$$E = mc^2$$

m

F

$$F = ma$$

a

$a_{gravity}$

g

$$F = m\frac{dv}{dt}$$

v

t

$$F = m\frac{d^2x}{dt^2}$$

x

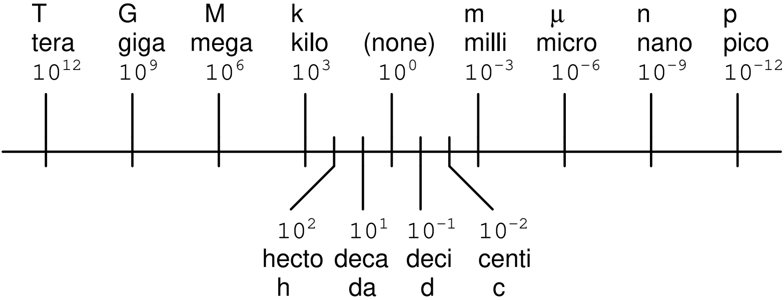
ρ

γ

$F_{weight} = mg$ Weight and Mass

$\gamma = \rho g$ Weight density and Mass density

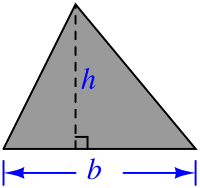
METRIC PREFIX SCALE



2

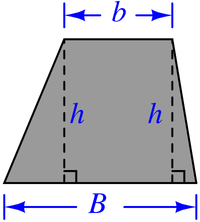
3

Triangle

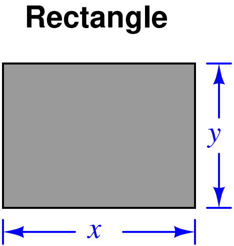


Area $A = \frac{1}{2} bh$

Trapezoid

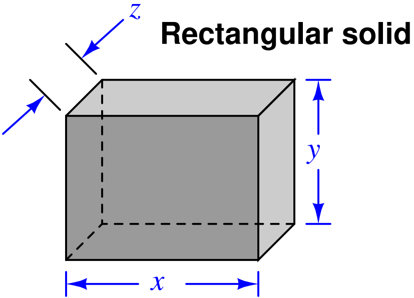


Area $A = \frac{1}{2} (b + B)h$



Perimeter $P = 2x + 2y$

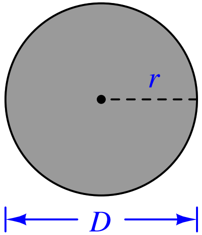
Area $A = xy$



Surface area $A = 2xy + 2yz + 2xz$

Volume $V = xyz$

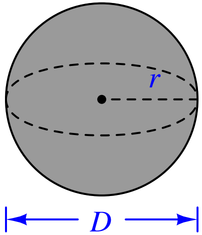
Circle



Circumference $C = \pi D = 2\pi r$

Area $A = \pi r^2$

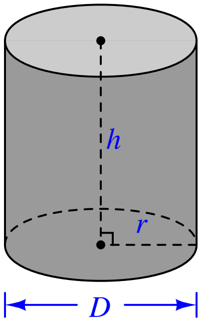
Sphere



Surface area $A = 4\pi r^2$

Volume $V = \frac{4}{3} \pi r^3$

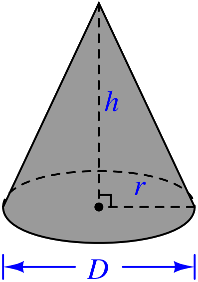
Right circular cylinder



Surface area $A = 2\pi r^2 + 2\pi r h$

Volume $V = \pi r^2 h$

Cone

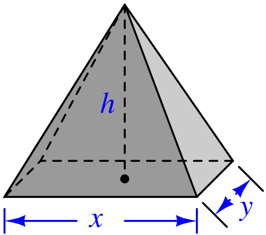


Surface area $A = \pi r \sqrt{r^2 + h^2} + \pi r^2$

Volume $V = \frac{1}{3} \pi r^2 h$

Note: the volume of any pyramid or cone is one-third the product of its height (h) and the area of its base.

Tetrahedron



Volume $V = \frac{1}{3} xyh$

$$P = IV$$

P

I

V

$$P = IV$$

$$[\text{Watts}] = [\text{Amperes}] \times [\text{Volts}] \qquad \text{or} \qquad [\text{W}] = [\text{A}][\text{V}]$$

$$\left[\frac{\text{Joules}}{\text{Seconds}}\right] = \left[\frac{\cancel{\text{Coulombs}}}{\text{Seconds}}\right] \times \left[\frac{\text{Joules}}{\cancel{\text{Coulombs}}}\right] \qquad \text{or} \qquad \left[\frac{\text{J}}{\text{s}}\right] = \left[\frac{\cancel{\text{C}}}{\text{s}}\right]\left[\frac{\text{J}}{\cancel{\text{C}}}\right]$$

$$35 \text{ qt} = ??? \text{ gal}$$

$$\frac{35 \text{ qt}}{1}$$

$$\left(\frac{35\text{ qt}}{1}\right)\left(\frac{1\text{ gal}}{4\text{ qt}}\right)$$

$$\left(\frac{35\ \cancel{\text{qt}}}{1}\right)\left(\frac{1\ \text{gal}}{4\ \cancel{\text{qt}}}\right) = 8.75\ \text{gal}$$

$$\left(\frac{40\ \cancel{\text{gal}}}{1}\right)\left(\frac{128\ \text{fl. oz.}}{1\ \cancel{\text{gal}}}\right) = 5120\ \text{fl. oz}$$

$$\left(\frac{5.5\ \cancel{\text{pt}}}{1}\right)\left(\frac{231\ \text{in}^3}{8\ \cancel{\text{pt}}}\right) = 158.8\ \text{in}^3$$

$$\left(\frac{1170\ \text{ł}}{1}\right)\left(\frac{4\ \text{qt}}{3.7854\ \text{ł}}\right) = 1236\ \text{qt}$$

×

$$\left(\frac{5.5\ \cancel{\text{pt}}}{1}\right)\left(\frac{231\ \text{in}^3}{8\ \cancel{\text{pt}}}\right)\left(\frac{1\ \text{ft}}{12\ \cancel{\text{in}}}\right) = 13.23\ \text{in}^2 \cdot \text{ft}$$

$$\frac{1}{12}\frac{\text{ft}}{\text{in}}$$

$$\left(\frac{5.5\ \text{pt}}{1}\right)\left(\frac{231\ \text{in}^3}{8\ \text{pt}}\right)\left(\frac{1\ \text{ft}}{12\ \text{in}}\right)^3$$

$$\left(\frac{5.5\ \text{pt}}{1}\right)\left(\frac{231\ \text{in}^3}{8\ \text{pt}}\right)\left(\frac{1^3\ \text{ft}^3}{12^3\ \text{in}^3}\right)$$

1^3

$$12^3$$

$$\left(\frac{5.5\ \cancel{\text{pt}}}{1}\right)\left(\frac{231\ \cancel{\text{in}}^3}{8\ \cancel{\text{pt}}}\right)\left(\frac{1\ \text{ft}^3}{1728\ \cancel{\text{in}}^3}\right) = 0.0919\ \text{ft}^3$$

$$\left(\frac{205\ \cancel{\text{ft}^3}}{\cancel{\text{min}}}\right)\left(\frac{1^3\ \text{yd}^3}{3^3\ \cancel{\text{ft}^3}}\right)\left(\frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}}\right)\left(\frac{24\ \cancel{\text{hr}}}{1\ \text{day}}\right) = 10933.3\ \text{yd}^3/\text{day}$$

=

O

—

10

2

4

10^{-5}

$\approx$

σ

10^{23}

$$6.02214179 \times 10^{23}$$

$$0.00000030 \times 10^{23}$$

N_A

-1

k

10^{-23}

e

10^{-19}

10^4

G

10^{-11}

R

h

$$10^{-34}$$

10^{-8}

4

2.

C

$$\left[\frac{\text{Joules}}{\text{Seconds}}\right] = \left[\frac{\text{Coulombs}}{\text{Seconds}}\right] \times \left[\frac{\text{Joules}}{\text{Coulombs}}\right] \qquad \text{or} \qquad \left[\frac{\text{J}}{\text{s}}\right] = \left[\frac{\text{C}}{\text{s}}\right]\left[\frac{\text{J}}{\text{C}}\right]$$

$$[J] = \frac{[\mathrm{kg}][\mathrm{m}^2]}{[\mathrm{s}^2]}$$

Physical quantity	**SI unit**	**SI symbol**
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

$$E = mc^2$$

E

$$3 \times 10^8$$

$$F = ma$$

$100.\overline{0}$

W

T

$$\vec{F}$$

$$W = \vec{F} \cdot \vec{x}$$

$\vec{x}$

$$W = Fx$$

$$W = -Fx$$

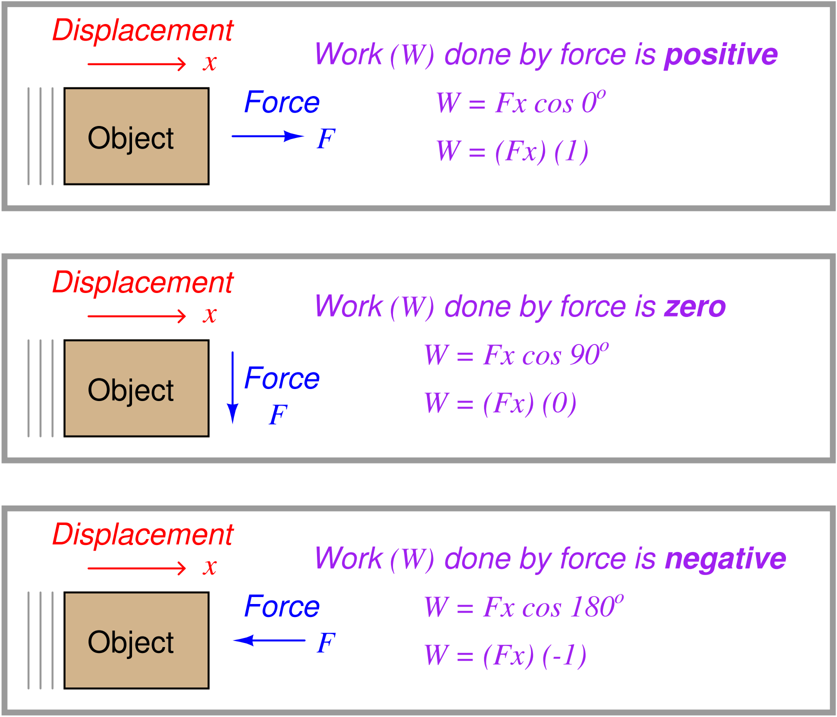
$\cos\theta$

$$W = Fx\cos\theta$$

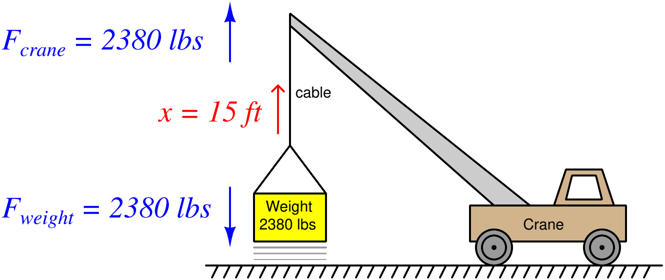
θ

$$\cos 0^o = 1$$

$$\cos 180^o = -1$$


Displacement
x
Object
Force
F
Work (W) done by force is positive
W = Fx cos 0°
W = (Fx) (1)
Displacement
x
Object
Force
F
Work (W) done by force is zero
W = Fx cos 90°
W = (Fx) (0)
Displacement
x
Object
Force
F
Work (W) done by force is negative
W = Fx cos 180°
W = (Fx) (-1)

Crane lifts weight 15 feet up



Crane does work on weight $W_{crane} = (2380\ lb)(15\ ft)(\cos 0^o) = +35700$ ft-lbs

Work is done on the weight $W_{weight} = (2380\ lb)(15\ ft)(\cos 180^o) = -35700$ ft-lbs

$$W_{crane} = +35700$$

$$F_{crane} =$$

$x =$

$$\theta = 0$$

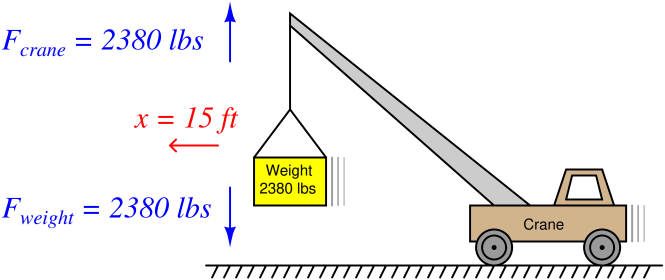
$$W_{weight} = -35700$$

$$F_{weight} =$$

$$\theta = 180^o$$

$$\theta = 90^o$$

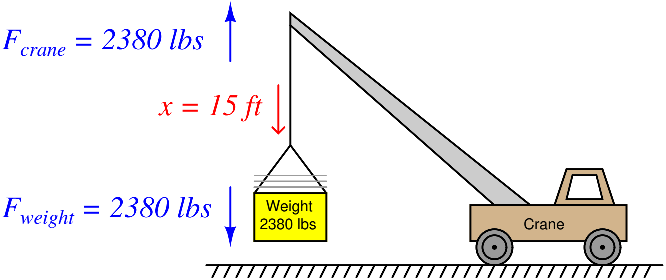
Crane moves weight 15 feet along the ground



No work done on or by the crane $W_{crane} = (2380 \text{ lb})(15 \text{ ft})(\cos 90^o) = 0$ ft-lbs

No work done on or by the weight $W_{weight} = (2380 \text{ lb})(15 \text{ ft})(\cos -90^o) = 0$ ft-lbs

Crane lowers weight 15 feet back to ground



Work is done on the crane $W_{crane} = (2380\ lb)(15\ ft)(\cos 180^o) = -35700$ ft-lbs

Weight does work on crane $W_{weight} = (2380\ lb)(15\ ft)(\cos 0^o) = +35700$ ft-lbs

$$W = \vec{F} \cdot \vec{x}$$

$$F = mg$$

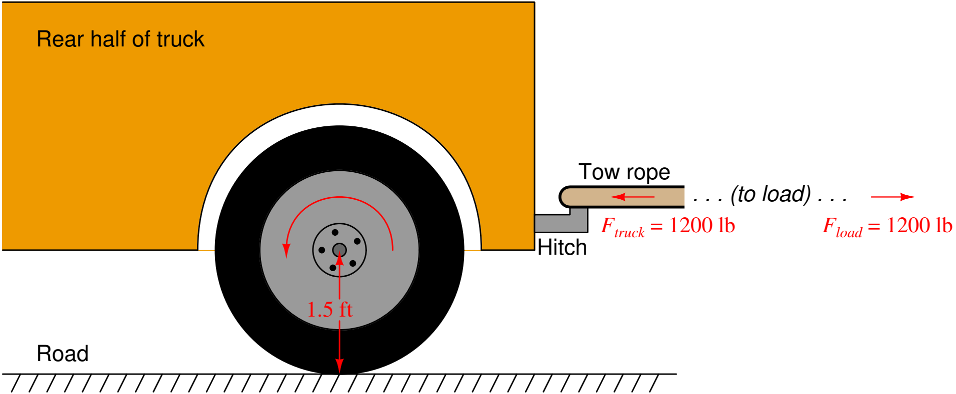
$$x = h$$

$$W = E_P$$

$$E_p = mgh$$

$$E_p$$

$$E_p = mgh$$



Rear half of truck
Tow rope
. . . (to load) . . .
F_{truck} = 1200 lb
F_{load} = 1200 lb
Hitch
1.5 ft
Road

$$W_{truck} = Fx\cos\theta$$

$$W_{truck} = (1200 \text{ lb})(40 \text{ ft}) \cos 0^o$$

$$W_{truck} = 48000 \text{ lb-ft}$$

$$W_{load} = Fx\cos\theta$$

$$W_{load} = (1200 \text{ lb})(40 \text{ ft}) \cos 180^o$$

$$W_{load} = -48000 \text{ lb-ft}$$

$$2 \times \pi \times 1.5$$

$$C = \pi D = 2\pi r$$

$\div$

$\mathcal{T}$

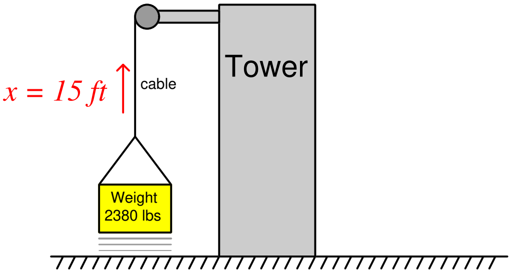
$$\tau = rF$$

$$W = k\tau x$$

2π

$$W = 2\pi\tau x$$

Winch lifts weight 15 feet up



$$W = 2\pi\tau x$$

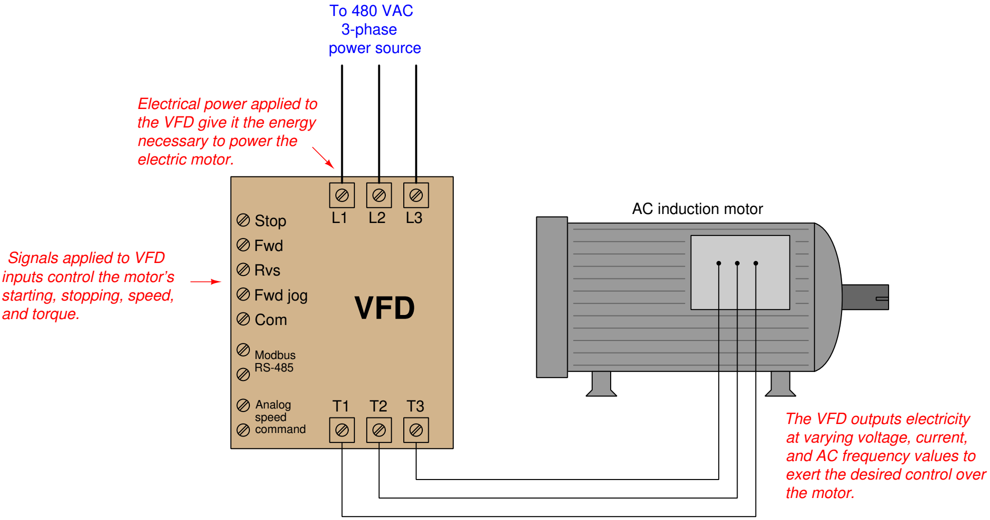
$$\tau = (0.25 \text{ ft})(2380 \text{ lb})$$

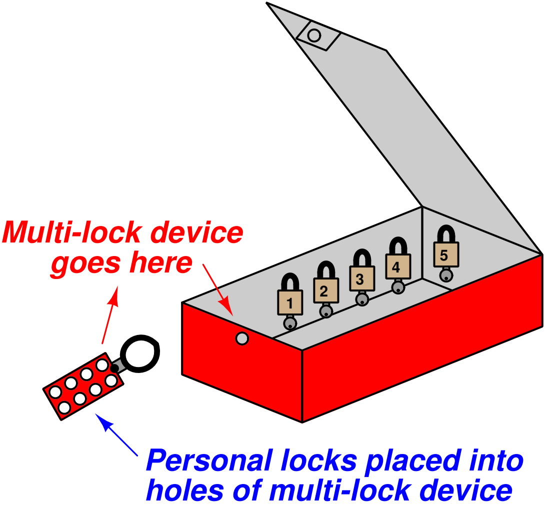
$$\tau = 595 \text{ lb-ft}$$

$$x = \frac{W}{2\pi\tau}$$

$$x = \frac{35700 \text{ ft-lb}}{(2\pi)(595 \text{ lb-ft})}$$

$$x = 9.549 \text{ revolutions}$$


To 480 VAC
3-phase
power source
Electrical power applied to the VFD give it the energy necessary to power the electric motor.
L1
L2
L3
Stop
Fwd
Rvs
Fwd jog
Com
VFD
Modbus
RS-485
Analog
speed
command
T1
T2
T3
Signals applied to VFD inputs control the motor's starting, stopping, speed, and torque.
AC induction motor
The VFD outputs electricity at varying voltage, current, and AC frequency values to exert the desired control over the motor.


Multi-lock device goes here
1
2
3
4
5
Personal locks placed into holes of multi-lock device

Energy Control Procedure

Revision Number & Date one *7/23/2009*

Ingersol Rand KVS 412 *Minor maintenance*

Items to be completed before proceeding

Initial all steps

Initials	Step	Item
TZ	1	Only qualified \authorized employees are allowed to complete this task.
TZ	2	Verify equipment has not changed before relying on this procedure
TZ	3	Redline and update any changes & notify effected employee if required
TZ	4	Notify all effected employees before starting
TZ	5	Notify Gas Control
TZ	6	If the crane is to be used complete crane inspection
TZ	7	Complete all required documentation
TZ	8	Indentify required forms, Use updated forms
TZ	9	Hot Work Permit WGP- 0059 Procedure 65.0020.05
TZ	10	Crane pre use inspection. Form Attachment A Procedure 65.00.08.06
	11	Drawing ######## Not available at this time

Date & Time	9-28-11 10:00 a.m.
Authorized Technician	Thiessen Collins
Scope of work	Spark plug wires expansion inlet

Out of Service

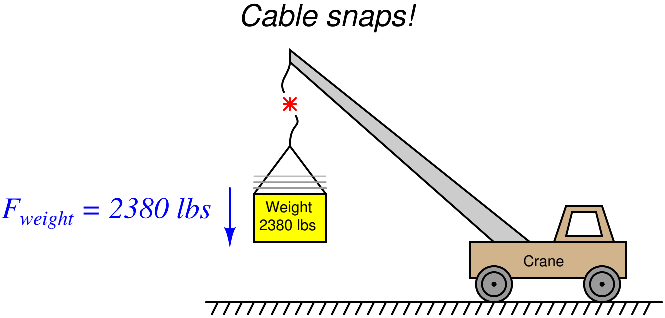
Step	Initials	Lock #	Task
1	TZ	1	Tag out unit mode switch in off position
2	TZ	2	Close starting air block valve. Lock and tag.
3	TZ	3	Close fuel block valve. Lock and tag.

Return to Service

Step	Initials	Lock # off	Task
1			Remove tag from unit mode switch. Place switch in local manual
2			Remove lock from starting air block valve open valve.
3			Remove tag from fuel block valve open valve
4			Reset unit panel alarms
5			Place unit panel selector switch in remote auto.

Affected employee log

Lock	On	Off	Name
1	10:00		[illegible]
CW	10:40		[illegible]
CW		12:40	[illegible]


Cable snaps!
F_{weight} = 2380 lbs
Weight
2380 lbs
Crane

$$E_k = \frac{1}{2}mv^2$$

$$E_k$$

$$E_p + E_k = \text{constant}$$

$$E_p \text{ (initial)} = E_k \text{ (final)}$$

$$mgh_i = \frac{1}{2}mv_f^2$$

$$gh_i = \frac{1}{2}v_f^2$$

$$E_p = mgh \qquad \text{Potential energy due to elevation}$$

$$E_k = \frac{1}{2}mv^2 \qquad \text{Kinetic energy due to velocity}$$

$E = mc^2$ Mass-to-energy conversion

$$\frac{[\mathrm{kg}][\mathrm{m}^2]}{[\mathrm{s}^2]} = [\mathrm{kg}]\left[\frac{\mathrm{m}}{\mathrm{s}^2}\right][\mathrm{m}] \qquad \text{Potential energy due to elevation}$$

$$\frac{[\mathrm{kg}][\mathrm{m}^2]}{[\mathrm{s}^2]} = [\mathrm{kg}]\left[\frac{\mathrm{m}}{\mathrm{s}}\right]^2 \qquad \text{Kinetic energy due to velocity}$$

$$\frac{[\mathrm{kg}][\mathrm{m}^2]}{[\mathrm{s}^2]} = [\mathrm{kg}]\left[\frac{\mathrm{m}}{\mathrm{s}}\right]^2 \qquad \text{Mass-to-energy conversion}$$

$$P = \frac{dW}{dt}$$

$$F = kx$$

$$F = -kx$$

$$E_p = Fx$$

$$E_p = Fx$$

$$F\,dx$$

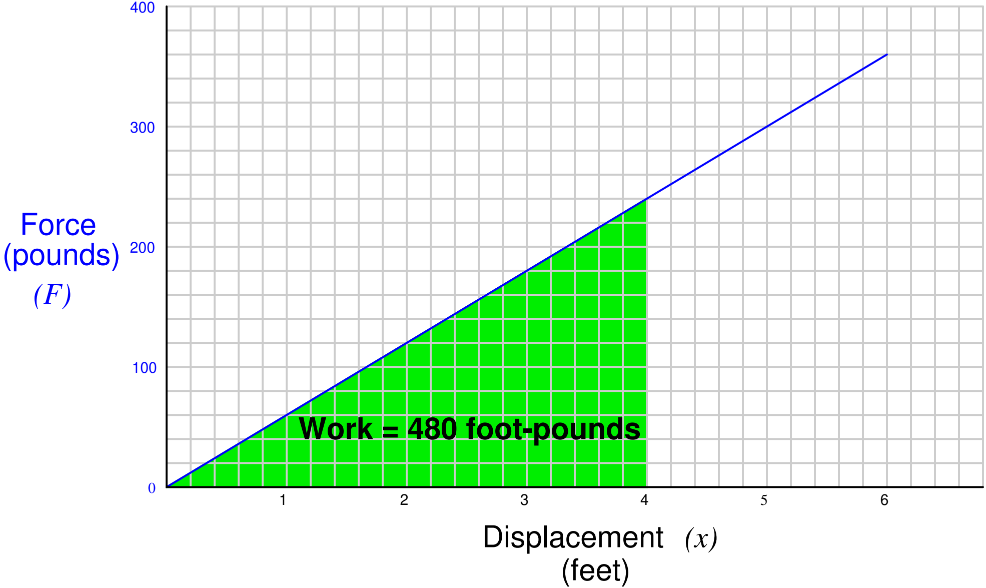
$$kx\,dx$$

$$\int$$

$$E_p = \int kx \, dx$$

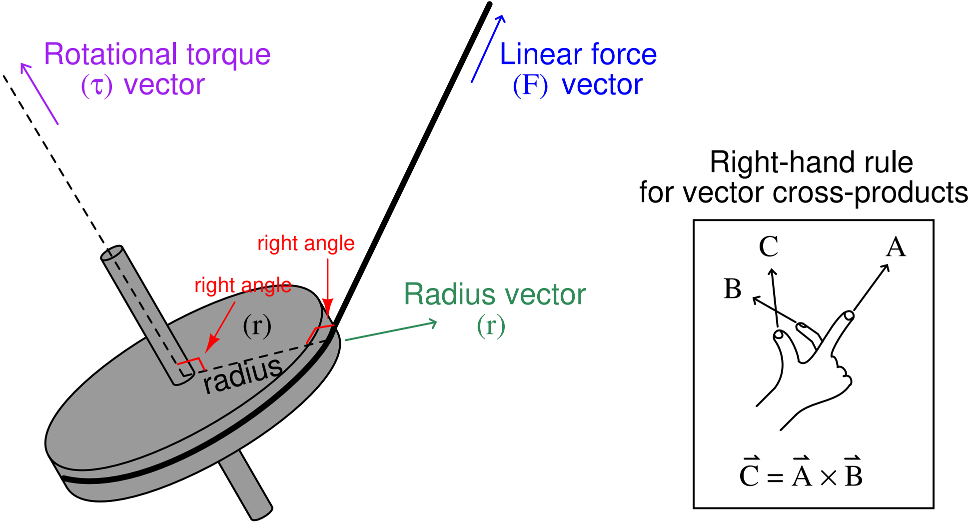
$$E_p = \frac{1}{2}kx^2 + E_0$$

$$E_0$$



Force
(pounds)
(F)
400
300
200
100
0
1
2
3
4
5
6
Work = 480 foot-pounds
Displacement (x)
(feet)

$$E_p = \frac{1}{2}kx^2$$

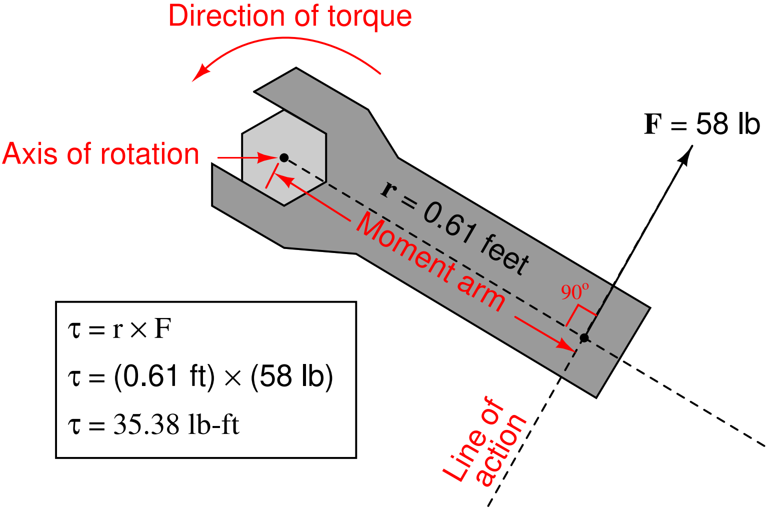


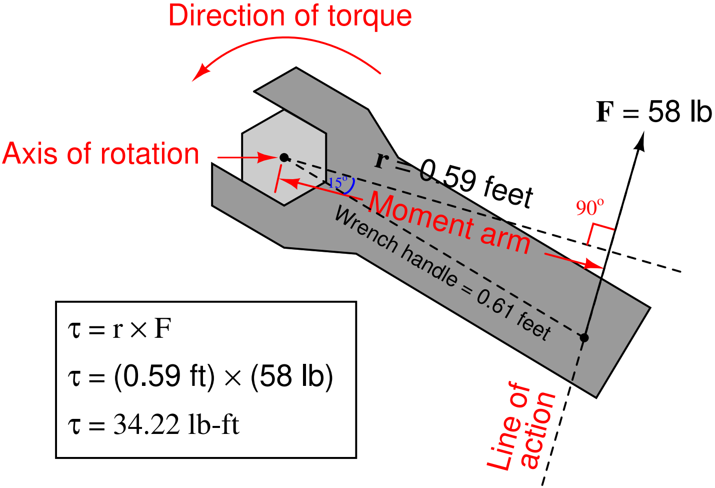
Rotational torque
(τ) vector
Linear force
(F) vector
right angle
right angle
(r)
radius
Radius vector
(r)
Right-hand rule
for vector cross-products
C
B
A
$\vec{C} = \vec{A} \times \vec{B}$

$\vec{r}$

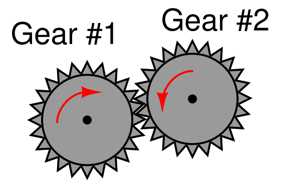
$\vec{\mathcal{T}}$

$$\vec{\tau} = \vec{r} \times \vec{F}$$


Direction of torque
F = 58 lb
Axis of rotation
r = 0.61 feet
Moment arm
90°
Line of action
τ = r × F
τ = (0.61 ft) × (58 lb)
τ = 35.38 lb-ft



Direction of torque
Axis of rotation
F = 58 lb
r = 0.59 feet
15°
Moment arm
90°
Wrench handle = 0.61 feet
Line of action
τ = r × F
τ = (0.59 ft) × (58 lb)
τ = 34.22 lb-ft


Gear #1
Gear #2

$$\frac{\tau_1}{\tau_2} = \frac{n_1}{n_2}$$

τ_1

$$\tau_2$$

n_1

n_2

ω

$$\frac{\omega_1}{\omega_2} = \frac{n_2}{n_1}$$

ω_1

ω_2

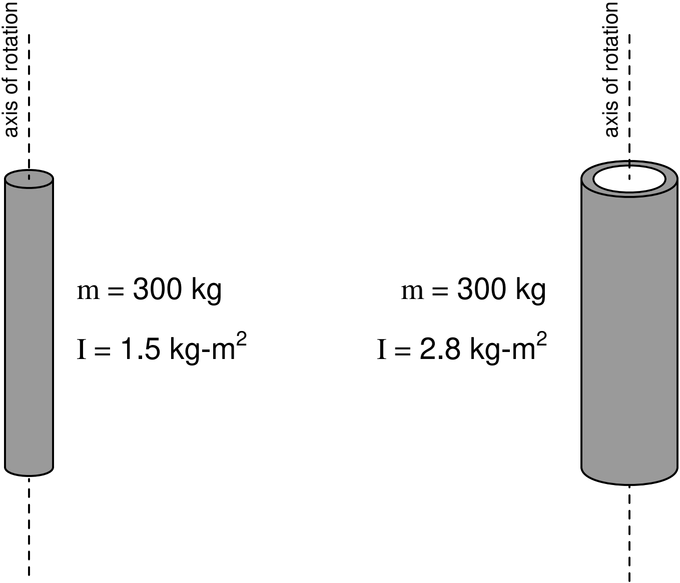
Linear quantity, symbol, and unit	**Rotational quantity, symbol, and unit**
Force (F) N	Torque (τ) N-m
Linear displacement (x) m	Angular displacement (θ) $radian$
Linear velocity (v) m/s	Angular velocity (ω) rad/s
Linear acceleration (a) m/s^2	Angular acceleration (α) rad/s^2
Mass (m) kg	Moment of Inertia (I) kg-m^2

$$F = ma \qquad \tau = I\alpha$$

$$v = \frac{dx}{dt} \qquad \text{(Velocity as the time-derivative of displacement)} \qquad \omega = \frac{d\theta}{dt}$$

$$a = \frac{dv}{dt} \qquad \text{(Acceleration as the time-derivative of velocity)} \qquad \alpha = \frac{d\omega}{dt}$$

$$a = \frac{d^2x}{dt^2} \qquad \text{(Acceleration as the second time-derivative of displacement)} \qquad \alpha = \frac{d^2\theta}{dt^2}$$

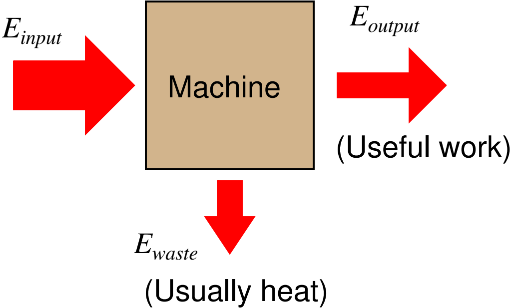


axis of rotation
m = 300 kg
I = 1.5 kg-m^2
axis of rotation
m = 300 kg
I = 2.8 kg-m^2

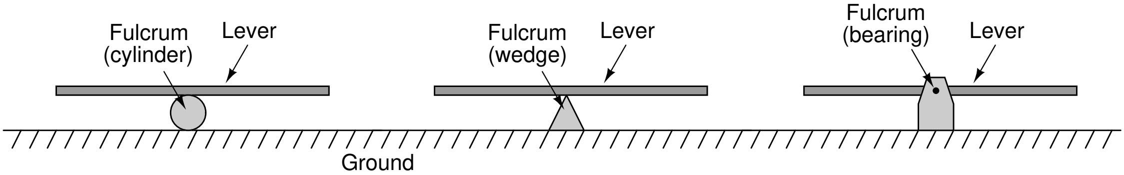
$$W = Fx \qquad\qquad W = \tau\theta$$

$$E_k = \frac{1}{2}mv^2 \qquad E_k = \frac{1}{2}I\omega^2$$

η



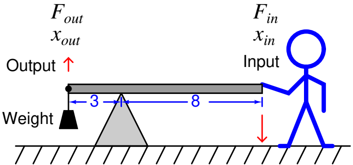
$$\text{Efficiency} = \eta = \frac{E_{output}}{E_{input}}$$


Fulcrum (cylinder)
Lever
Fulcrum (wedge)
Lever
Fulcrum (bearing)
Lever
Ground

$$\frac{8}{3}$$

First-class lever

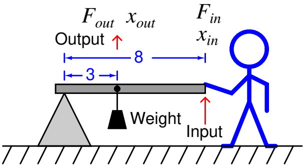
(Output and input on opposite sides of the fulcrum)



$$\frac{F_{out}}{F_{in}} = \frac{x_{in}}{x_{out}} = \frac{8}{3}$$

Second-class lever

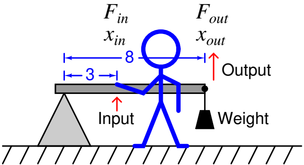
(Output between input and the fulcrum)



$$\frac{F_{out}}{F_{in}} = \frac{x_{in}}{x_{out}} = \frac{8}{3}$$

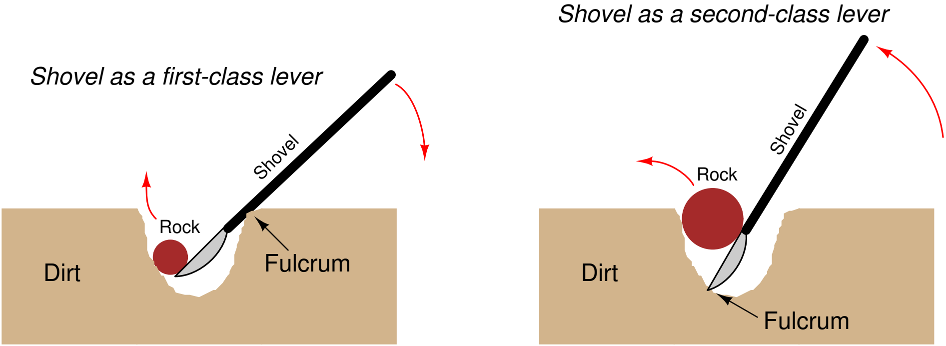
Third-class lever

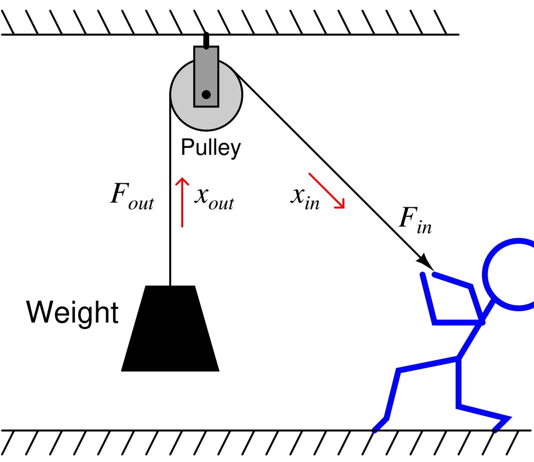
(Input between output and the fulcrum)



$$\frac{F_{out}}{F_{in}} = \frac{x_{in}}{x_{out}} = \frac{3}{8}$$

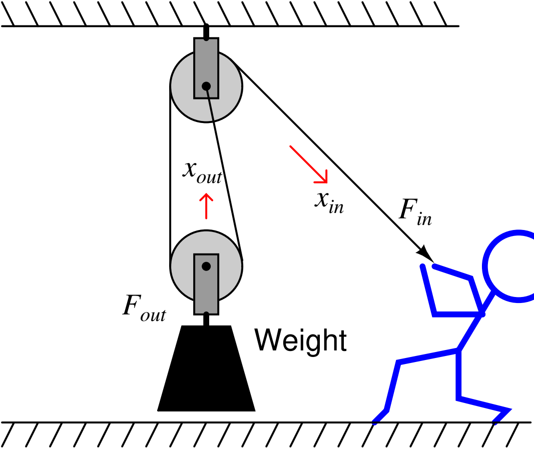
$$\frac{F_{out}}{F_{in}}$$


Shovel as a first-class lever
Shovel
Rock
Fulcrum
Dirt
Shovel as a second-class lever
Shovel
Rock
Dirt
Fulcrum



Pulley
F_{out}
x_{out}
x_{in}
F_{in}
Weight

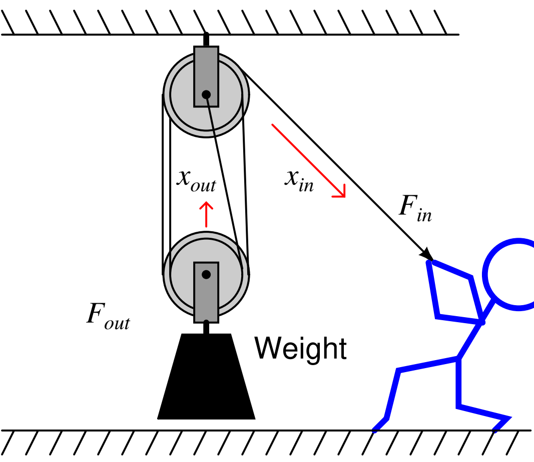
$$F_{out} = F_{in}$$



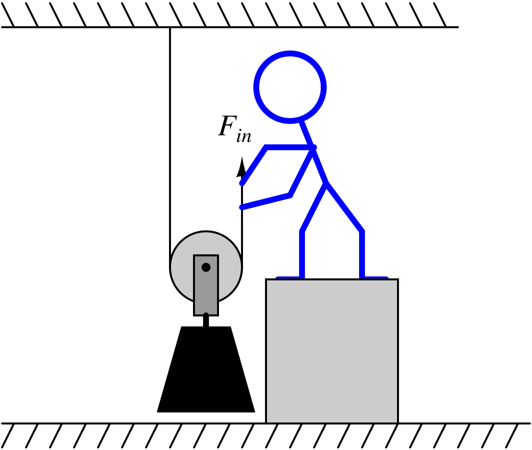
x_{out}
x_{in}
F_{in}
F_{out}
Weight

$$F_{in}$$

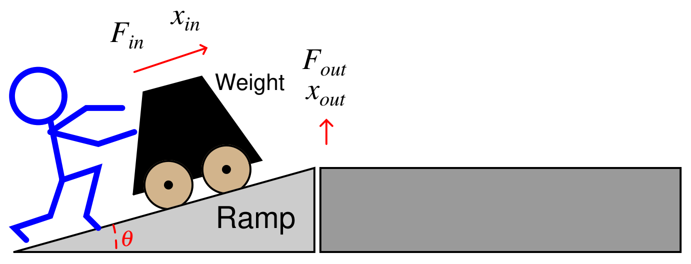
F_{out}



x_{out}
x_{in}
F_{in}
F_{out}
Weight

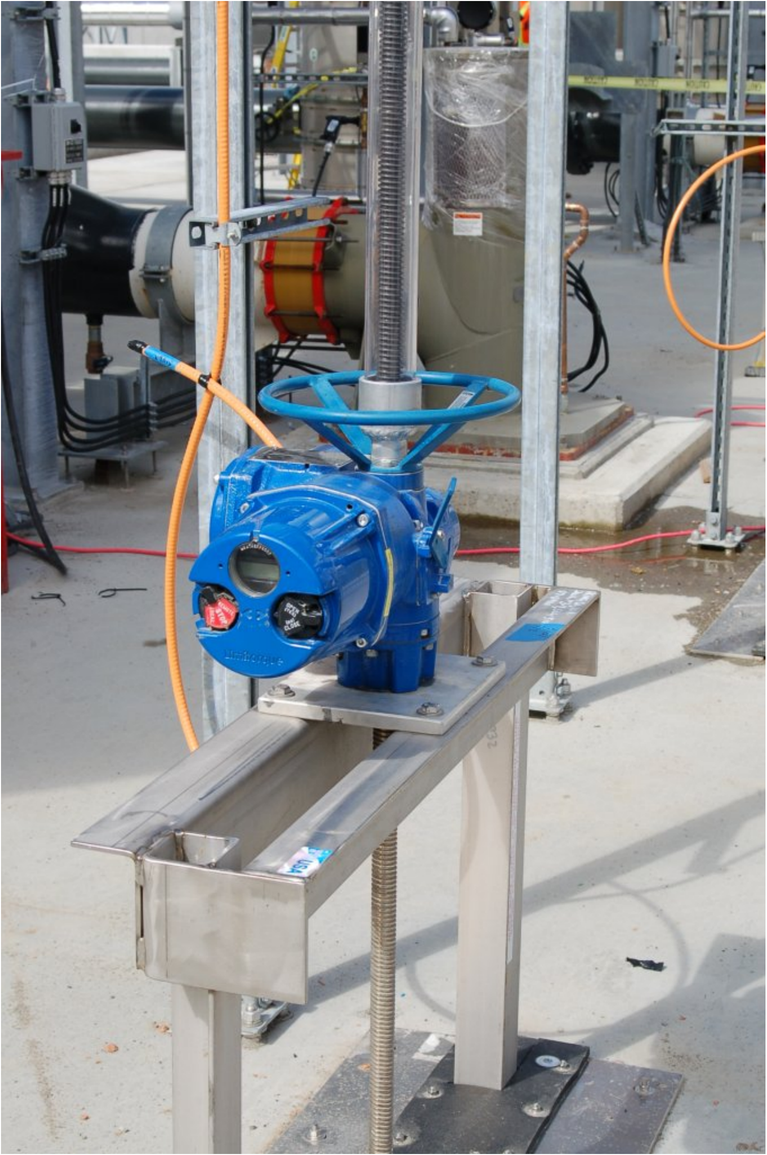

F_{in}

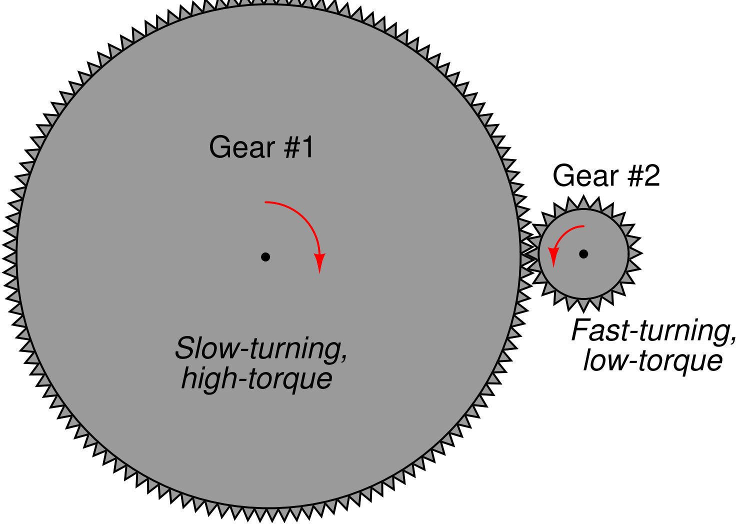

275 TON



F_{in}
x_{in}
Weight
F_{out}
x_{out}
Ramp
θ

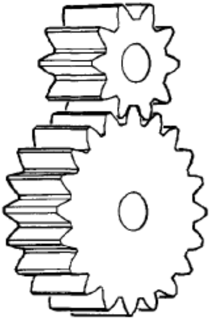
$$\csc\theta = \frac{\text{hypotenuse}}{\text{opposite}}$$


STOP
OPEN
CLOSE

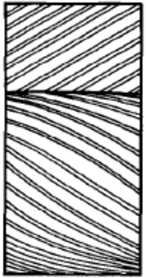

Gear #1
Slow-turning,
high-torque
Gear #2
Fast-turning,
low-torque

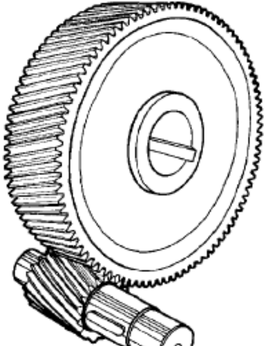
$$\vec{\tau} = \vec{r} \times \vec{F}$$

$$\frac{15}{4}$$

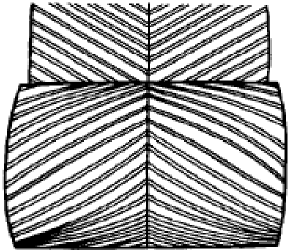


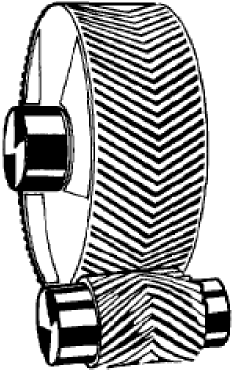
Single-helical teeth



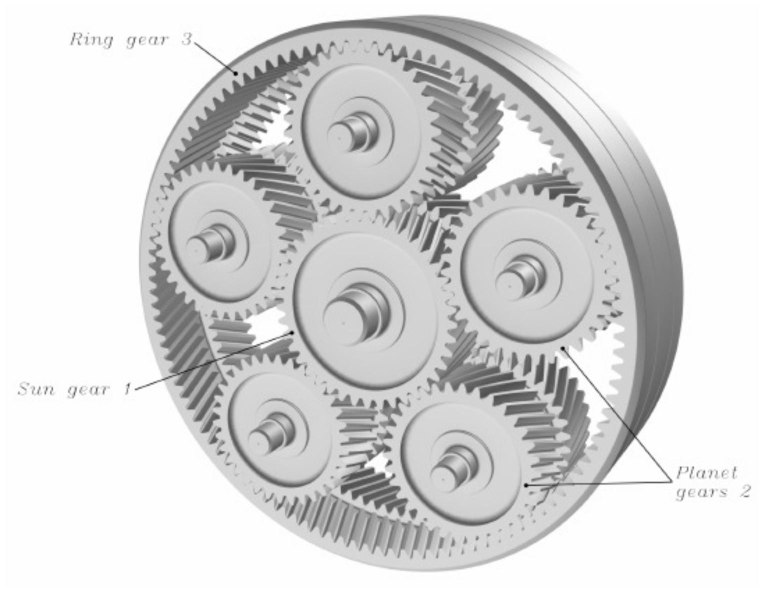


Double-helical teeth






ER MFG. & ENGINE CO.


Ring gear 3
Sun gear 1
Planet
gears 2

TM

$N_{driving}$

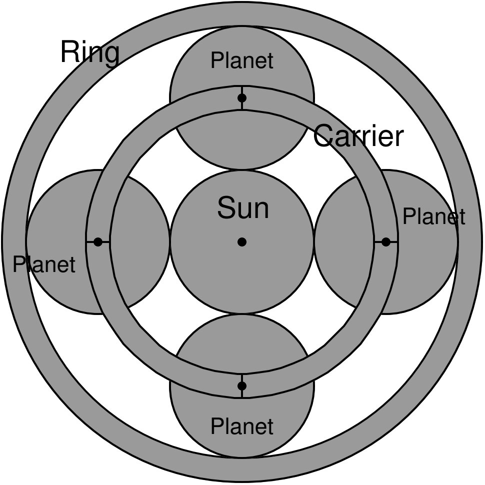
N_{driven}

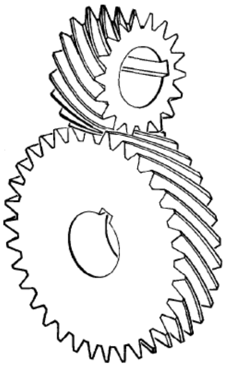
$$x : 1$$

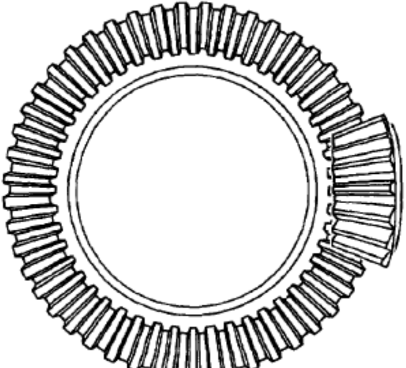
$$\frac{N_r}{N_s} + 1$$

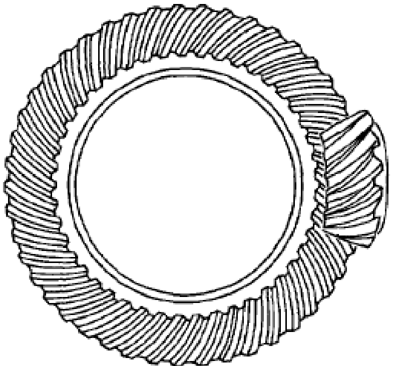
$$\frac{N_s}{N_r} + 1$$

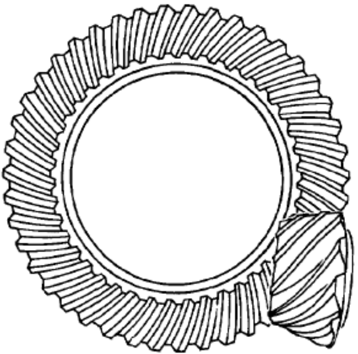
$$-\frac{N_r}{N_s}$$


Ring
Planet
Carrier
Sun
Planet
Planet
Planet

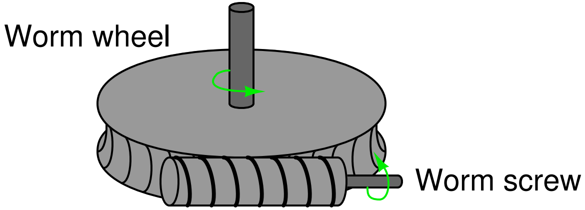


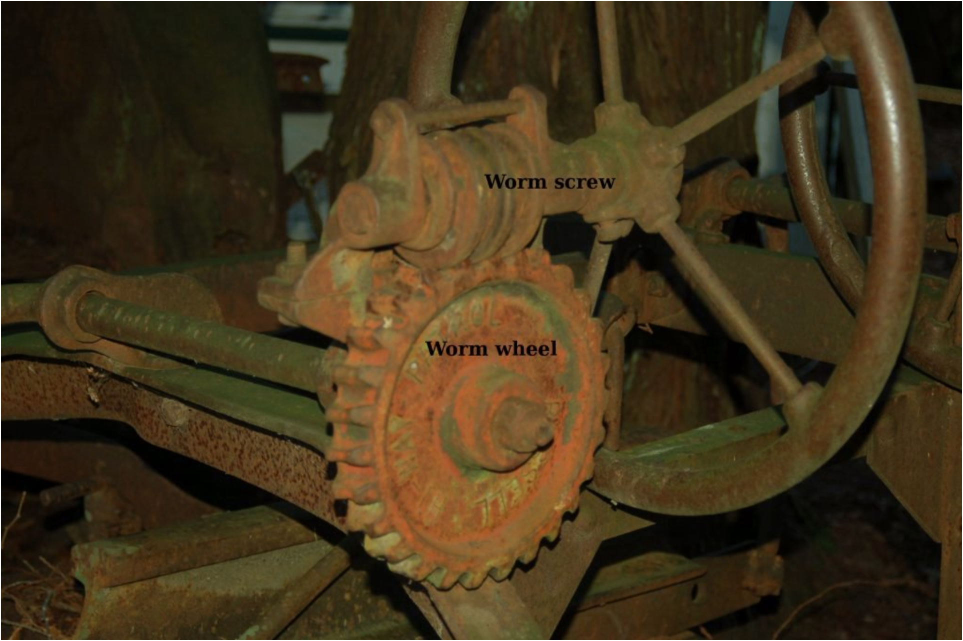


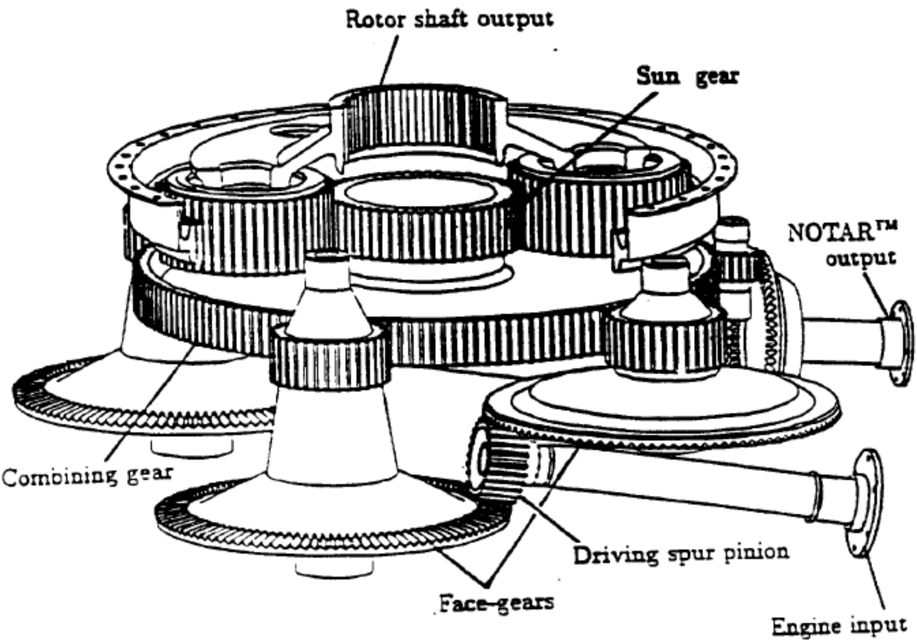




Worm gear mechanism

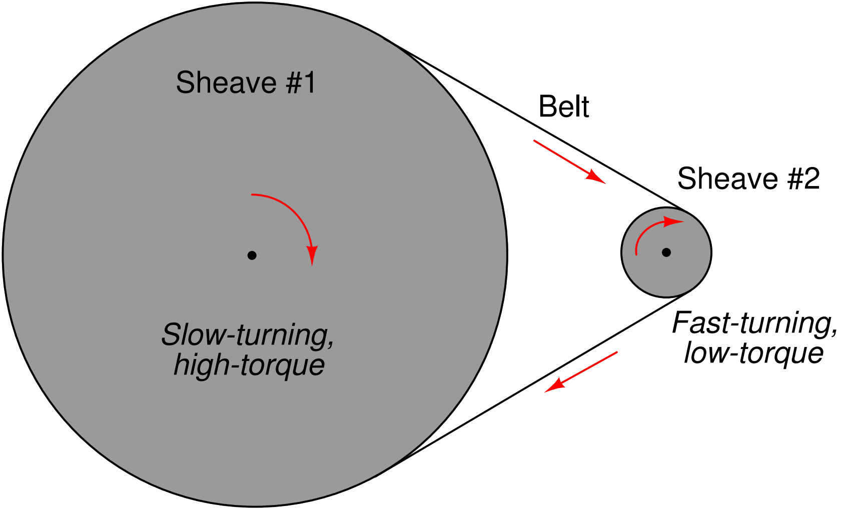


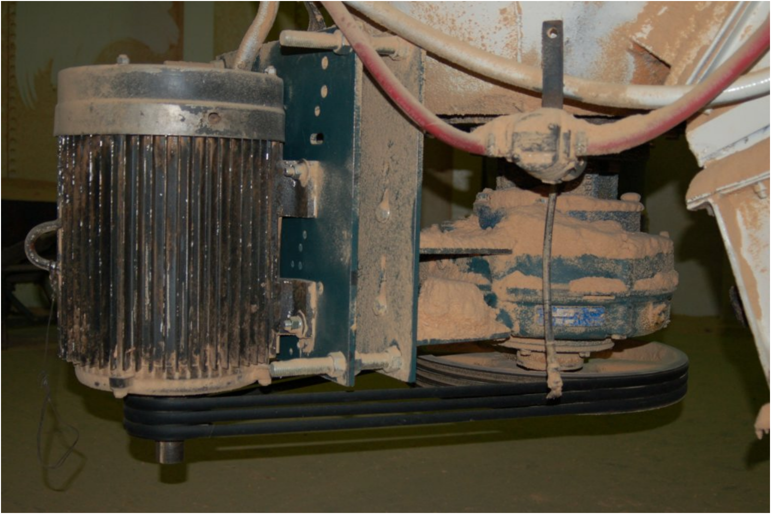

Worm screw
Worm wheel

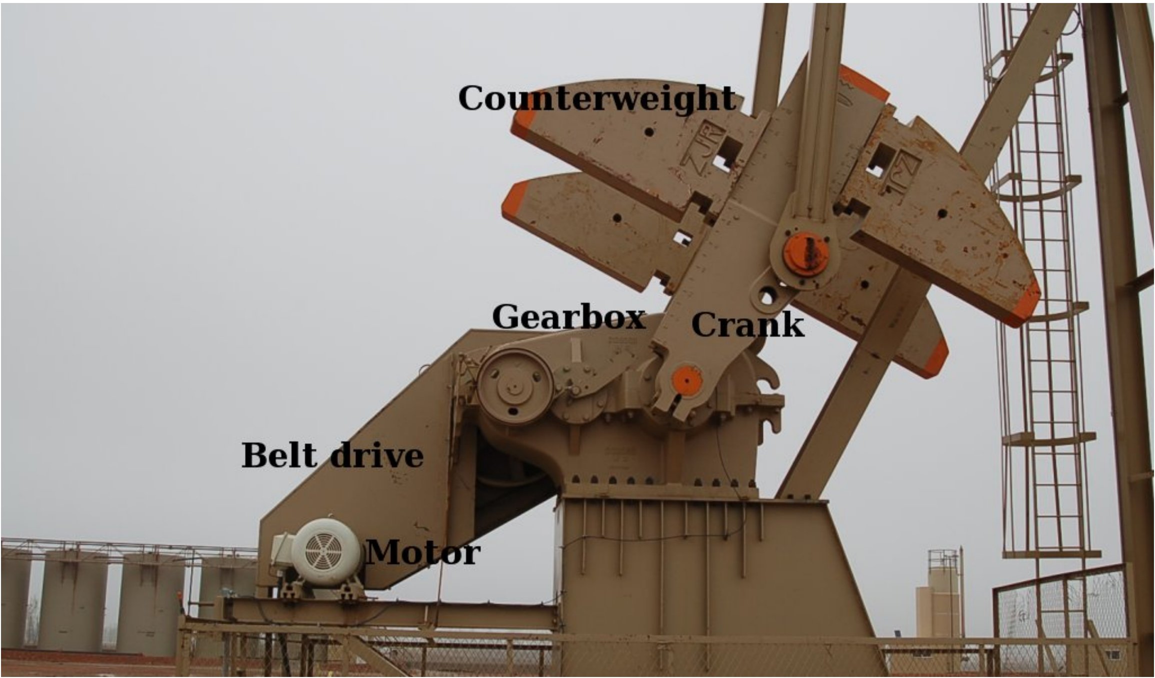

Rotor shaft output
Sun gear
NOTAR™ output
Combining gear
Driving spur pinion
Face-gears
Engine input


W.L.L. 3,335 LB
MSA
The Safety Company
NOT IN STOCK
Rx= 0.03
Ax= 0.02

$$\frac{1}{111.5}$$


Sheave #1
Belt
Sheave #2
Slow-turning,
high-torque
Fast-turning,
low-torque




Counterweight
Gearbox
Crank
Belt drive
Motor


deore

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

$\overline{v}$

$$\overline{v^2}$$

-23

$$-273.15$$

-459.67

Melting or boiling substance	^oC	^oF	K	^oR
Melting point of water (H_2O)	0	32	273.15	491.67
Boiling point of water (H_2O)	100	212	373.15	671.67
Melting point of ammonia (NH_3)	-77.7	-107.9	195.45	351.77
Boiling point of ammonia (NH_3)	-33.6	-28.5	239.55	431.17
Melting point of gold (Au)	1063	1945	1336	2405
Melting point of magnesium (Mg)	651	1203.8	924.2	1663.5
Boiling point of acetone (C_3H_6O)	56.5	133.7	329.65	593.37
Boiling point of propane (C_3H_8)	-42.1	-43.8	231.05	415.87
Boiling point of ethanol (C_2H_6O)	78.4	173.1	351.55	632.77

-77.7

ΔT

Fuel	**Combustion heat** (kcal/g)	**Combustion heat** (BTU/lb)
Methane (CH_4)	13.3	23940
Methanol (CH_4O)	5.43	9767
Ethanol (C_2H_6O)	7.10	12783
Propane (C_3H_8)	12.1	21700
Carbon monoxide (CO)	2.415	4347

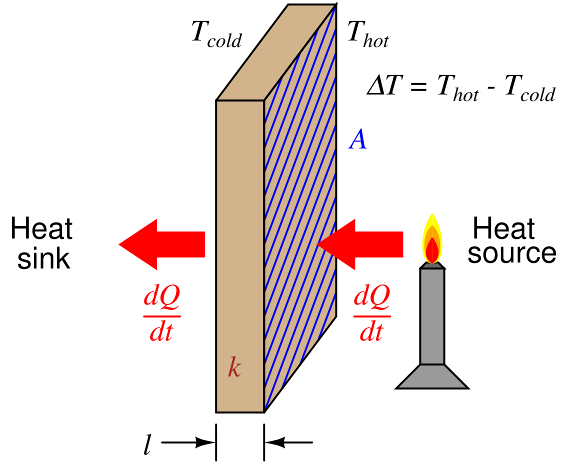
$$\frac{dQ}{dt}$$

$$\frac{dQ}{dt} = e\sigma AT^4$$

A

$$\frac{dQ}{dt} = \frac{kA\Delta T}{l}$$

l



T_{cold}
T_{hot}
$\Delta T = T_{hot} - T_{cold}$
A
Heat sink
Heat source
$\frac{dQ}{dt}$
$\frac{dQ}{dt}$
k
l

$$R = \frac{l}{k}$$

$$l = kR$$

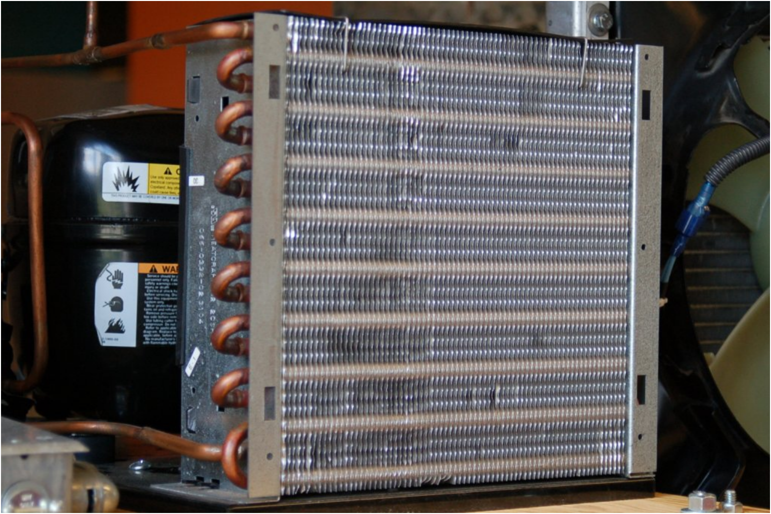
kR

$$\frac{dQ}{dt} = \frac{kA\Delta T}{kR}$$

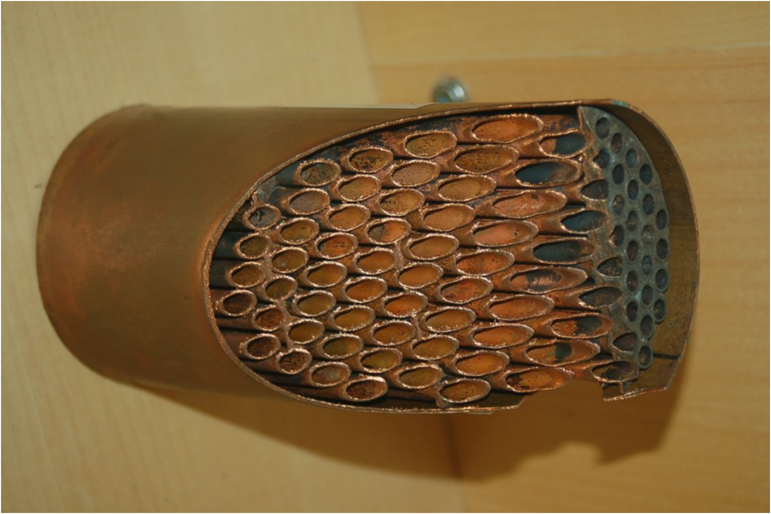
$$\frac{dQ}{dt} = \frac{A \Delta T}{R}$$

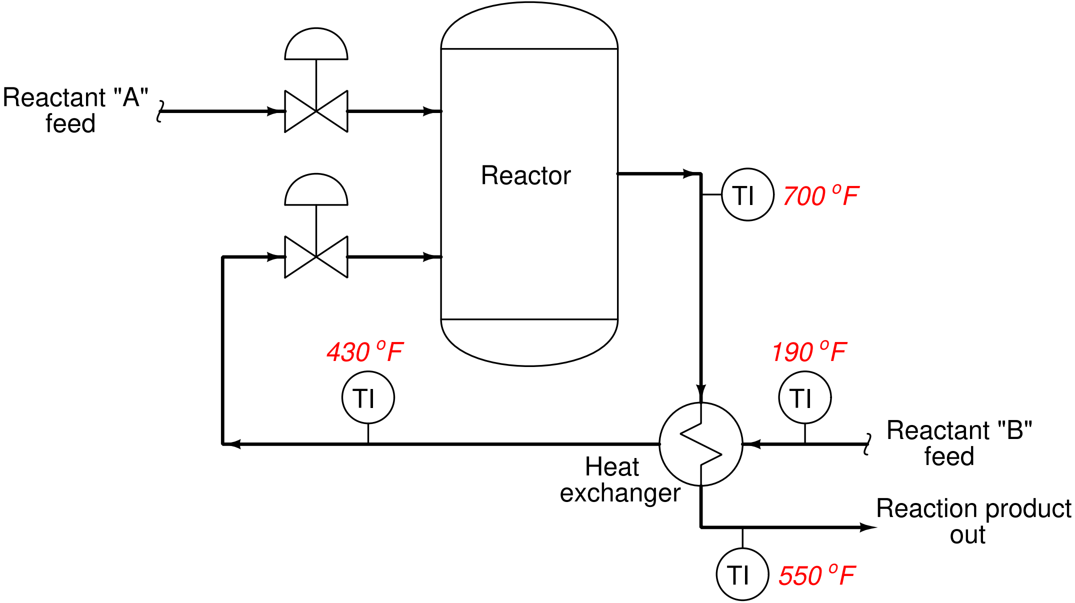
$$\frac{[\mathrm{BTU}]}{[\mathrm{h}]} = \frac{[\mathrm{ft}^2][^o\mathrm{F}]}{\frac{[\mathrm{ft}^2][\mathrm{h}][^o\mathrm{F}]}{[\mathrm{BTU}]}}$$

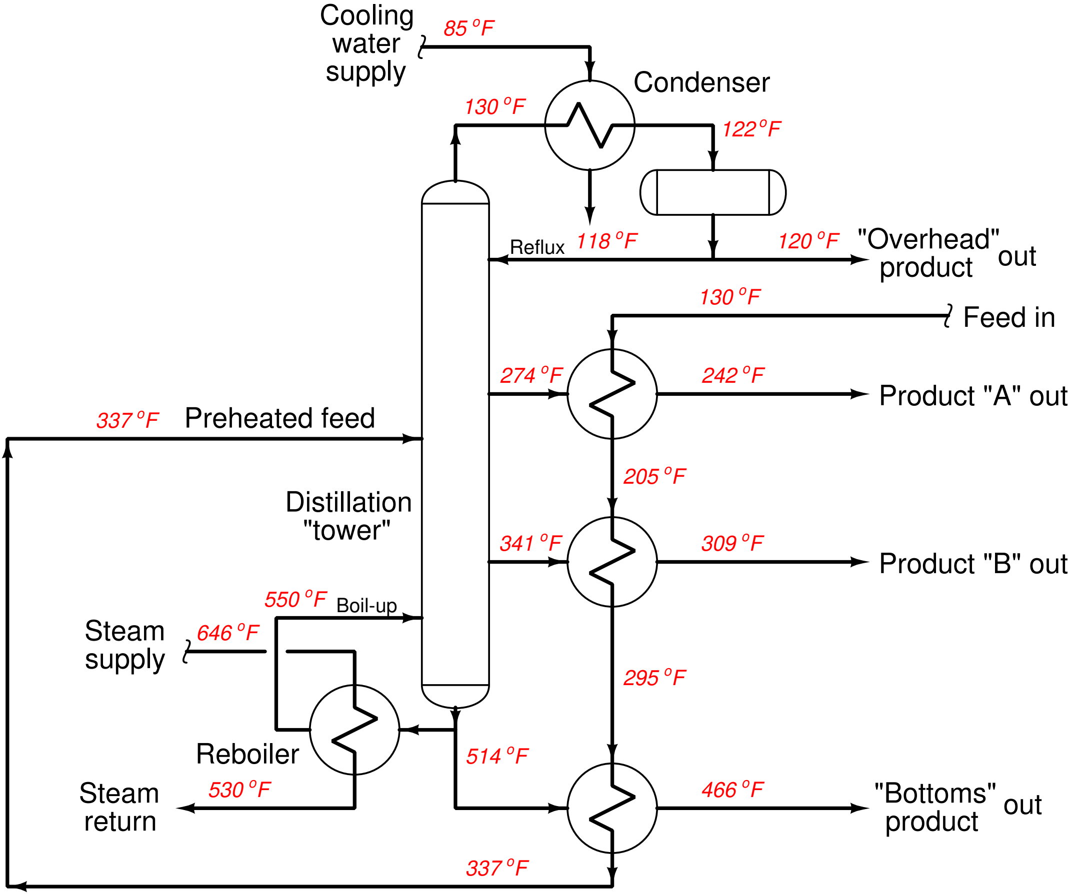
$$\frac{dQ}{dt} = \frac{(2400 \text{ ft}^2)(30^o \text{ F})}{4 \text{ ft}^2 \cdot \text{h} \cdot^o \text{F/BTU}} = 18000 \text{ BTU per hour}$$



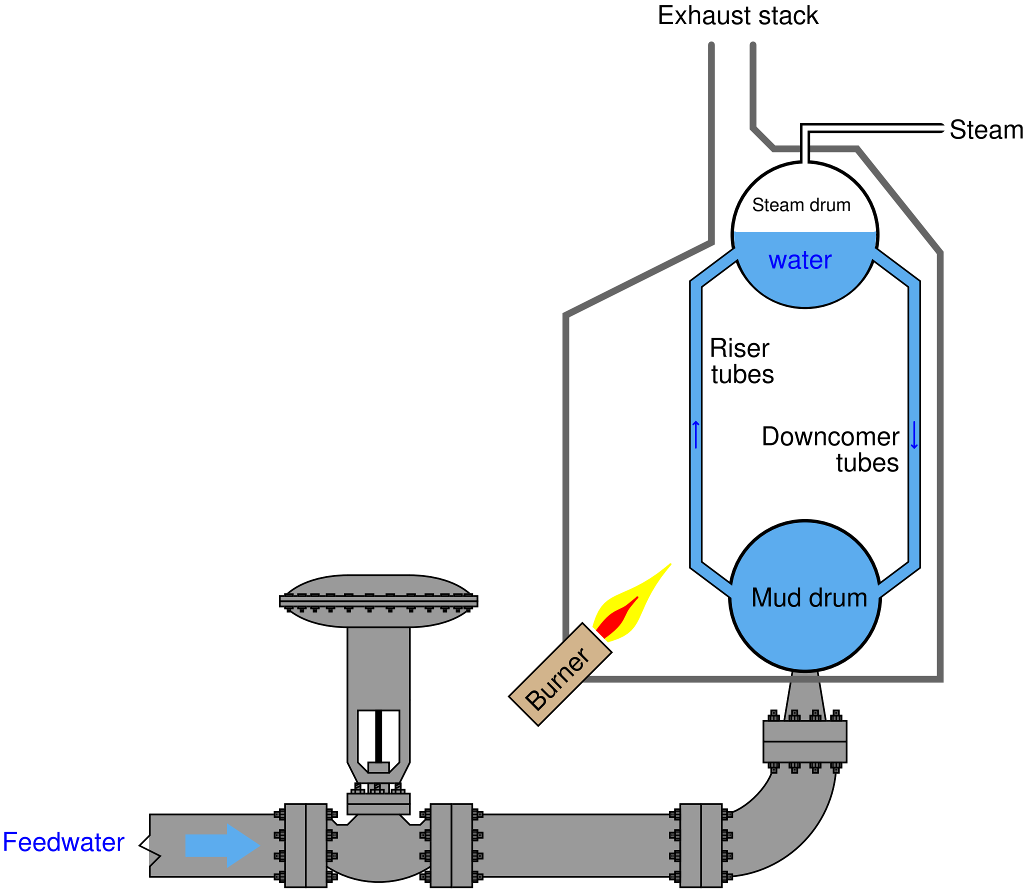

MARINE COOLING SYSTEMS
3883 Irongate Rd.
Bellingham, WA 98226
(360) 734-6860




Reactant "A" feed
Reactor
TI
700 °F
430 °F
TI
190 °F
TI
Reactant "B" feed
Heat exchanger
Reaction product out
TI
550 °F

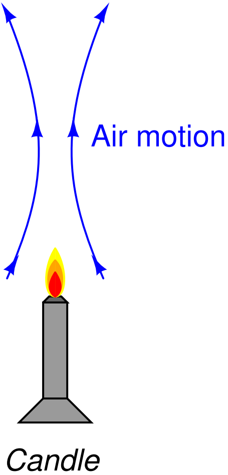


Cooling water supply
85 °F
Condenser
130 °F
122 °F
118 °F
Reflux
120 °F
"Overhead" product out
130 °F
Feed in
274 °F
242 °F
Product "A" out
337 °F
Preheated feed
205 °F
Distillation "tower"
341 °F
309 °F
Product "B" out
550 °F
Boil-up
Steam supply
646 °F
295 °F
Reboiler
514 °F
Steam return
530 °F
466 °F
"Bottoms" product out
337 °F



Exhaust stack
Steam
Steam drum
water
Riser
tubes
Downcomer
tubes
Mud drum
Burner
Feedwater

Natural convection near a candle flame



$$Q \propto m\Delta T$$

Q

$$Q = mc\Delta T$$

$$Q = mc\Delta T$$

$$Q = mc[T_2 - T_1]$$

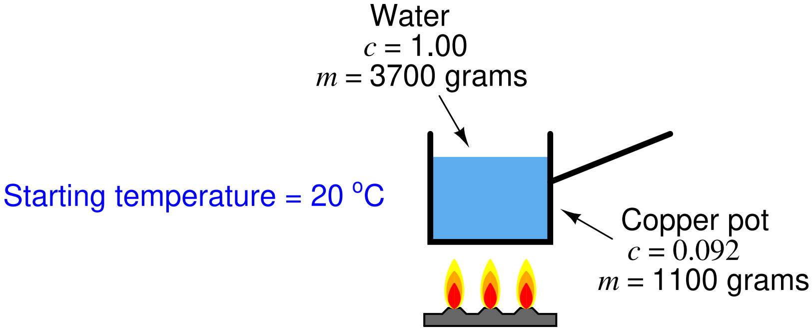
$$Q = m \int_{T_1}^{T_2} c \, dT$$

$c\,dT$

T_1

T_2

Substance	**Specific heat value** (c) cal/g·^{o}C or BTU/lb·^{o}F
Aluminum (solid)	0.215
Iron (solid)	0.108
Copper (solid)	0.092
Lead (solid)	0.031
Ice (solid)	0.50
Water (liquid)	1.00
Methanol (liquid)	0.609
Ethanol (liquid)	0.587
Acetone (liquid)	0.521
Hydrogen (gas)	3.41
Helium (gas)	1.24
Nitrogen (gas)	0.249
Oxygen (gas)	0.219
Steam (gas)	0.476



$$\frac{dQ}{dt} = 5000 \text{ BTU/h} = 350 \text{ cal/s}$$

Time of heating = 40 seconds

$$Q = \left(\frac{dQ}{dt}\right)t = \left(\frac{350\text{ cal}}{\text{s}}\right)40\text{ s} = 14000\text{ calories}$$

$$Q_{total} = Q_{pot} + Q_{water}$$

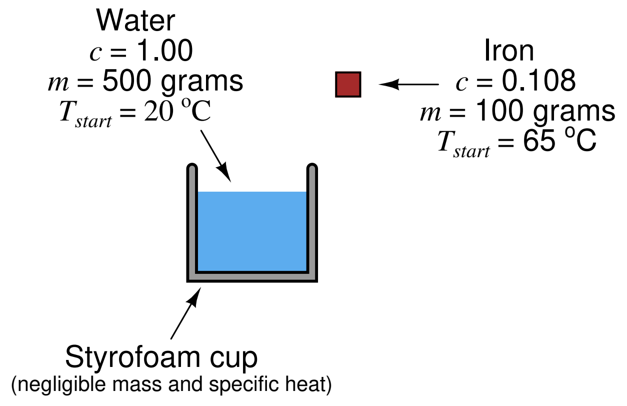
$$Q_{total} = m_{pot}c_{pot}\Delta T + m_{water}c_{water}\Delta T$$

$$Q_{total} = (m_{pot}c_{pot} + m_{water}c_{water})\Delta T$$

$$\Delta T = \frac{Q_{total}}{m_{pot}c_{pot} + m_{water}c_{water}}$$

$$\Delta T = \frac{14000 \text{ cal}}{(1100 \text{ g})(0.092\frac{\text{cal}}{\text{g}^o\text{C}}) + (3700 \text{ g})(1\frac{\text{cal}}{\text{g}^o\text{C}})}$$

$$\Delta T = 3.68\ ^{o}\mathrm{C}$$


Water
$c = 1.00$
$m = 500$ grams
$T_{start} = 20$ °C
Iron
$c = 0.108$
$m = 100$ grams
$T_{start} = 65$ °C
Styrofoam cup
(negligible mass and specific heat)

$$T_{final} - T_{start}$$

$$Q_{iron} + Q_{water} = 0$$

$$Q_{iron} = Q_{water}$$

$$m_{iron}c_{iron}\Delta T_{iron} = m_{water}c_{water}\Delta T_{water}$$

$$m_{iron}c_{iron}(65\ {}^{o}\mathrm{C} - T) = m_{water}c_{water}(T - 20\ {}^{o}\mathrm{C})$$

$$m_{iron}c_{iron}(65) - m_{iron}c_{iron}T = m_{water}c_{water}T - m_{water}c_{water}(20)$$

$$m_{iron}c_{iron}(65) + m_{water}c_{water}(20) = m_{iron}c_{iron}T + m_{water}c_{water}T$$

$$m_{iron}c_{iron}(65) + m_{water}c_{water}(20) = T(m_{iron}c_{iron} + m_{water}c_{water})$$

$$T = \frac{m_{iron}c_{iron}(65) + m_{water}c_{water}(20)}{m_{iron}c_{iron} + m_{water}c_{water}}$$

$$T = \frac{(100 \text{ g})(0.108 \text{ cal/g}^o\text{C})(65^o\text{C}) + (500 \text{ g})(1 \text{ cal/g}^o\text{C})(20^o\text{C})}{(100 \text{ g})(0.108 \text{ cal/g}^o\text{C}) + (500 \text{ g})(1 \text{ cal/g}^o\text{C})}$$

$$T = 20.95\ ^{o}\mathrm{C}$$

Fluid analogy for heat and temperature

Same heat, different temperature

Same temperature, different heat

$$mc$$

$$Q = (1 \text{ lb}) \left(1 \frac{\text{BTU}}{\text{lb}^o\text{F}} \right) (125\ ^o\text{F} - 32\ ^o\text{F})$$

$$Q = 93 \text{ BTU}$$

$$170 - 125$$

$$Q = (70\ \mathrm{g}) \left(1 \frac{\mathrm{cal}}{\mathrm{g}^o\mathrm{C}} \right) (100\ ^o\mathrm{C} - 24\ ^o\mathrm{C})$$

$$Q = 5320 \text{ cal}$$

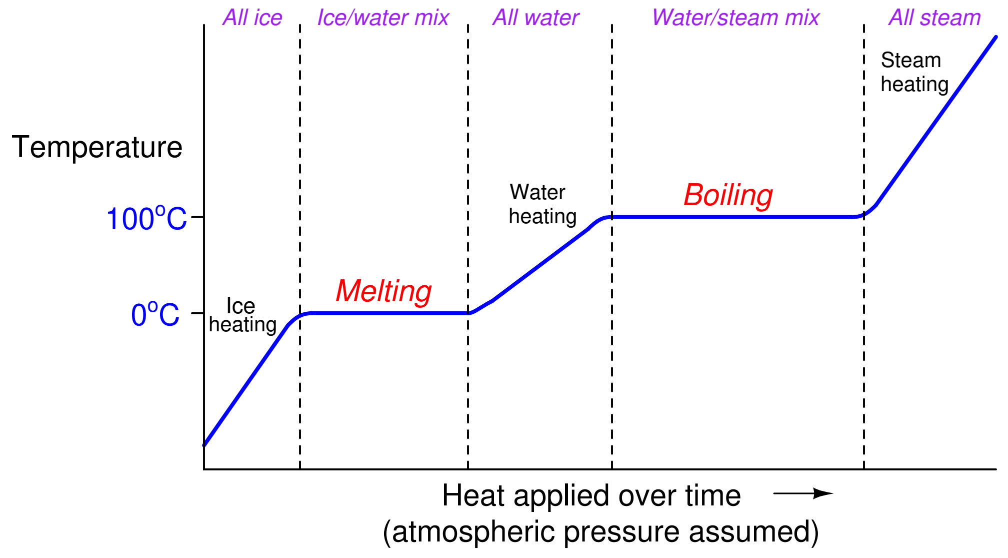
$$Q = mL$$

L

$\frac{5}{9}$

$$\frac{9}{5}$$

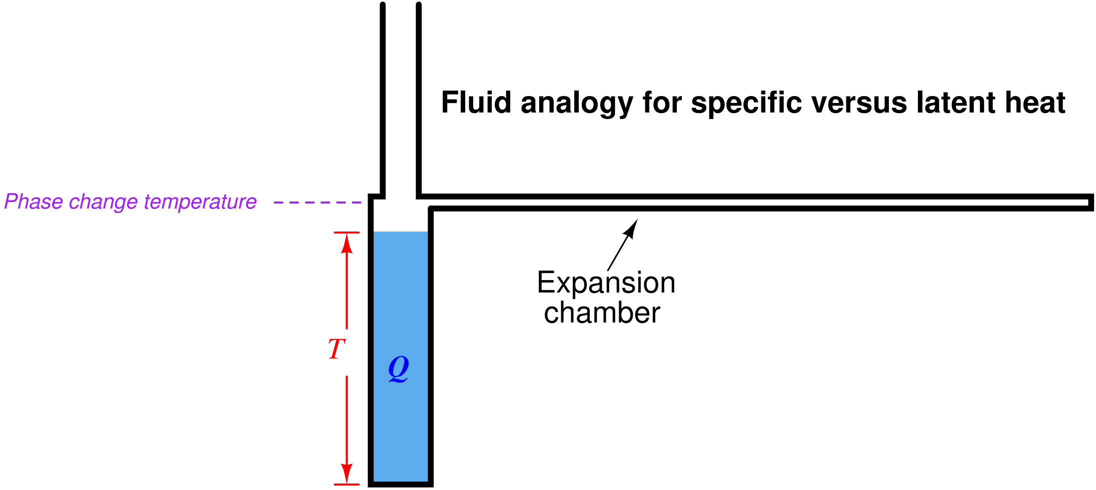
Fluid (@ 70 ^{o}F)	$L_{vaporization}$, BTU/lb	$L_{vaporization}$, cal/g	c_{liquid}
Water	970.3	539.1	1
Ammonia	508.6	282.6	1.1
Carbon dioxide	63.7	35.4	0.66
Butane	157.5	87.5	0.56
Propane	149.5	83.06	0.6



All ice
Ice/water mix
All water
Water/steam mix
All steam
Temperature
100°C
0°C
Ice heating
Melting
Water heating
Boiling
Steam heating
Heat applied over time
(atmospheric pressure assumed)

$$c = 0.5$$

$$c = 0.476$$

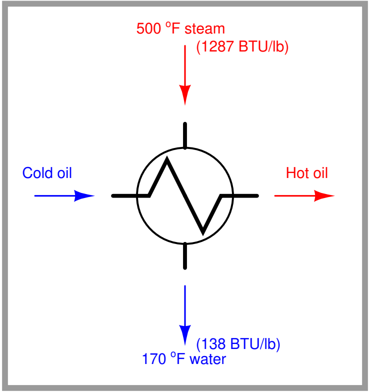


Fluid analogy for specific versus latent heat
Phase change temperature
Expansion chamber
T
Q

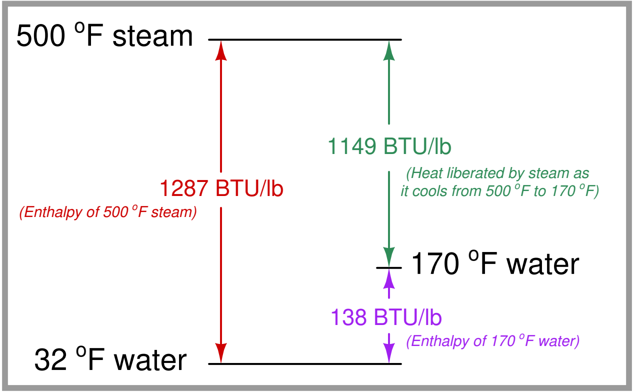
h_g

Heat loss mechanism	**Formula**	**Quantity**
Cooling vapor	$Q = mc\Delta T$	$(1)(0.476)(500 - 212) = 137$ BTU
Phase change	$Q = mL$	$(1)(970) = 970$ BTU
Cooling liquid	$Q = mc\Delta T$	$(1)(1)(212 - 32) = 180$ BTU
TOTAL		1287 BTU

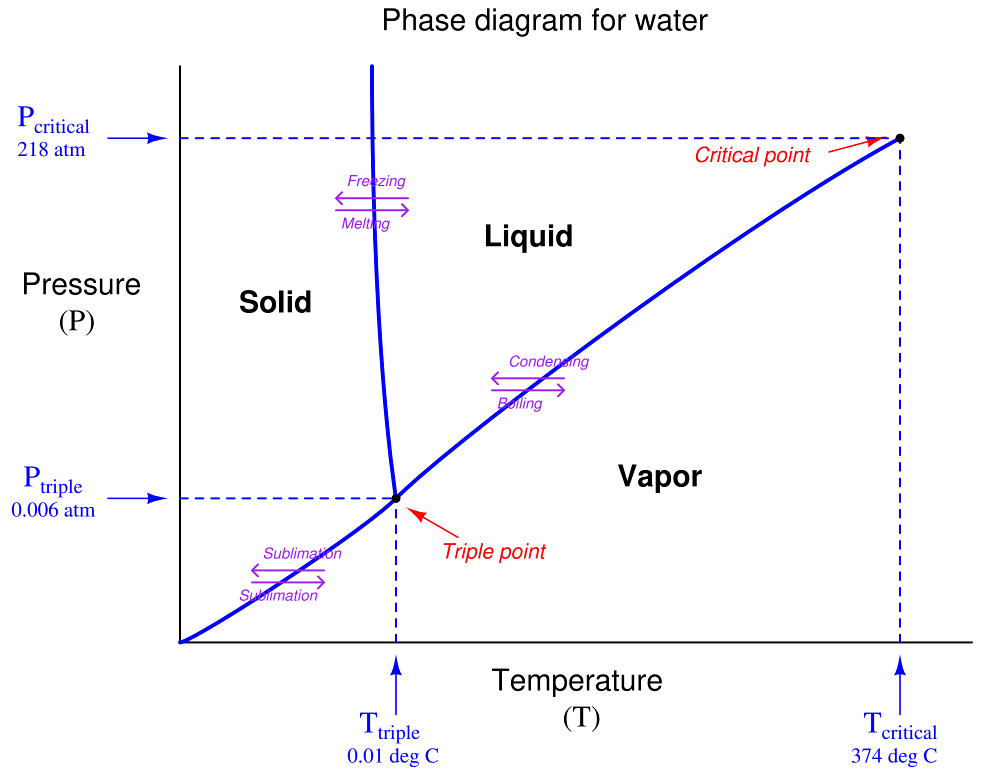
Heat exchanger application



Thermal diagram



$$Q = mL$$



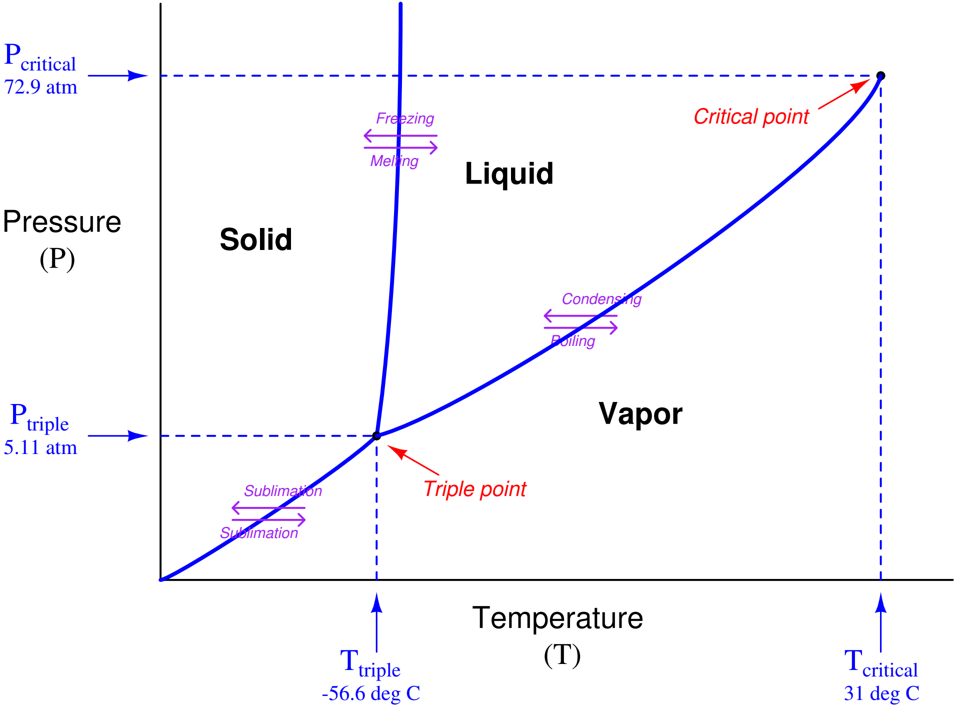
Phase diagram for water
$P_{critical}$
218 atm
Critical point
Freezing
Melting
Liquid
Pressure
(P)
Solid
Condensing
Boiling
Vapor
P_{triple}
0.006 atm
Triple point
Sublimation
Sublimation
Temperature
(T)
T_{triple}
0.01 deg C
$T_{critical}$
374 deg C

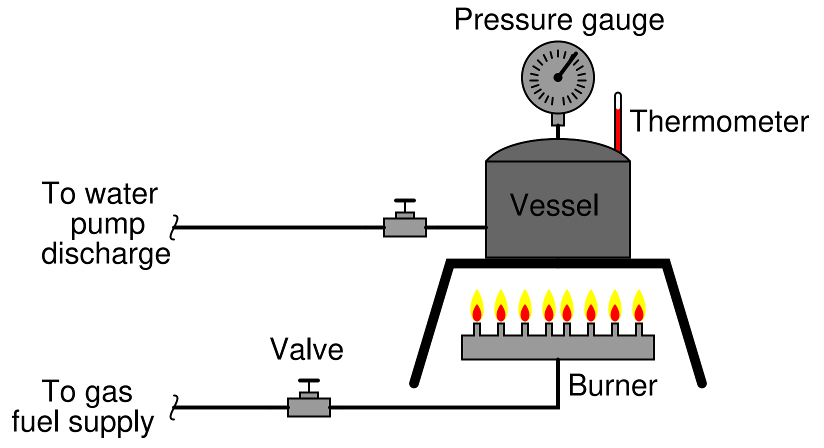

V-387
MAWP
15000-PSIG
0
0
0

-118.57

-181.43

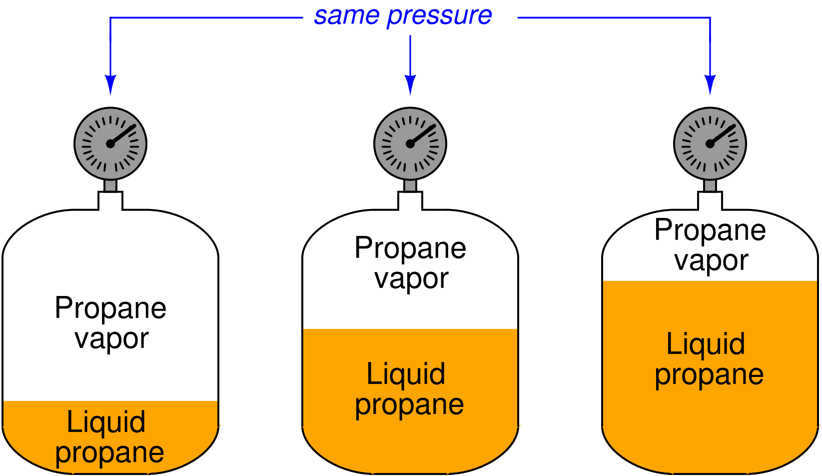
Phase diagram for carbon dioxide



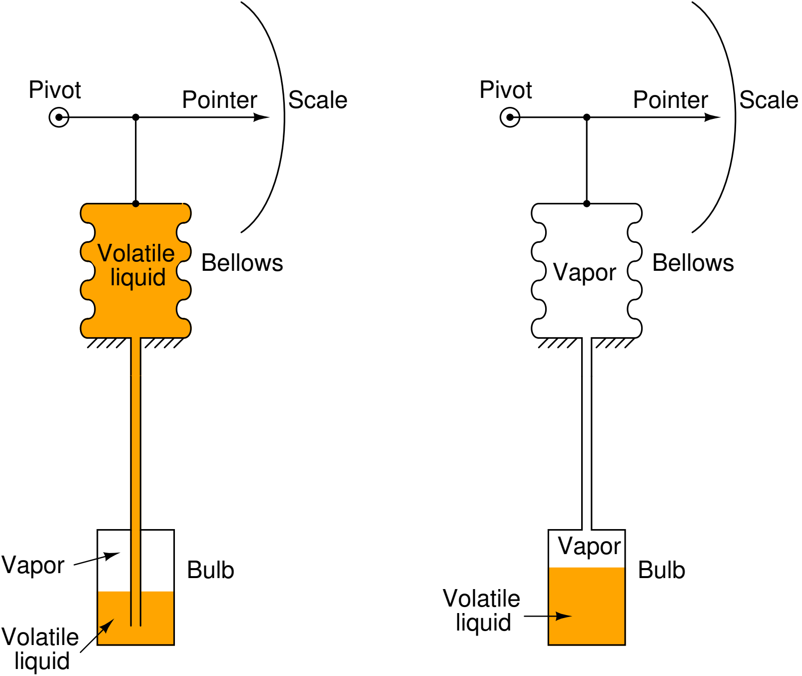

Pressure gauge
Thermometer
Vessel
To water
pump
discharge
Valve
Burner
To gas
fuel supply

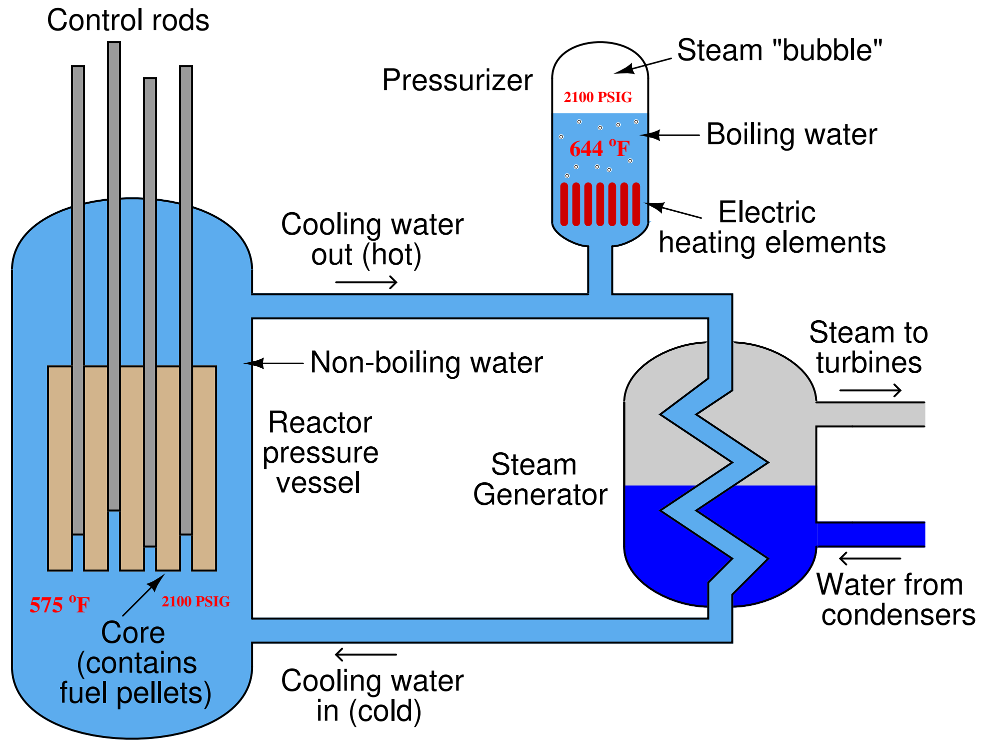
-14.61

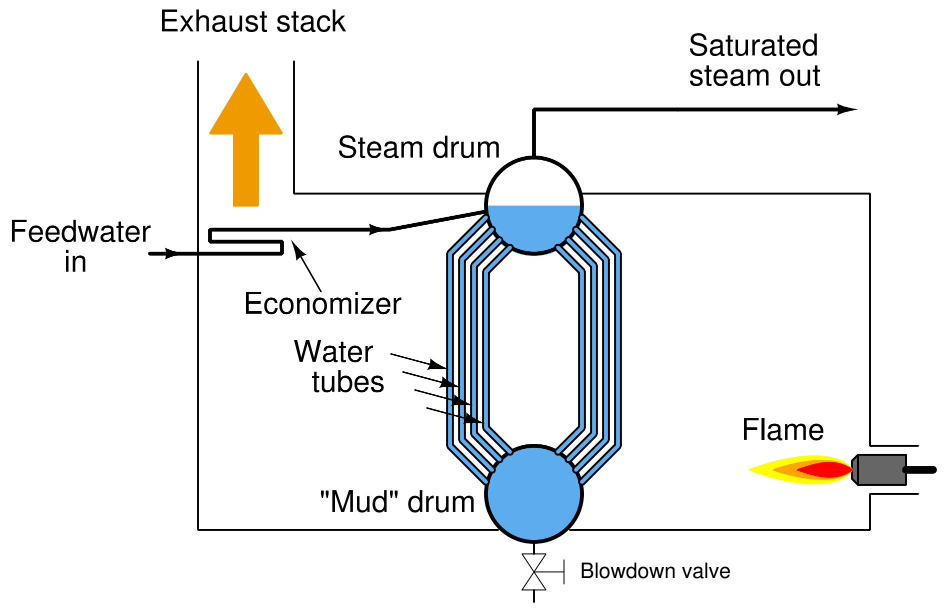
$$N_{freedom} + N_{phase} = N_{substance} + 2$$

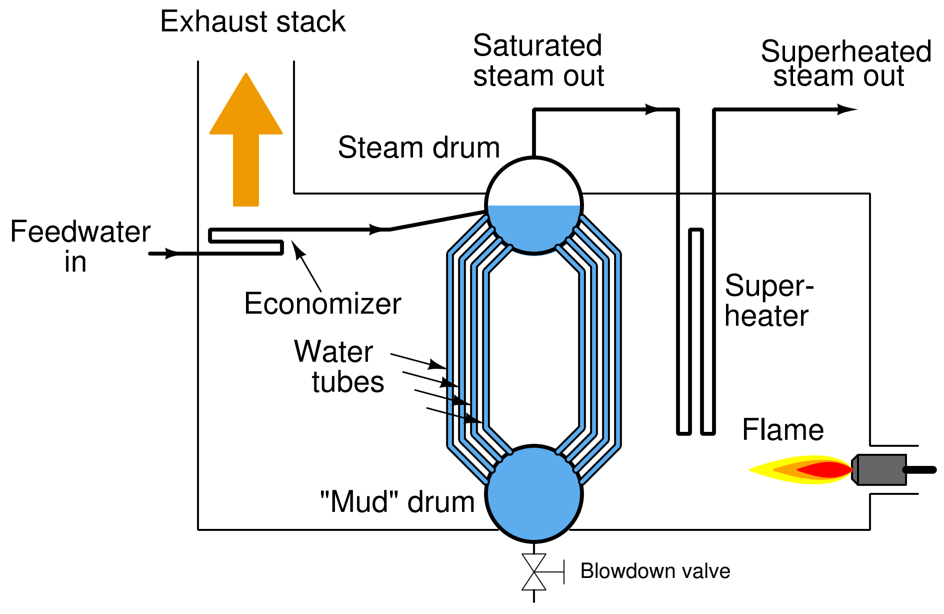


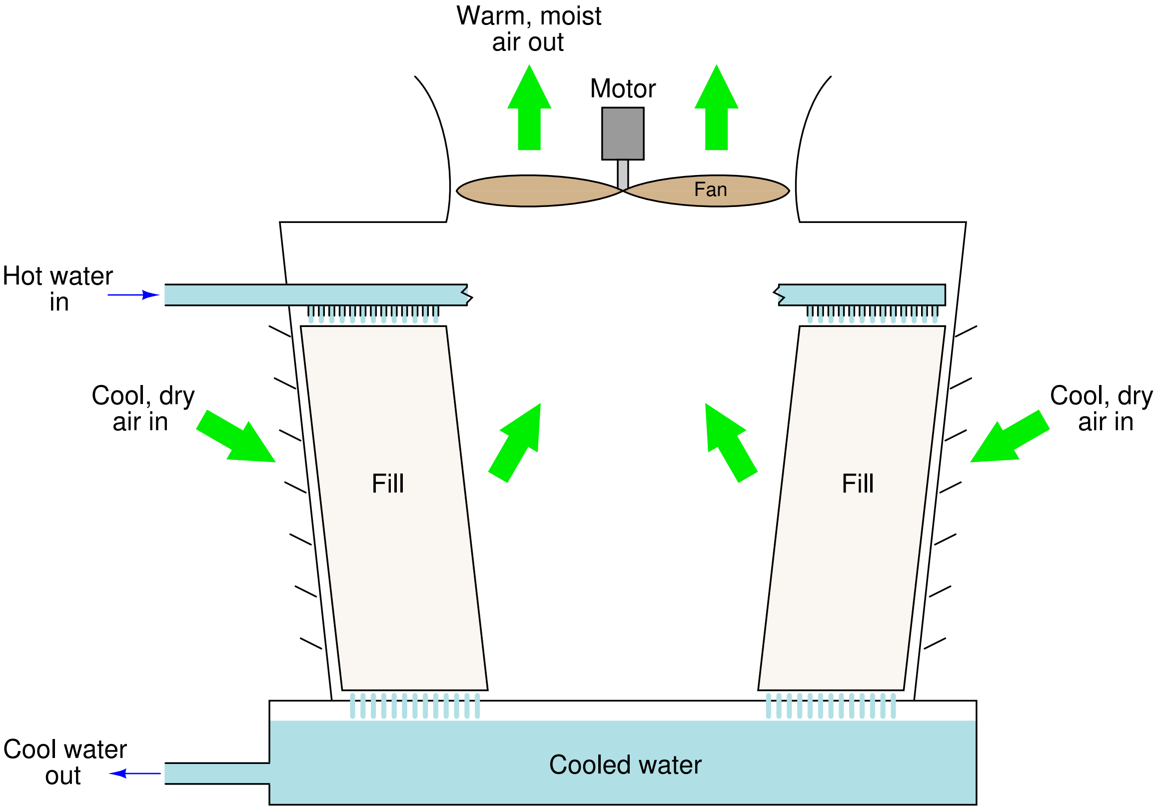
same pressure
Propane vapor
Liquid propane
Propane vapor
Liquid propane
Propane vapor
Liquid propane

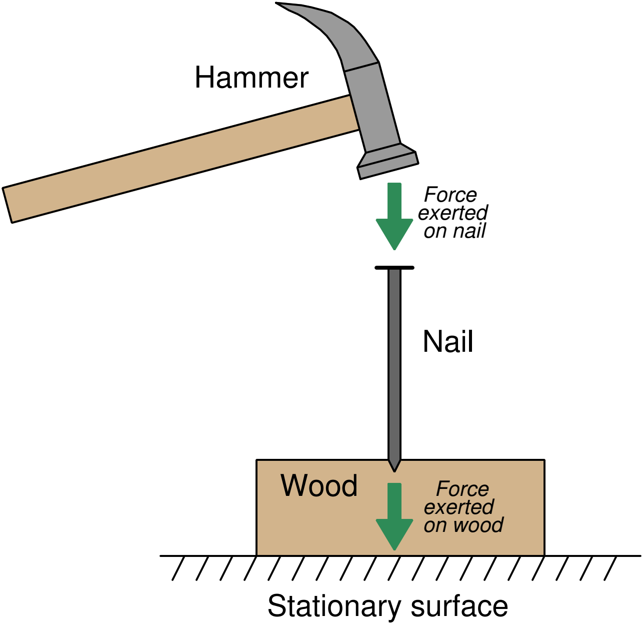

Pivot
Pointer
Scale
Volatile liquid
Bellows
Vapor
Bulb
Volatile liquid
Pivot
Pointer
Scale
Vapor
Bellows
Vapor
Bulb
Volatile liquid

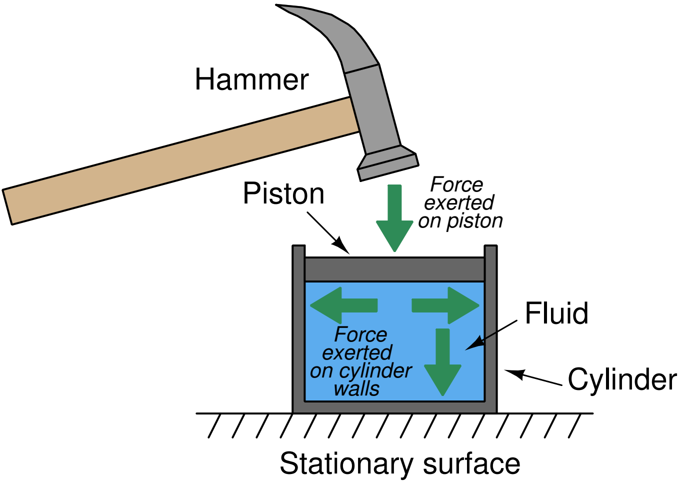

Control rods
Pressurizer
Steam "bubble"
2100 PSIG
Boiling water
644 °F
Electric
heating elements
Cooling water
out (hot)
Non-boiling water
Steam to
turbines
Reactor
pressure
vessel
Steam
Generator
Water from
condensers
575 °F
2100 PSIG
Core
(contains
fuel pellets)
Cooling water
in (cold)


Exhaust stack
Saturated steam out
Steam drum
Feedwater in
Economizer
Water tubes
Flame
"Mud" drum
Blowdown valve

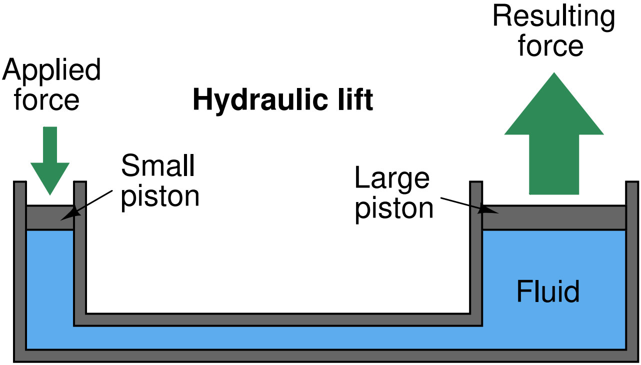

Exhaust stack
Saturated steam out
Superheated steam out
Steam drum
Feedwater in
Economizer
Super-heater
Water tubes
Flame
"Mud" drum
Blowdown valve

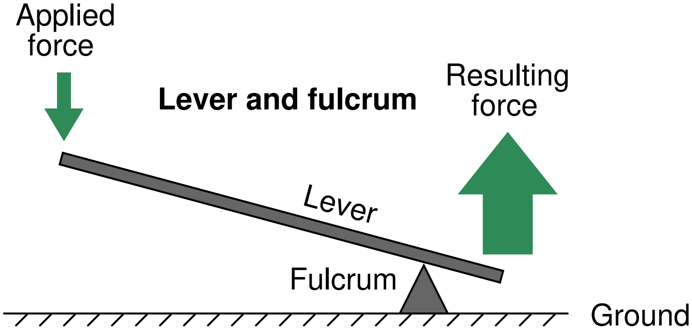

Warm, moist air out
Motor
Fan
Hot water in
Cool, dry air in
Fill
Fill
Cool, dry air in
Cool water out
Cooled water


Hammer
Force exerted on nail
Nail
Wood
Force exerted on wood
Stationary surface


Hammer
Piston
Force exerted on piston
Force exerted on cylinder walls
Fluid
Cylinder
Stationary surface

$$P = \frac{F}{A}$$


Hydraulic lift
Applied force
Resulting force
Small piston
Large piston
Fluid

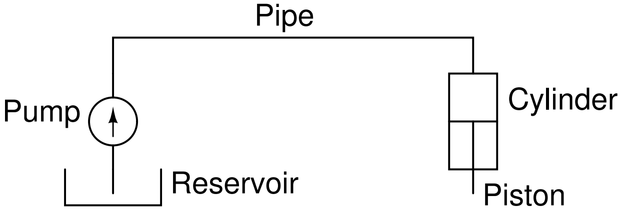

Lever and fulcrum
Applied force
Resulting force
Lever
Fulcrum
Ground

$$A = \pi r^2$$

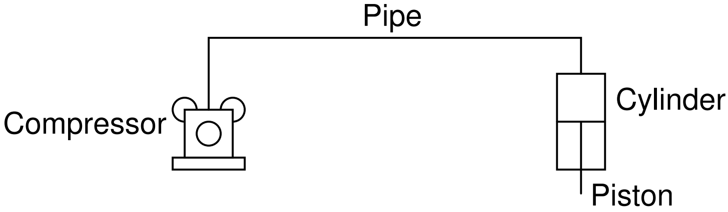
$$\text{Power} = (\text{Voltage in})(\text{Current in}) = (\text{Voltage out})(\text{Current out})$$

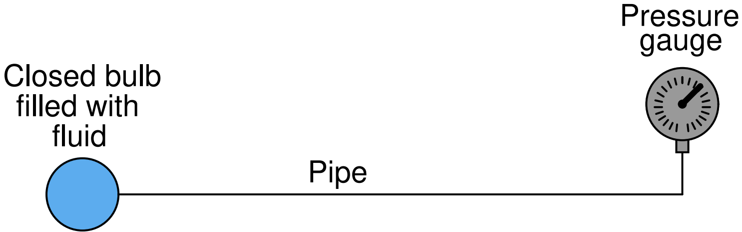
$$\text{Work} = (\text{Force in})(\text{Distance in}) = (\text{Force out})(\text{Distance out})$$

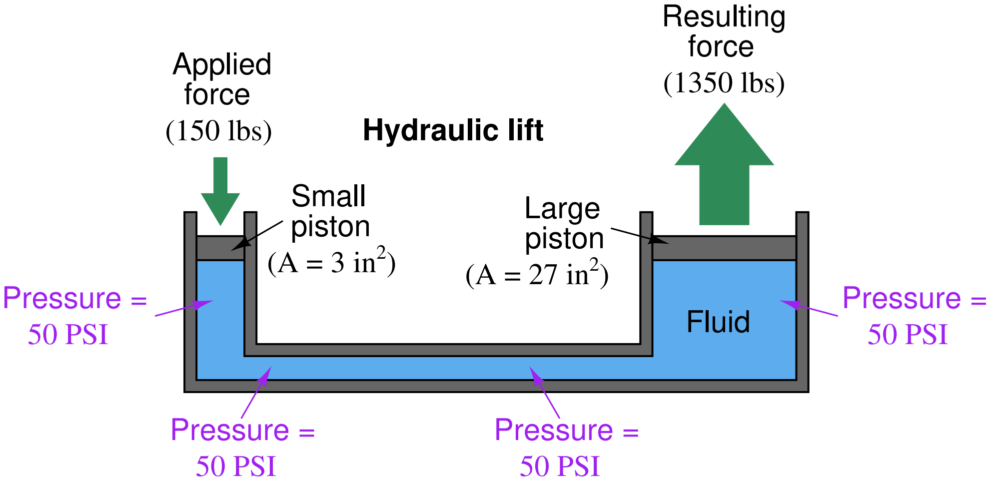
Hydraulic power system



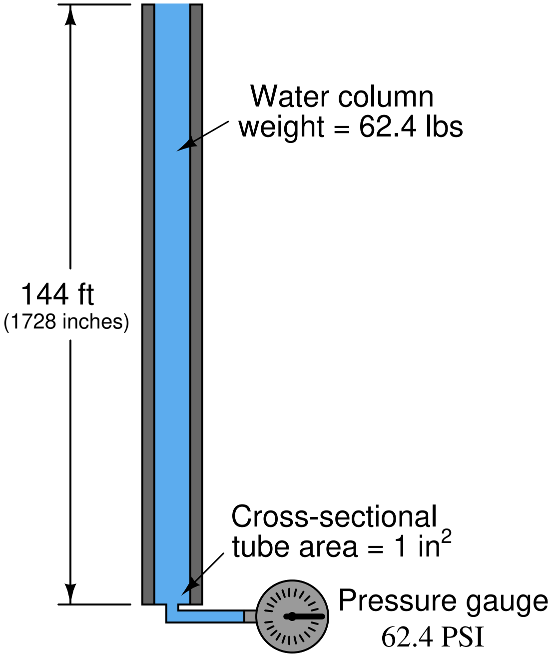
Pneumatic power system

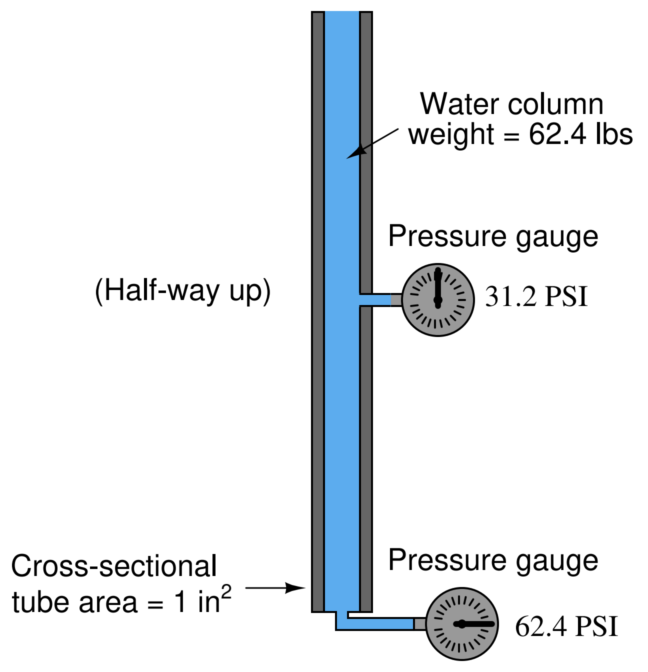


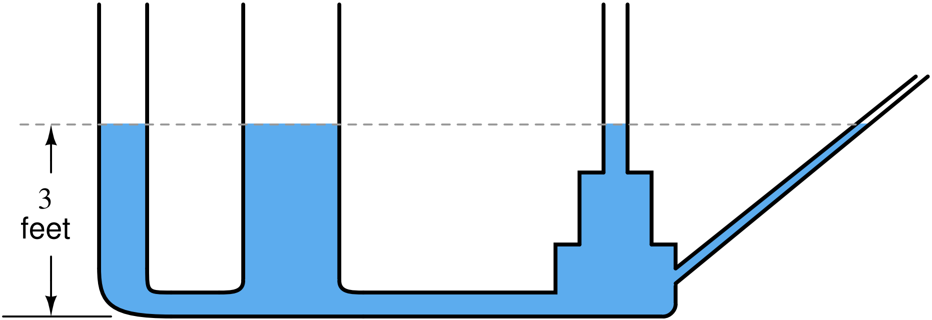

Pressure gauge
Closed bulb filled with fluid
Pipe



Applied force
(150 lbs)
Hydraulic lift
Resulting force
(1350 lbs)
Small piston
(A = 3 in²)
Large piston
(A = 27 in²)
Fluid
Pressure = 50 PSI
Pressure = 50 PSI
Pressure = 50 PSI
Pressure = 50 PSI


Water column
weight = 62.4 lbs
144 ft
(1728 inches)
Cross-sectional
tube area = 1 in^2
Pressure gauge
62.4 PSI

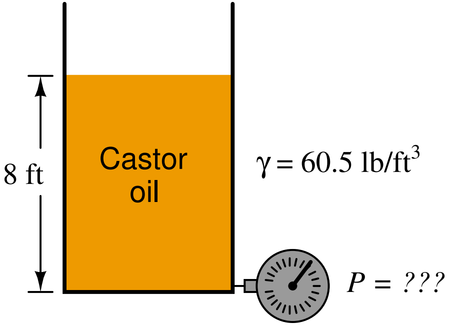

Water column
weight = 62.4 lbs
Pressure gauge
(Half-way up)
31.2 PSI
Pressure gauge
Cross-sectional
tube area = 1 in^2
62.4 PSI


3
feet

$$P = \rho g h$$

$$P = \gamma h$$

$$\left[\frac{\mathrm{lb}}{\mathrm{ft}^2}\right] = \left[\frac{\mathrm{lb}}{\mathrm{ft}^3}\right]\left[\frac{\mathrm{ft}}{1}\right]$$


8 ft
Castor oil
$\gamma = 60.5$ lb/ft^3
$P = ???$

$$P = \left(\frac{60.5\ \text{lb}}{\text{ft}^3}\right)(8\ \text{ft})$$

$$P = \frac{484\ \mathrm{lb}}{\mathrm{ft}^2}$$

$$P = \left(\frac{484 \text{ lb}}{\text{ft}^2}\right)\left(\frac{1 \text{ ft}^2}{144 \text{ in}^2}\right)$$

$$P = \frac{3.36 \text{ lb}}{\text{in}^2} = 3.36 \text{ PSI}$$

$$\text{Specific gravity of any liquid} = \frac{D_{liquid}}{D_{water}}$$

$$\text{Specific gravity of glycerin} = \frac{D_{glycerin}}{D_{water}} = \frac{78.6\ \text{lb/ft}^3}{62.4\ \text{lb/ft}^3} = 1.26$$

$$\text{Degrees API} = \frac{141.5}{\text{Specific gravity}} - 131.5$$

$$\text{Degrees Twaddell} = 200 \times (\text{Specific gravity} - 1)$$

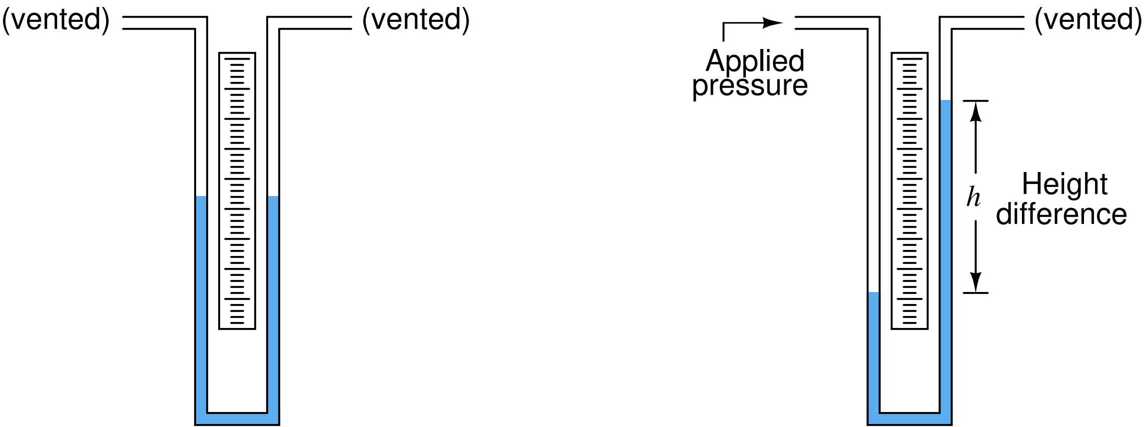
$$\text{Degrees Baumé (light)} = \frac{140}{\text{Specific gravity}} - 130$$

$$\text{Degrees Baumé (heavy)} = 145 - \frac{145}{\text{Specific gravity}}$$

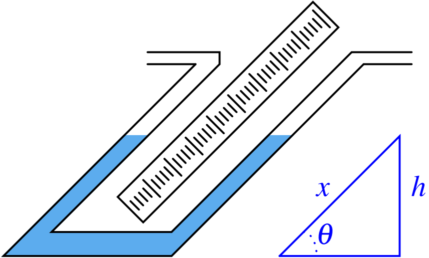
$$\text{Degrees Baumé (heavy, old Dutch)} = 144 - \frac{144}{\text{Specific gravity}}$$

$$\text{Degrees Baumé (heavy, Gerlach scale)} = 146.78 - \frac{146.78}{\text{Specific gravity}}$$

U-tube manometer



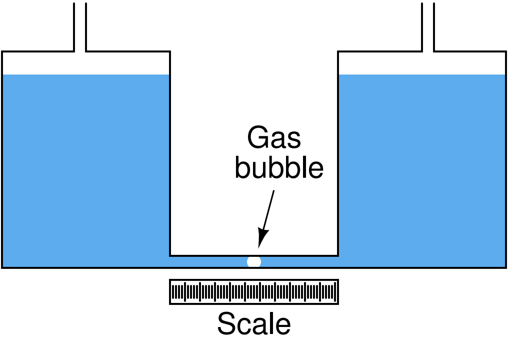
Inclined manometer



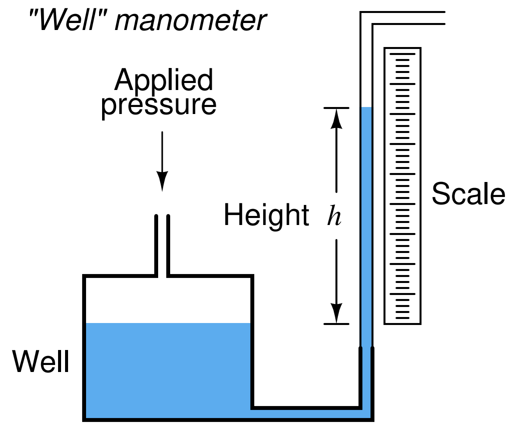
$$\sin\theta = \frac{h}{x}$$

$$\frac{1}{\sin\theta}$$

A simple micromanometer



$$x = \frac{\gamma h A_{large}}{2A_{small}}$$


"Well" manometer
Applied pressure
Height h
Scale
Well

$$\frac{1}{256}$$

$$\frac{255}{256}$$

Gauge pressure	**Fluid example**	**Absolute pressure**
90 PSIG	Bicycle tire air pressure	104.7 PSIA
35 PSIG	Automobile tire air pressure	49.7 PSIA
0 PSIG	Atmospheric pressure at sea level	14.7 PSIA
−9.8 PSIG (9.8 PSI vacuum)	Engine manifold vacuum under idle conditions	4.9 PSIA
−14.7 PSIG (14.7 PSI vacuum)	Perfect vacuum (no fluid molecules present)	0 PSIA

$$\frac{35\ \cancel{\text{PSI}}}{1} \times \frac{27.68\text{ "W.C.}}{1\ \cancel{\text{PSI}}} = 968.8\text{ "W.C.}$$

$$35\ \mathrm{PSIG} + 14.7\ \mathrm{PSI} = 49.7\ \mathrm{PSIA}$$

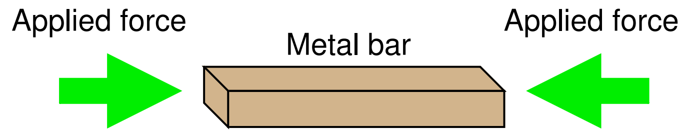
$$\frac{49.7\,\cancel{\text{PSIA}}}{1} \times \frac{27.68\,\text{"W.C.A}}{1\,\cancel{\text{PSIA}}} = 1375.7\,\text{"W.C.A}$$

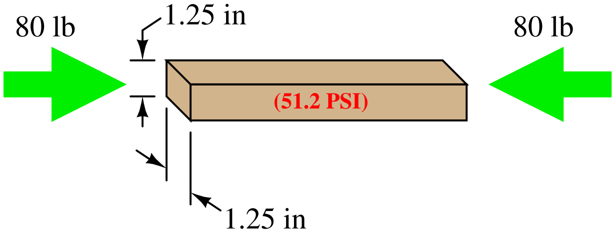
$$\frac{4.5\,\cancel{\text{atm}}}{1} \times \frac{14.7\,\text{PSIA}}{1\,\cancel{\text{atm}}} = 66.15\,\text{PSIA}$$

$$66.15 \text{ PSIA} - 14.7 \text{ PSI} = 51.45 \text{ PSIG}$$

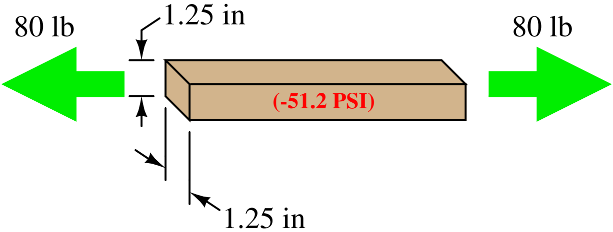
-14.7

$$\frac{49.7\,\cancel{\text{PSIA}}}{1} \times \frac{760\text{ torr}}{14.7\,\cancel{\text{PSIA}}} = 2569.5\text{ torr}$$


Applied force
Metal bar
Applied force

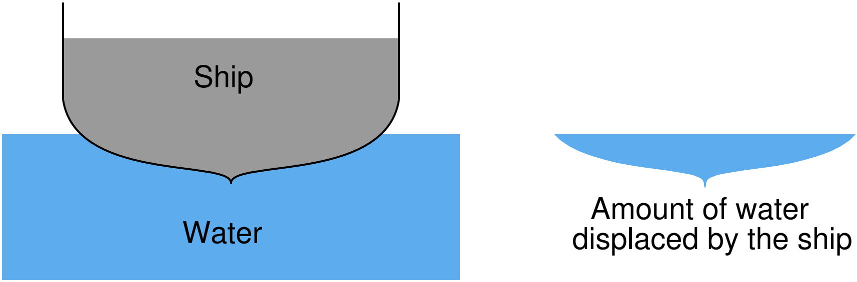

80 lb
1.25 in
80 lb
(51.2 PSI)
1.25 in

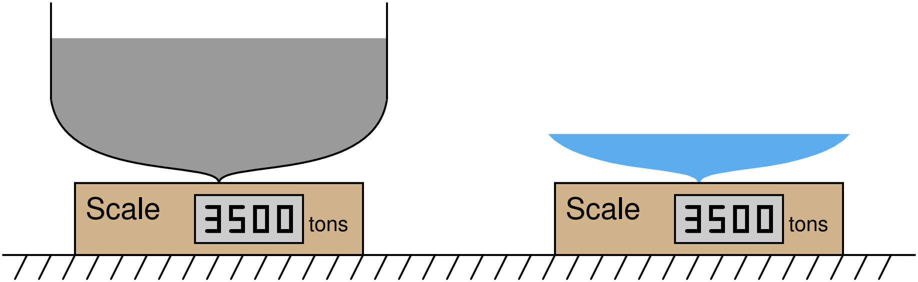
-51.2


80 lb
1.25 in
80 lb
(-51.2 PSI)
1.25 in

-0.2

-29


Ship
Water
Amount of water
displaced by the ship


Scale
3500
tons
Scale
3500
tons

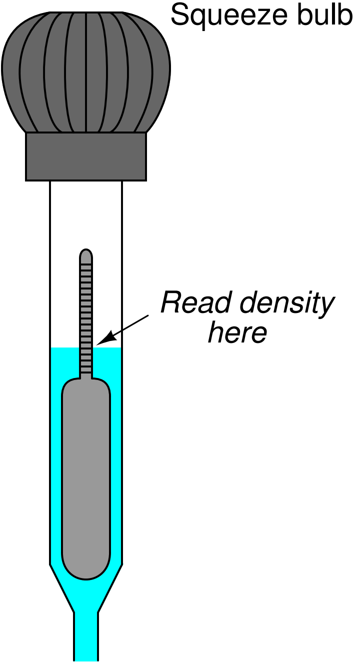
$$F_{buoyant} = \gamma V$$

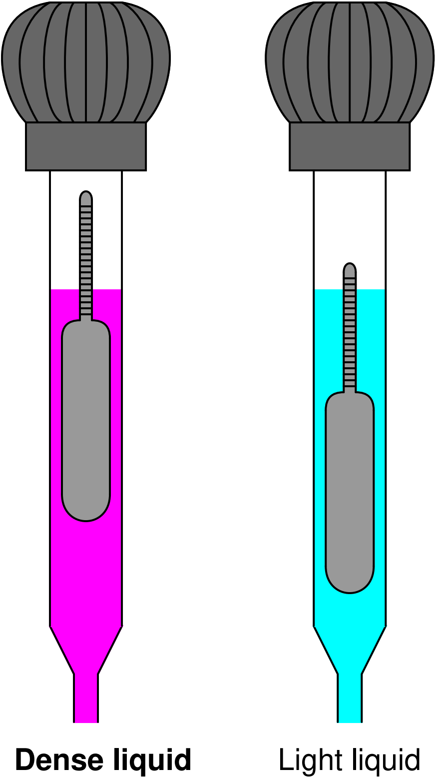
$$F_b$$

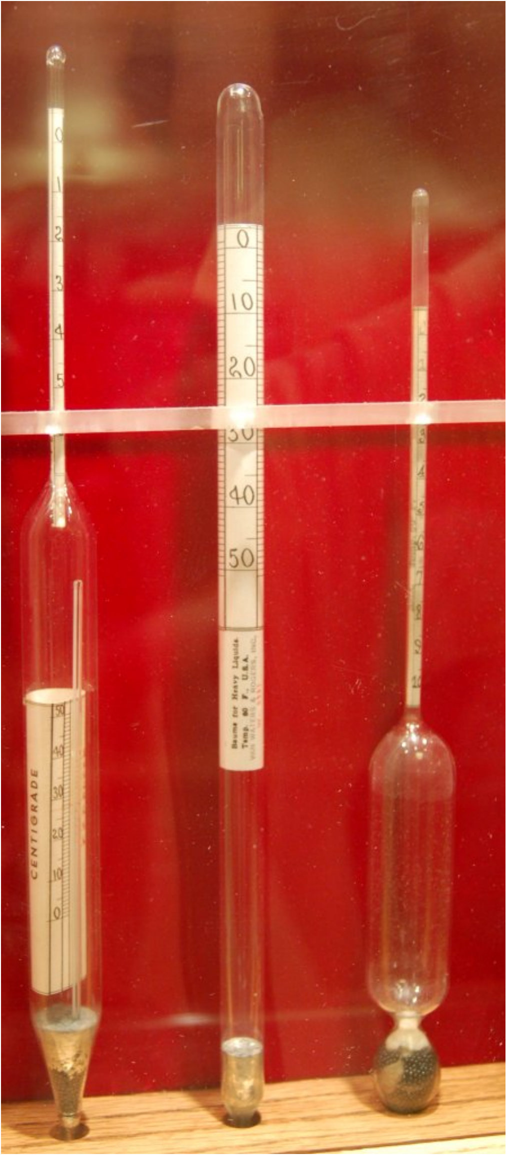
$$[\mathrm{lb}] = \frac{[\mathrm{lb}]}{[\mathrm{ft}^3]}[\mathrm{ft}^3]$$

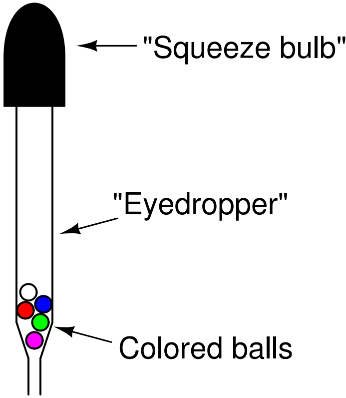
$$F_{weight} = mg$$

$$\text{Specific Gravity} = \frac{m_{dry}}{m_{dry} - m_{wet}} = \frac{m_{dry}g}{m_{dry}g - m_{wet}g} = \frac{\text{Dry weight}}{\text{Dry weight} - \text{Wet weight}}$$


Squeeze bulb
Read density here


Dense liquid
Light liquid


CENTIGRADE
Baume for Heavy Liquids
Temp. 60 F. U.S.A.


"Squeeze bulb"
"Eyedropper"
Colored balls

$$PV = nRT$$

n

$$R = 0.0821$$

N

$$PV = NkT$$

14

$$PV \propto T$$

$PV = \text{Constant}$ **Boyle's Law** (assuming constant temperature T)

$V \propto T$ **Charles's Law** (assuming constant pressure P)

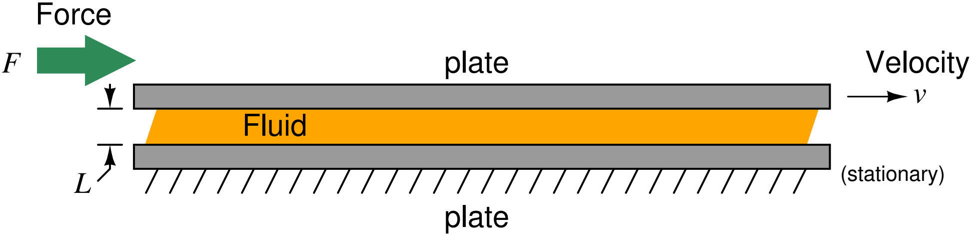
$P \propto T$ **Gay-Lussac's Law** (assuming constant volume V)

$$PV = ZnRT$$

Z

< 1

μ



Force
F
plate
Velocity
v
Fluid
L
(stationary)
plate

$$\eta = \frac{FL}{Av}$$

ν

$$\nu = \frac{\eta}{\rho}$$

$$\mathrm{Re} = \frac{D\overline{v}\rho}{\mu}$$

D

$$\mathrm{Re} = \frac{(3160)G_f Q}{D\mu}$$

$$G_f$$

$$\mathrm{Re} = \frac{[\mathrm{m}]\left[\frac{\mathrm{m}}{\mathrm{s}}\right]\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]}{[\mathrm{Pa}\cdot\mathrm{s}]}$$

$$\mathrm{Re} = \frac{\left[\frac{\mathrm{kg}}{\mathrm{m \cdot s}}\right]}{\left[\frac{\mathrm{N \cdot s}}{\mathrm{m^2}}\right]}$$

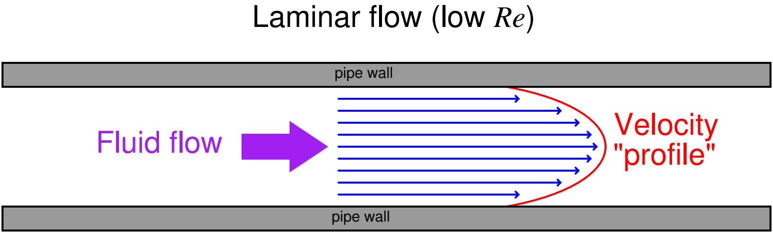
$$\mathrm{Re} = \left[\frac{\mathrm{kg}}{\mathrm{m}\cdot\mathrm{s}}\right]\cdot\left[\frac{\mathrm{m}^2}{\mathrm{N}\cdot\mathrm{s}}\right]$$

$$\mathrm{Re} = \left[\frac{\mathrm{kg} \cdot \mathrm{m}}{\mathrm{N} \cdot \mathrm{s}^2}\right]$$

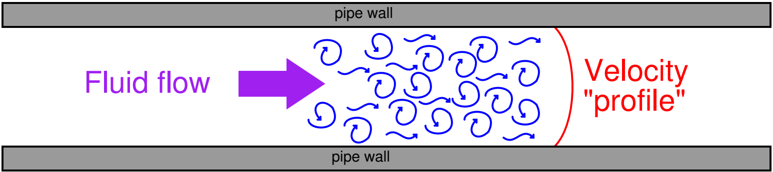
$$\mathrm{Re} = \left[\frac{\mathrm{kg} \cdot \mathrm{m} \cdot \mathrm{s}^2}{\mathrm{kg} \cdot \mathrm{m} \cdot \mathrm{s}^2}\right]$$

$$\mathrm{Re} = unitless$$

$$\mathrm{Re} = \frac{\left[\frac{\mathrm{in}\cdot\mathrm{cp}\cdot\mathrm{min}}{\mathrm{gal}}\right]\left[\frac{\mathrm{gal}}{\mathrm{min}}\right]}{[\mathrm{in}\cdot\mathrm{cp}]}$$


Laminar flow (low Re)
pipe wall
Fluid flow
Velocity "profile"
pipe wall

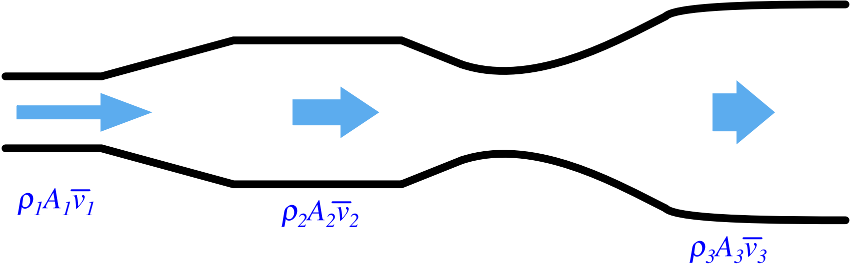
Turbulent flow (high Re)



<

>

$$\rho_1 A_1 \overline{v_1} = \rho_2 A_2 \overline{v_2} = \cdots \rho_n A_n \overline{v_n}$$



$\rho_1 A_1 \overline{v}_1$
$\rho_2 A_2 \overline{v}_2$
$\rho_3 A_3 \overline{v}_3$

$$\rho A\overline{v} = \left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]\left[\frac{\mathrm{m}^2}{1}\right]\left[\frac{\mathrm{m}}{\mathrm{s}}\right] = \left[\frac{\mathrm{kg}}{\mathrm{s}}\right]$$

$$\rho A \overline{v}$$

$$W = \rho A \overline{v}$$

$$A_1\overline{v_1} = A_2\overline{v_2}$$

$A\overline{v}$

$$A\overline{v} = \left[\frac{\mathrm{m}^2}{1}\right]\left[\frac{\mathrm{m}}{\mathrm{s}}\right] = \left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$$

$$Q = A\overline{v}$$

$$\overline{v} = \frac{Q}{A}$$

$$A = \pi r^2$$

$$A = \pi \left(\frac{1}{3} \text{ ft} \right)^2 = \frac{\pi}{9} \text{ ft}^2$$

$$\overline{v} = \frac{Q}{A} = \frac{\frac{5\ \text{ft}^3}{\text{min}}}{\frac{\pi}{9}\ \text{ft}^2}$$

$$\overline{v} = \left(\frac{5\ \text{ft}^3}{\text{min}}\right)\left(\frac{9}{\pi\ \text{ft}^2}\right)$$

$$\overline{v} = \frac{45 \text{ ft}}{\pi \text{ min}} = 14.32\frac{\text{ft}}{\text{min}}$$

$$Q = k\left(\frac{\Delta P D^4}{\mu L}\right)$$

$\times 10^5$

$$\Delta P$$

$$z_1\rho g + \frac{v_1^2\rho}{2} + P_1 = z_2\rho g + \frac{v_2^2\rho}{2} + P_2$$

$$z_1 + \frac{v_1^2}{2g} + \frac{P_1}{\gamma} = z_2 + \frac{v_2^2}{2g} + \frac{P_2}{\gamma}$$

Z

$$\gamma = \rho g$$

$z\rho g$ Elevation head

$\frac{v^2\rho}{2}$ Velocity head

P Pressure head

$E_p = mgh$ Potential energy formula

$$E_k = \frac{1}{2}mv^2 \qquad \text{Kinetic energy formula}$$

$$z\rho g + \frac{v^2\rho}{2} + P$$

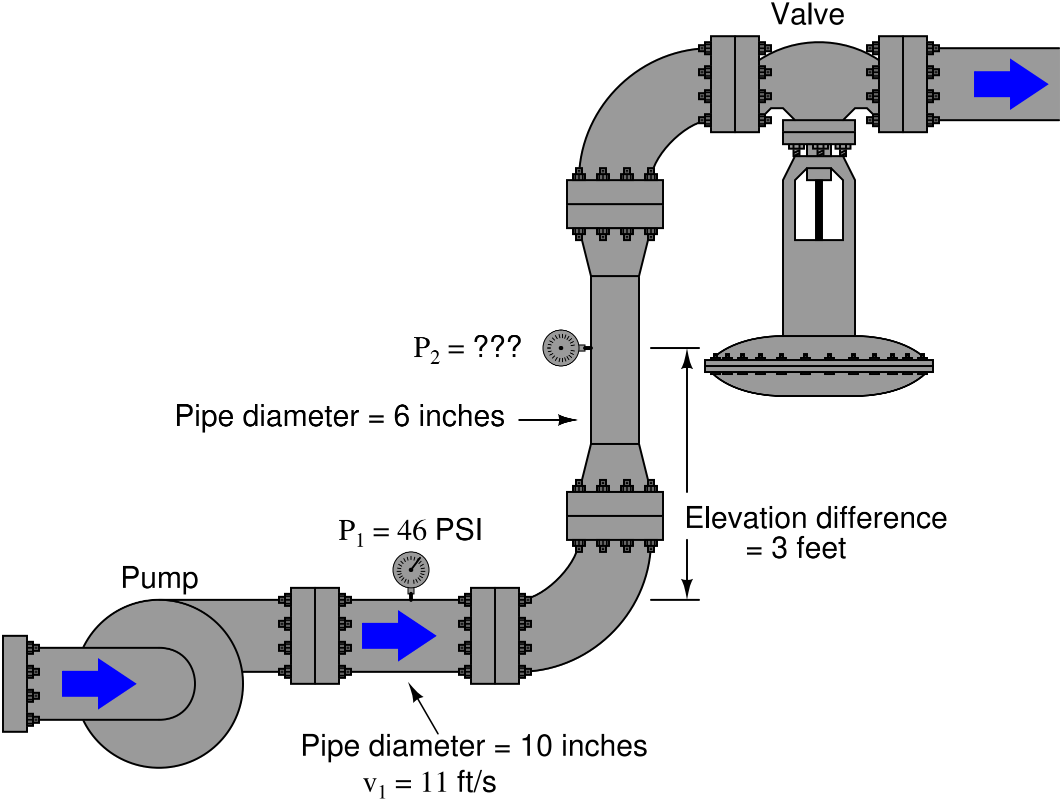
$$[\mathrm{ft}]\left[\frac{\mathrm{slug}}{\mathrm{ft}^3}\right]\left[\frac{\mathrm{ft}}{\mathrm{s}^2}\right]+\left[\frac{\mathrm{ft}}{\mathrm{s}}\right]^2\left[\frac{\mathrm{slug}}{\mathrm{ft}^3}\right]+\left[\frac{\mathrm{lb}}{\mathrm{ft}^2}\right]=\left[\frac{\mathrm{slug}}{\mathrm{ft}\cdot\mathrm{s}^2}\right]$$

$$[\mathrm{lb}] = [\mathrm{slug}] \left[\frac{\mathrm{ft}}{\mathrm{s}^2} \right]$$

$$\left[\frac{\mathrm{lb}}{\mathrm{ft}^2}\right] = \left[\frac{\mathrm{slug}\left[\frac{\mathrm{ft}}{\mathrm{s}^2}\right]}{\mathrm{ft}^2}\right] = \left[\frac{\mathrm{slug}}{\mathrm{ft}\cdot\mathrm{s}^2}\right]$$

$$z + \frac{v^2}{2g} + \frac{P}{\gamma}$$

$$[\mathrm{m}] + \left[\frac{\left[\frac{\mathrm{m}}{\mathrm{s}}\right]^2}{\left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]} \right] + \left[\frac{\left[\frac{\mathrm{N}}{\mathrm{m}^2}\right]}{\left[\frac{\mathrm{N}}{\mathrm{m}^3}\right]} \right] = [\mathrm{m}]$$



Valve
P_2 = ???
Pipe diameter = 6 inches
Elevation difference
= 3 feet
P_1 = 46 PSI
Pump
Pipe diameter = 10 inches
v_1 = 11 ft/s

P_2

Known quantity	**Comments**
z_1	0 ft (arbitrarily assigned as 0 height)
z_2	3 ft (if z_1 is 0 feet, then z_2 is 3 ft above it)
v_1	11 ft/s
P_1	46 PSI (*need to convert into PSF so all units match*)
g	32.2. ft/s^2

P_1

Unknown quantity	**Comments**
ρ	(needs to be in units of slugs/ft^3)
v_2	(needs to be in units of ft/s just like v_1)
P_2	(the quantity we are ultimately solving for)

v_2

$$F_W$$

$$F_W = mg$$

$$\frac{F_W}{V} = \frac{m}{V} g$$

$$\gamma = \rho g$$

$$\rho = \frac{\gamma}{g}$$

$$\rho = \frac{62.4 \text{ lb/ft}^3}{32.2 \text{ ft/s}^2} = 1.94 \text{ slugs/ft}^3$$

$$z_1\rho g + \frac{v_1^2\rho}{2} + P_1 = \text{Total head at 10-inch pipe}$$

Head	**Calculation** at 10 inch pipe	**Value**
$z_1 \rho g$	(0 ft) (1.94 slugs/ft^3) (32.2 ft/s^2)	0 lb/ft^2
$v_1^2 \rho / 2$	(11 ft/s)^2 (1.94 slugs/ft^3) / 2	117.4 lb/ft^2
P_1	(46 lb/in^2) (144 in^2/1 ft^2)	6624 lb/ft^2
Total	0 lb/ft^2 + 117.4 lb/ft^2 + 6624 lb/ft^2	**6741.4 lb/ft^2**

$$Q = A_1 v_1 = A_2 v_2$$

v_1

A_1

A_2

$$\frac{A_1}{A_2} = \frac{v_2}{v_1}$$

$$\frac{\pi(5\ \text{in})^2}{\pi(3\ \text{in})^2} = \frac{v_2}{v_1}$$

$$\frac{25}{9} = \frac{v_2}{v_1}$$

$$v_2 = 11 \text{ ft/s} \left(\frac{25}{9}\right)$$

$$v_2 = (11 \text{ ft/s})(2.778) = 30.56 \text{ ft/s}$$

$$z_2 \rho g + \frac{v_2^2 \rho}{2} + P_2 = \text{Total head at 6-inch pipe}$$

Head	**Calculation** at 6 inch pipe	**Value**
$z_2 \rho g$	(3 ft) (1.94 slugs/ft^3) (32.2 ft/s^2)	187.4 lb/ft^2
$v_2^2 \rho / 2$	(30.56 ft/s)^2 (1.94 slugs/ft^3) / 2	905.6 lb/ft^2
P_2		(unknown)
Total	187.4 lb/ft^2 + 905.6 lb/ft^2 + P_2	**1093 lb/ft^2** + P_2

$$6741.4 \text{ lb/ft}^2 = 1093 \text{ lb/ft}^2 + P_2$$

$$P_2 = 6741.4 \text{ lb/ft}^2 - 1093 \text{ lb/ft}^2 = 5648.3 \text{ lb/ft}^2$$

$$P_2 = (5648.3 \text{ lb/ft}^2)\left(\frac{1 \text{ ft}^2}{144 \text{ in}^2}\right)$$

$$P_2 = 39.2\ \mathrm{lb/in^2}$$

$$\rho = \gamma / g$$

(Given)

Goal

$$z_1 \rho g + \frac{v_1^2 \rho}{2} + P_1 = z_2 \rho g + \frac{v_2^2 \rho}{2} + P_2$$

(Given) (Given) (Given) (Given)

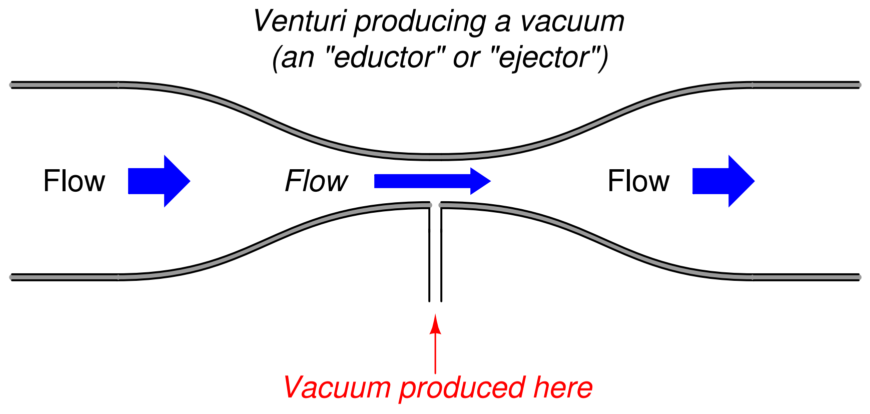
Convert to units of PSF

(Given)

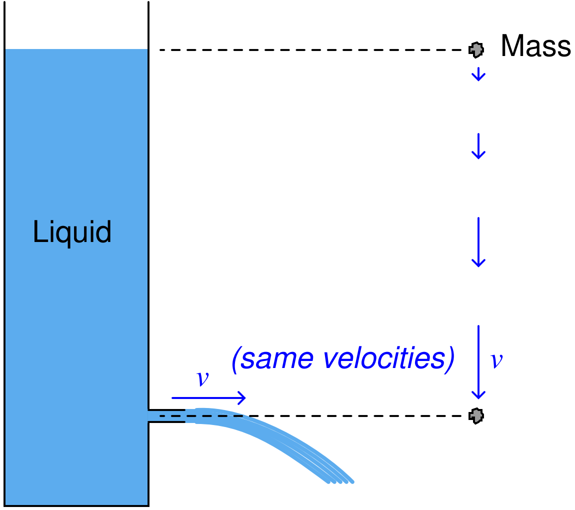
$$Q = A_1 v_1 = A_2 v_2$$

(Given)

$$A = \pi r^2 \qquad r = D/2$$


Venturi producing a vacuum
(an "eductor" or "ejector")
Flow
Flow
Flow
Vacuum produced here


AIR, INSTRUMENT
CAUTION
CAUTION
RELEASE CYLINDER
PRESSURE BEFORE
MANUAL OPERATION



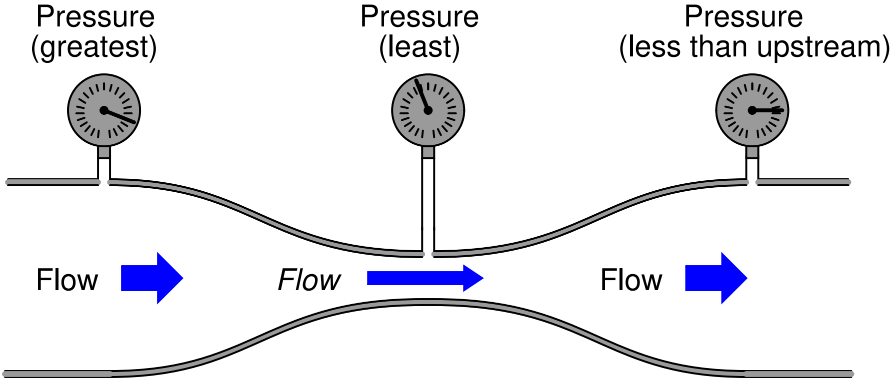
Mass
Liquid
(same velocities)
v
v

$$mgh = \frac{1}{2}mv^2$$

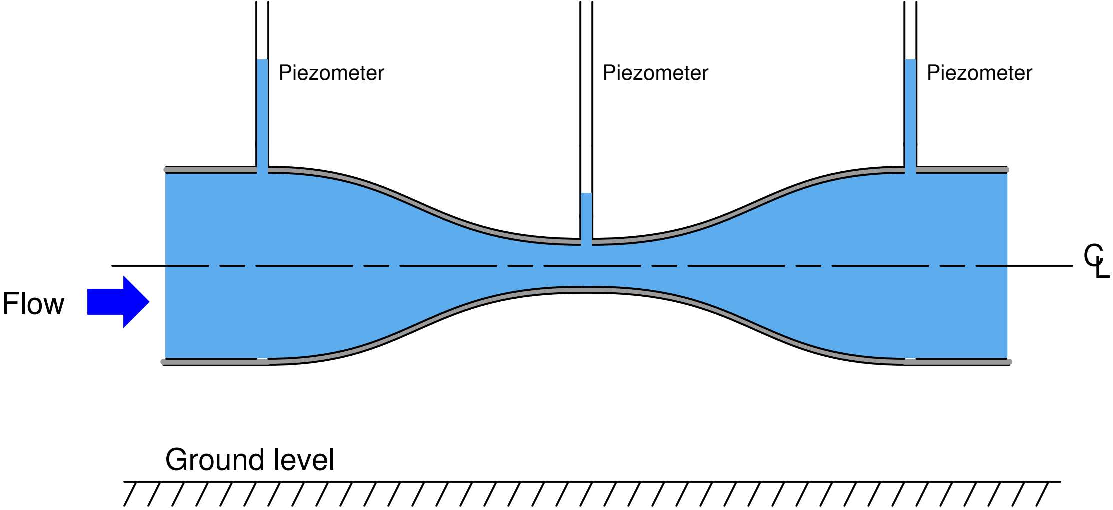
$$gh = \frac{1}{2}v^2$$

$$2gh = v^2$$

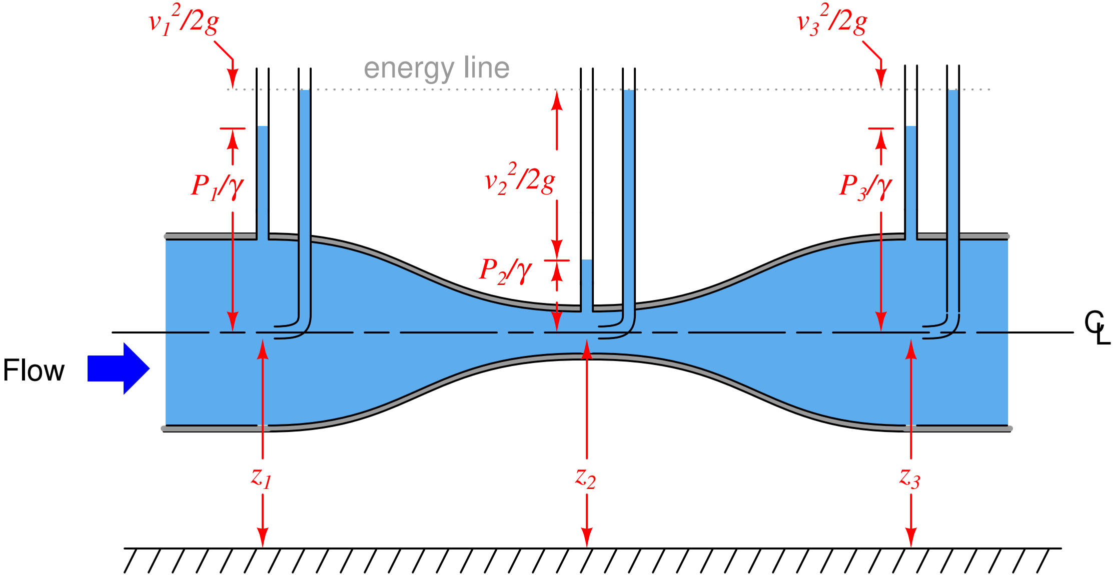
$$v = \sqrt{2gh}$$



Pressure
(greatest)
Pressure
(least)
Pressure
(less than upstream)
Flow
Flow
Flow


Piezometer
Piezometer
Piezometer
C
L
Flow
Ground level

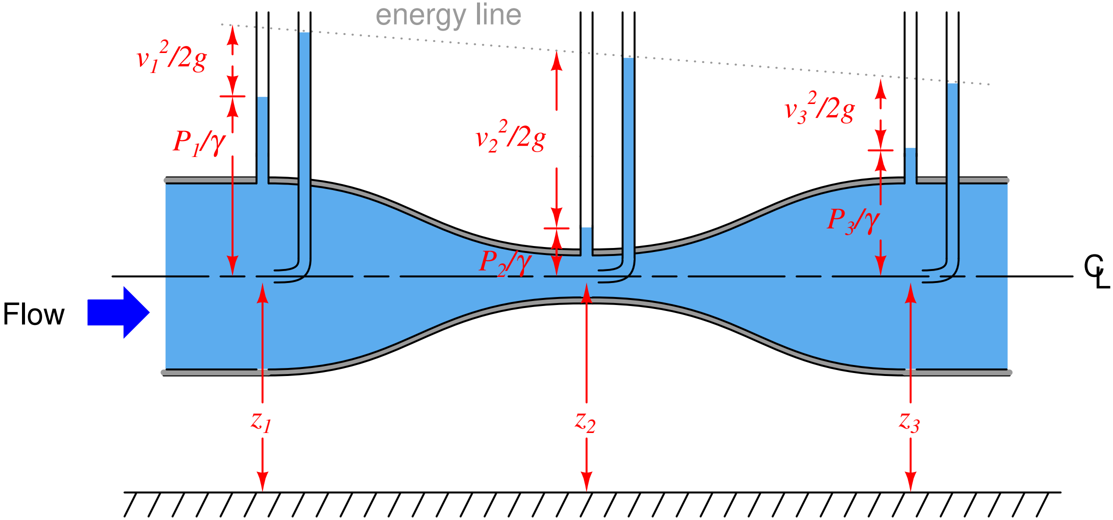
$$z + \frac{v^2}{2g} + \frac{P}{\gamma} = (\text{constant})$$



$v_1^2/2g$
$v_3^2/2g$
energy line
P_1/γ
$v_2^2/2g$
P_3/γ
P_2/γ
$\mathbb{C}$
Flow
z_1
z_2
z_3

$$\frac{v^2}{2g}$$

$$\frac{P}{\gamma}$$


energy line
$v_1^2/2g$
P_1/γ
$v_2^2/2g$
P_2/γ
$v_3^2/2g$
P_3/γ
Flow
z_1
z_2
z_3
℄