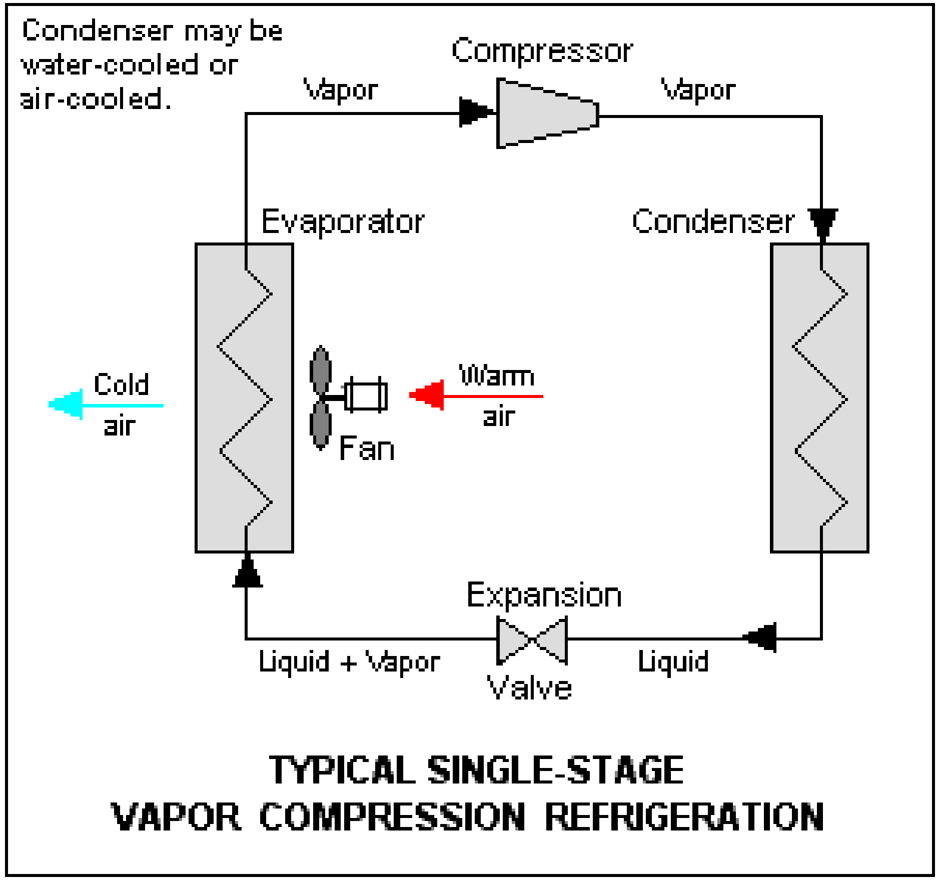
- Useful for maintaining temperatures
  - Exact*
  - Convenient
- Frustratingly energy intensive
- *Pressure dependent



# Refrigeration

- Best conceptualized as a ‘heat pump’
  - Carnot cycle
  - Bulky, complex, noisy
  - Can be very efficient
- Thermoelectric effect
  - Compact, simple, silent
  - Not typically very efficient

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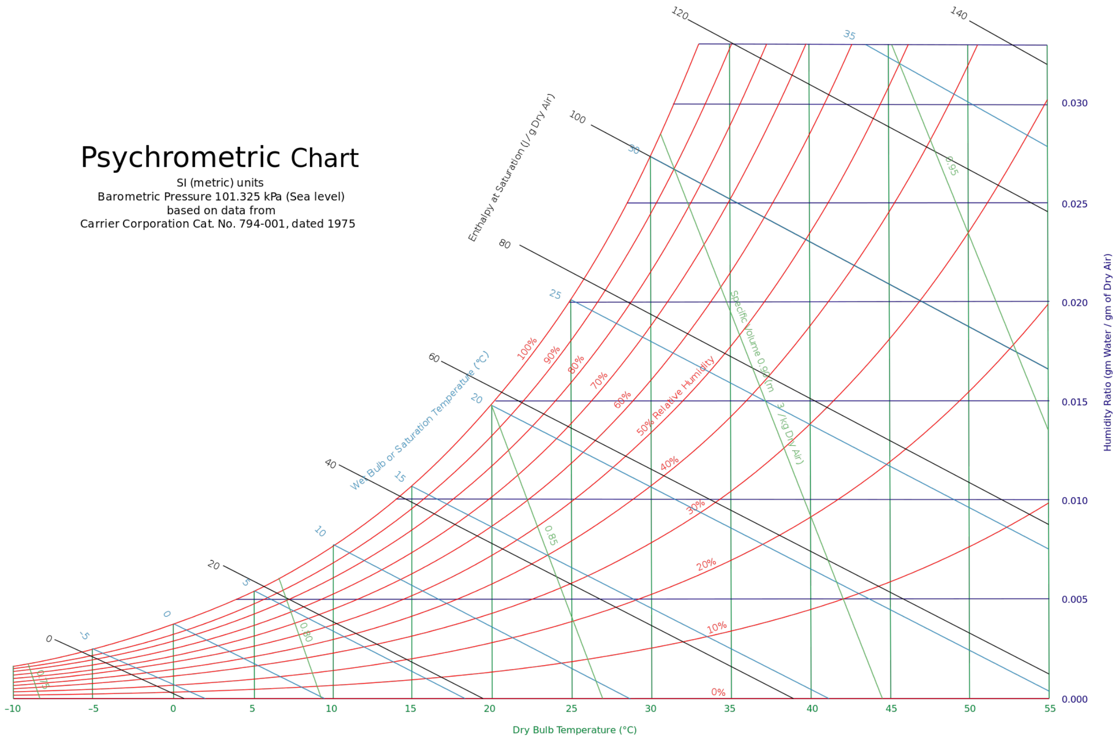
# Psychrometrics

- Study of gas-vapor mixtures
- Most commonly used in climate control
- Dew Point
  - Temperature at which condensation occurs for a given air-water mixture
- Wet Bulb Temperature
  - Temperature of a thermometer that is wet (i.e. takes into account humidity)
  - Is more accurately how it “feels”
- Humidity

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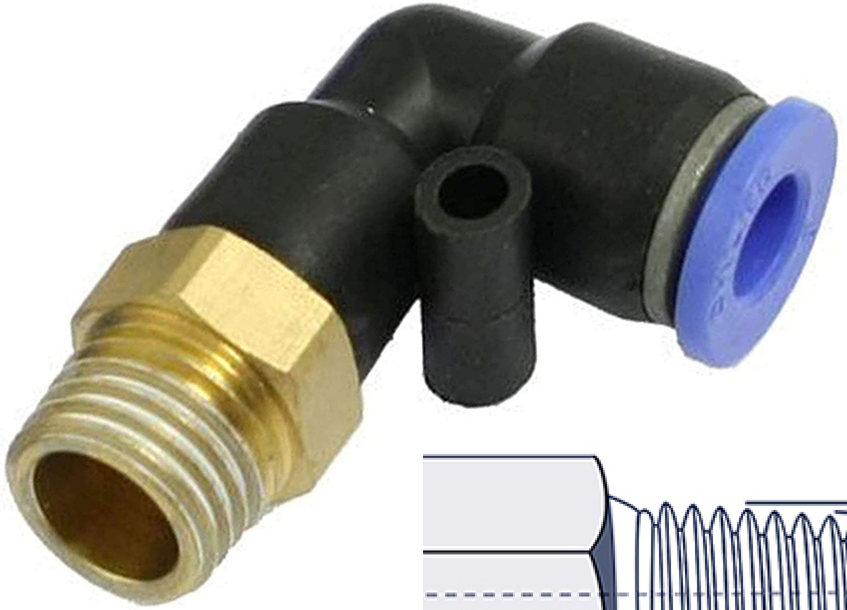
# Resources for Design

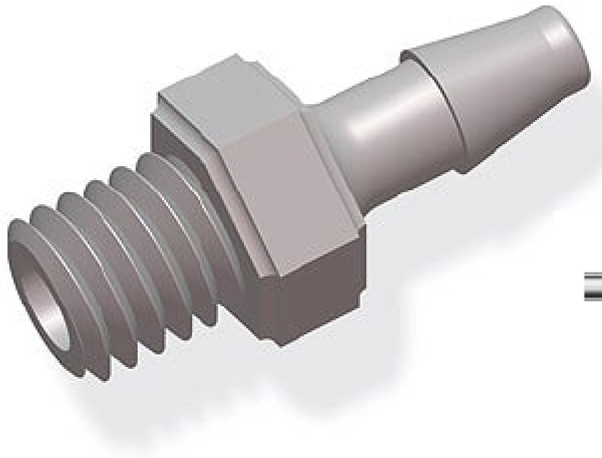
# Design Resources

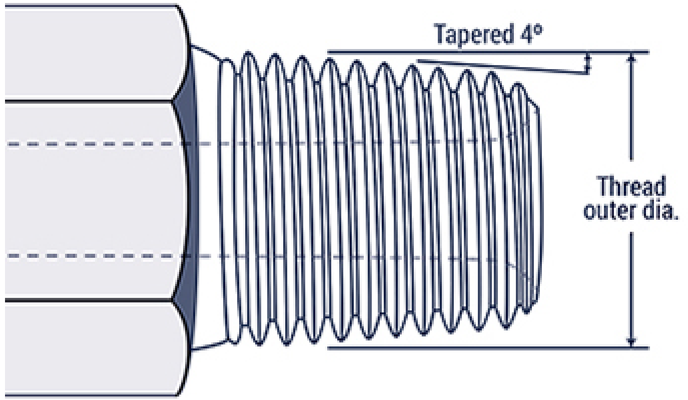
- Piping
- ~~Pressure Vessels~~
- Pumps
- Valves

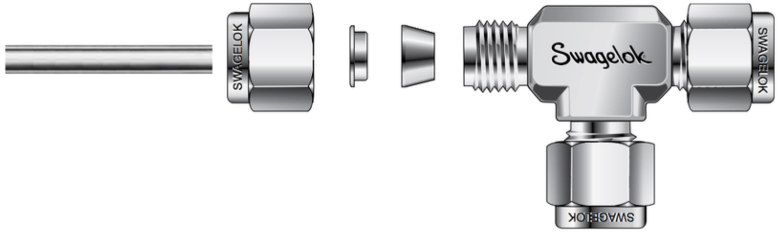
# Piping

- Diameter
  - No-slip condition and ‘head loss’
- Material
  - Weight, price, etc. (as you would any material!)
  - Galvanic Corrosion
- Rigid vs. flexible
- Connection types:
  - Push-to-connect
  - Barbs
  - Swagelok
  - Pipe thread
  - Other



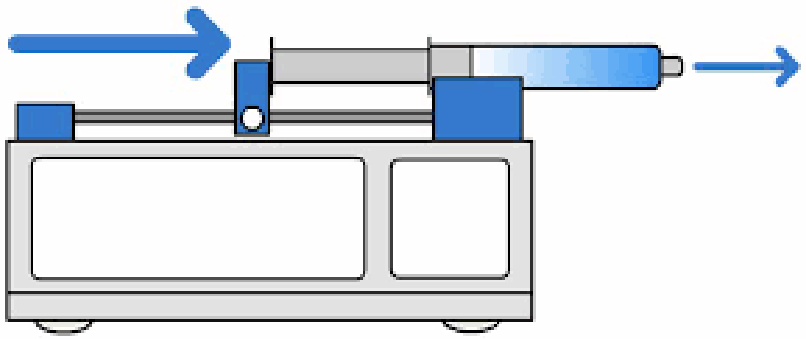




# Pumps

- Pump Curves
- Types of Pump
  - Low viscosity pumps
  - High viscosity pumps
- Others
  - Syringe Pump
  - Bladders, bellows, solenoid diaphragms, etc.
  - Specialty vacuum pumps
- Head Pressure
  - Pressure measurement
  - Piping resistance
- Self-priming pumps
- Pulsatile vs. Constant



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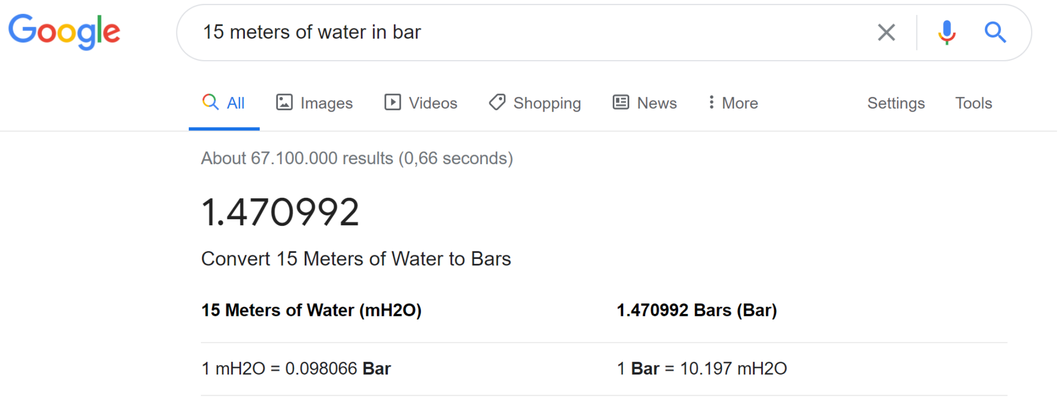
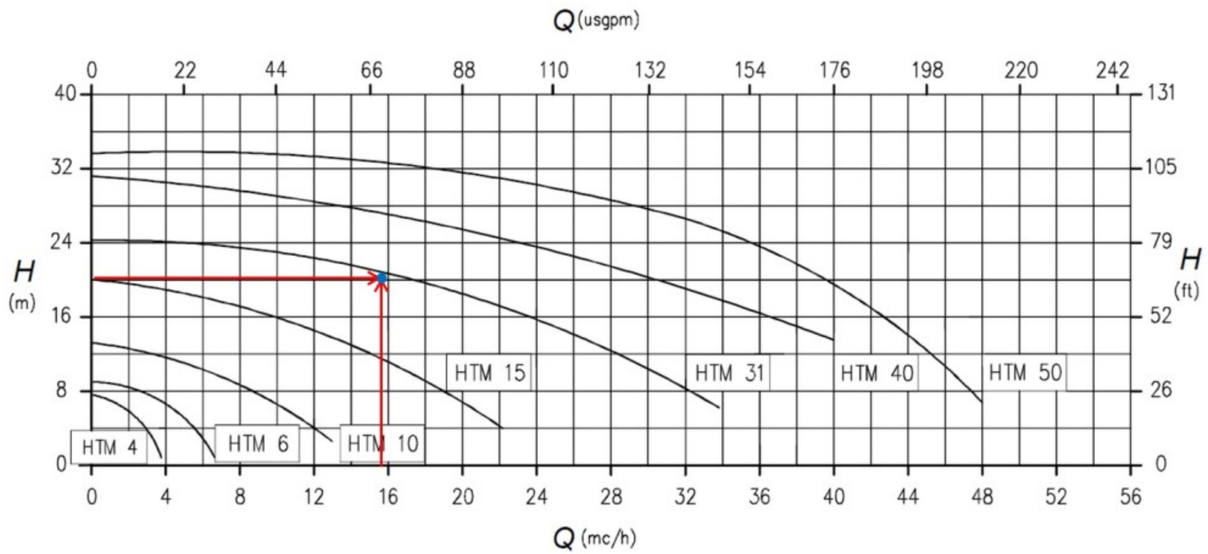
# Pump Curves

- Head (in length) vs. Flow (in volume/time)
- Head -> Pressure
  - Convert

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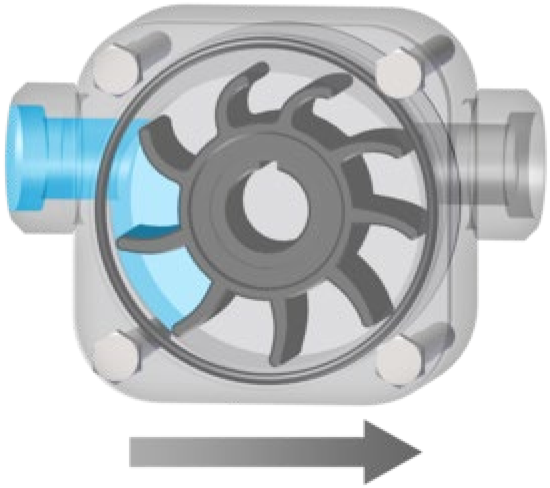
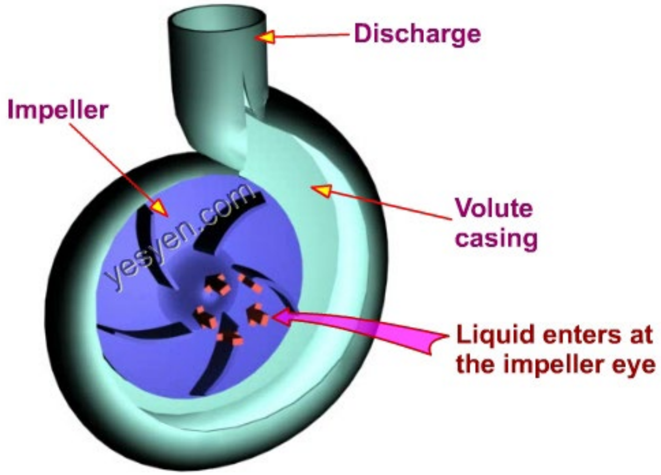
# Pump Types: Low Viscosity

- Fans
- Impeller
- Centrifugal



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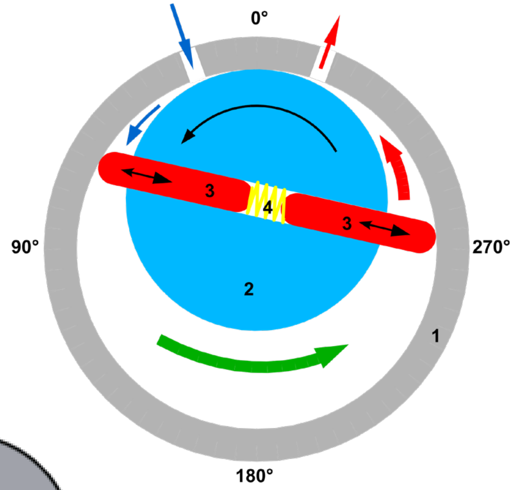
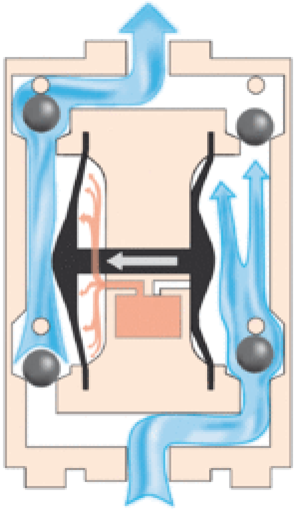
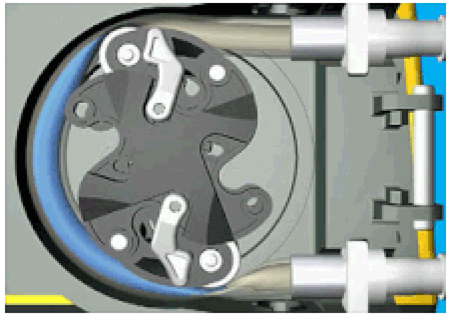
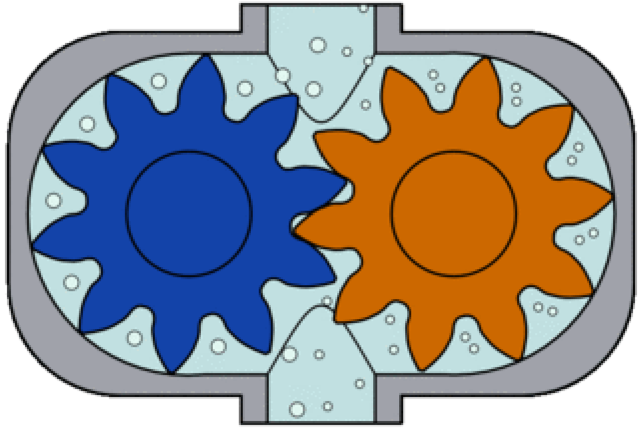
# Pump Types: High Viscosity

- Scroll Pump
- Vane Pump
- External Gear Pump
- Internal Gear Pump
- Peristaltic Pump
- Diaphragm Pump







# Valves

- Valve Functions:
  - Check Valve
    - Tesla Valve
  - On/Off Valve
  - Regulators
    - Pressure output control
  - Relief Valve
  - Throttling Valve
    - Flow rate output control

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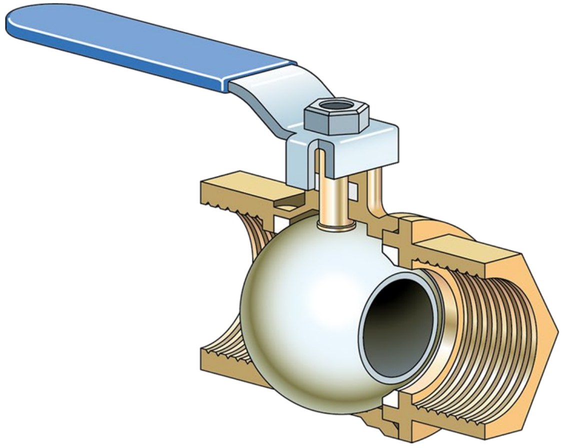
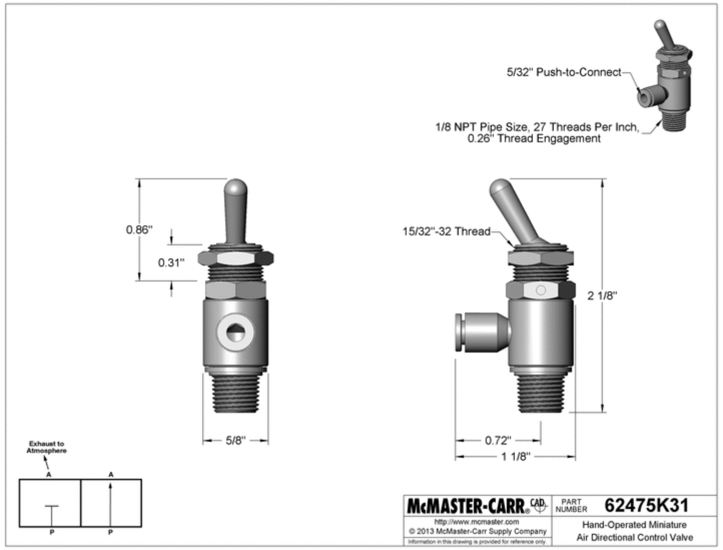
# On/Off Valves

- Toggle Valve
- Ball Valve
  - Typically hand-driven
  - Typically on/off, but can be throttling
- Solenoid Valve
  - Electrically controlled
  - Heat when active
  - Bi-latching available



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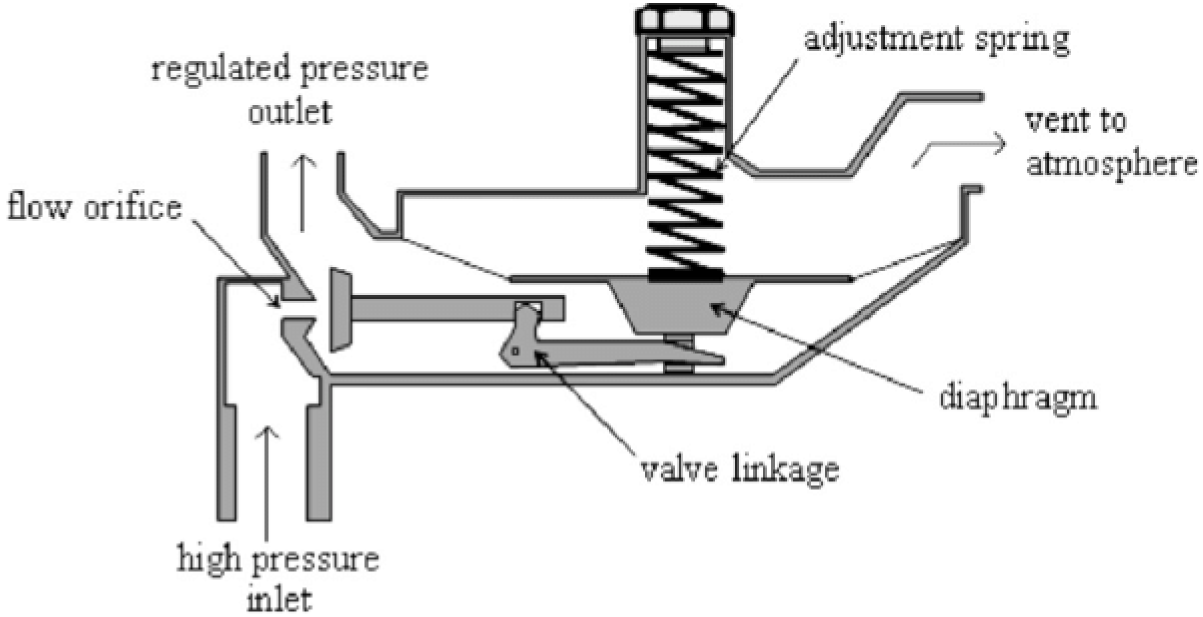
# Regulators

- Regulators use known area and springs to adjust pressure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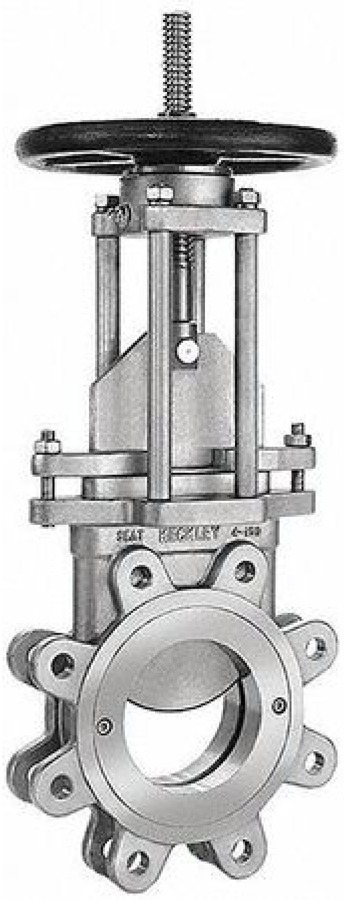
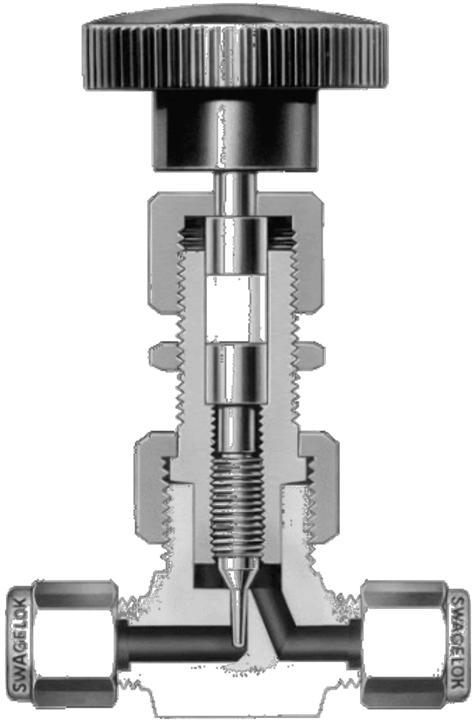
# Throttling Valves

- Needle Valve
  - Useful as flow-controller in pneumatics!
- Gate/Knife Valve
- Butterfly Valve
- Flow Control Valve
- Dampers



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Engineering is about creativity.

Look for those opportunities to think outside the cylinder.

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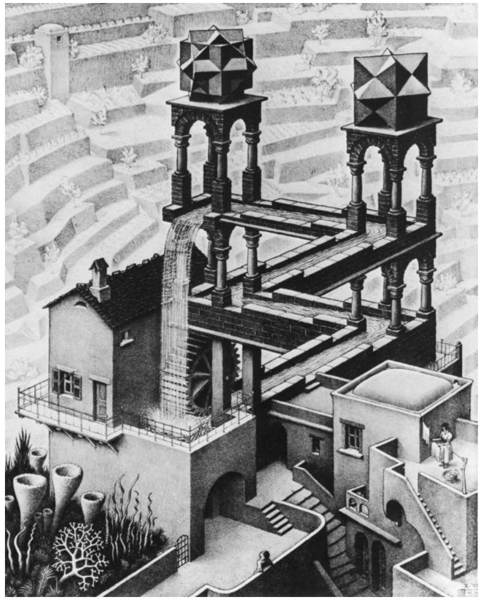

# Questions?  Office Hours!

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