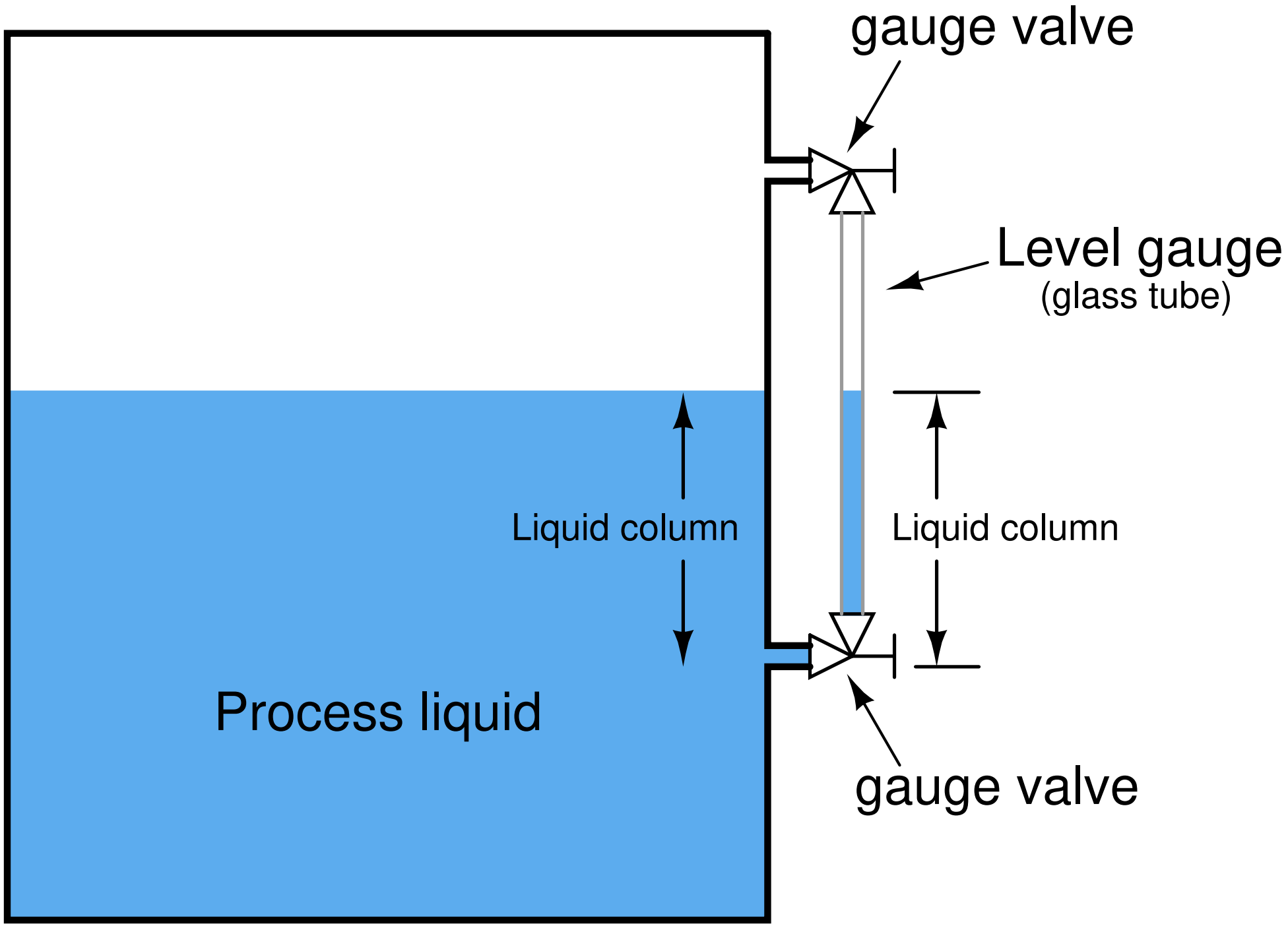
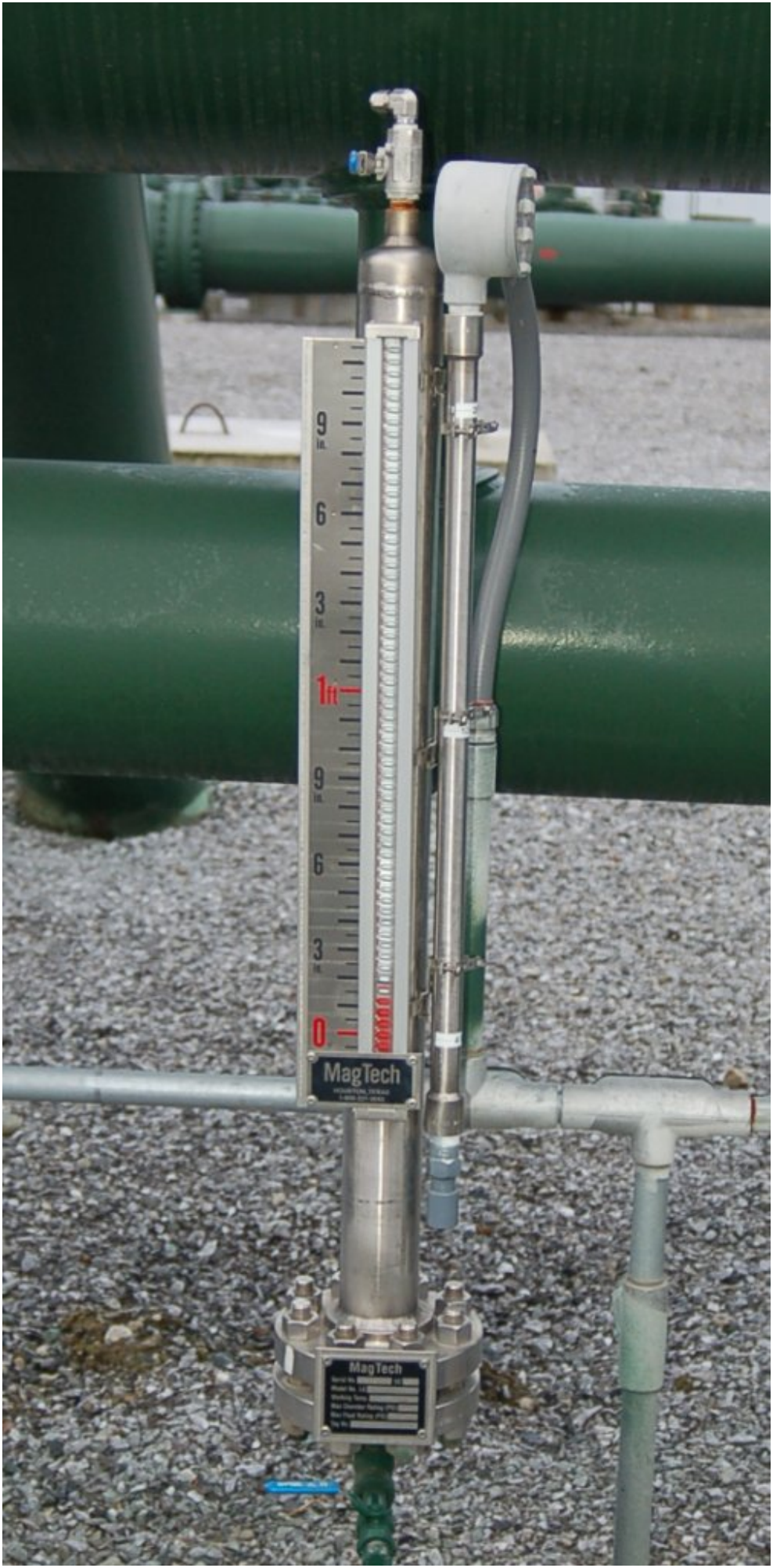
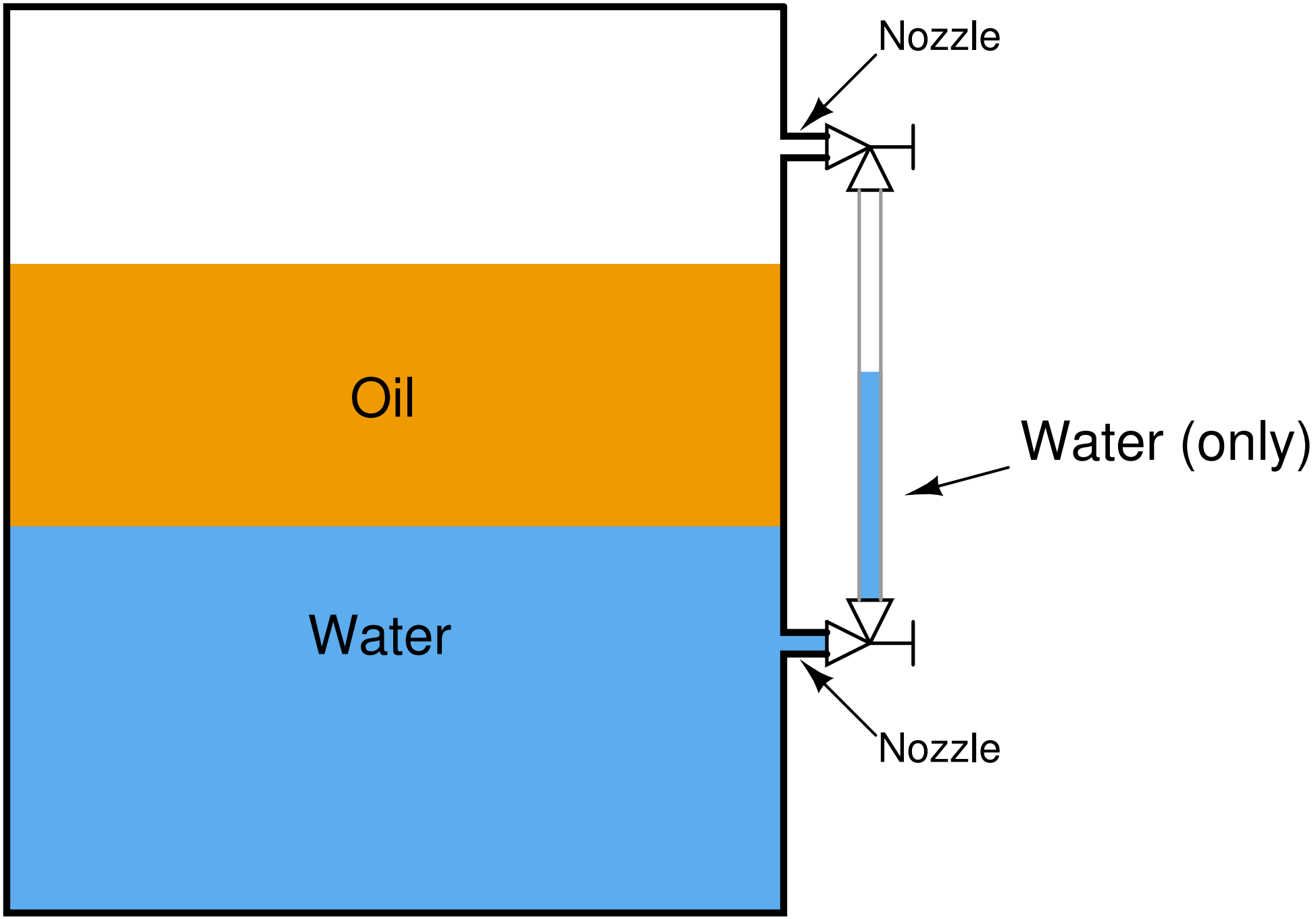
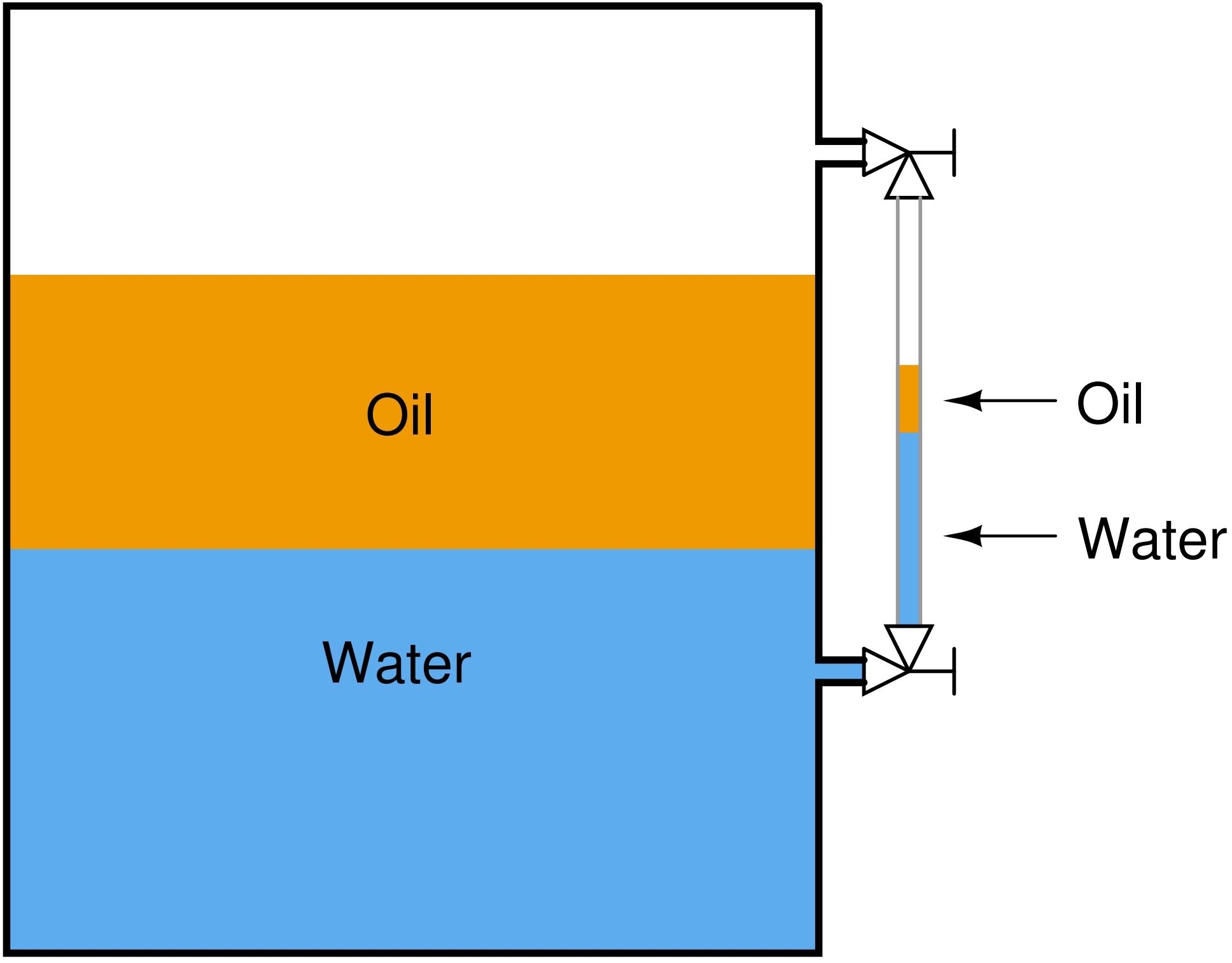
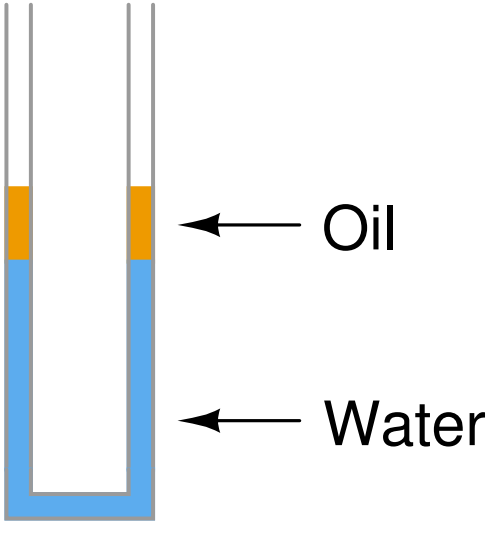
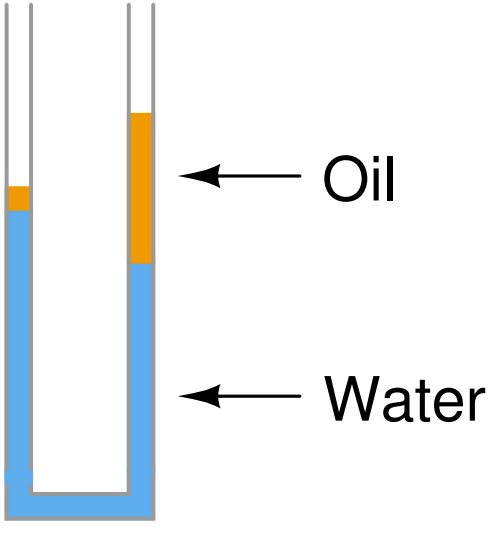

gauge valve
Level gauge
(glass tube)
Liquid column
Liquid column
Process liquid
gauge valve

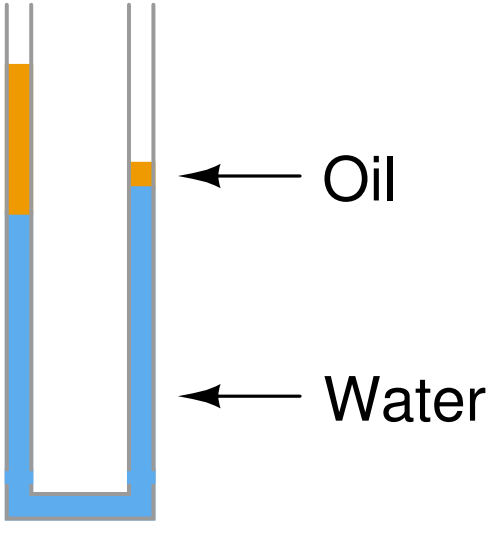

9
6
3
1
9
6
3
0
MagTech
MagTech

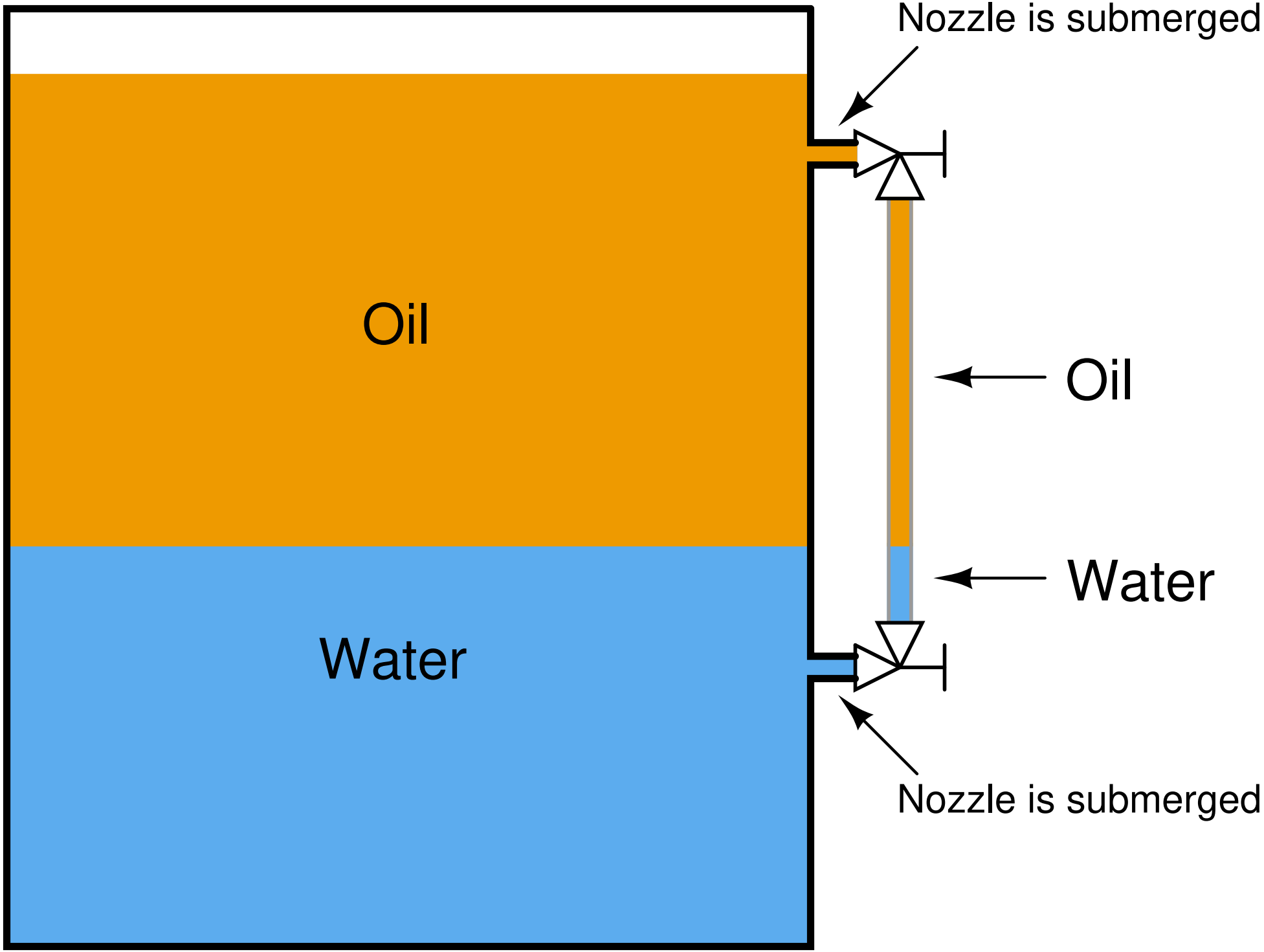

Nozzle
Oil
Water (only)
Water
Nozzle

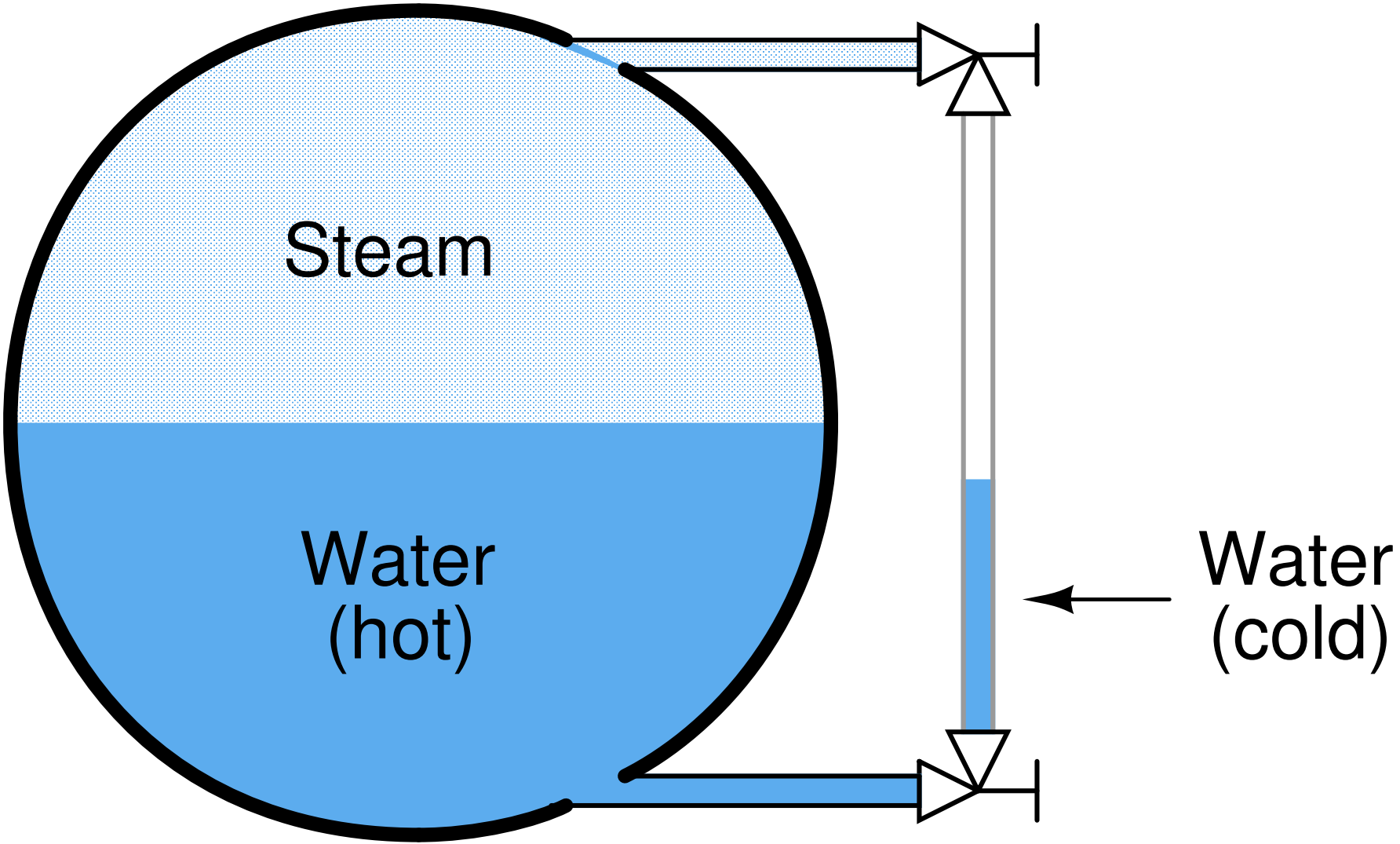

Oil
Water
Oil
Water


Oil
Water

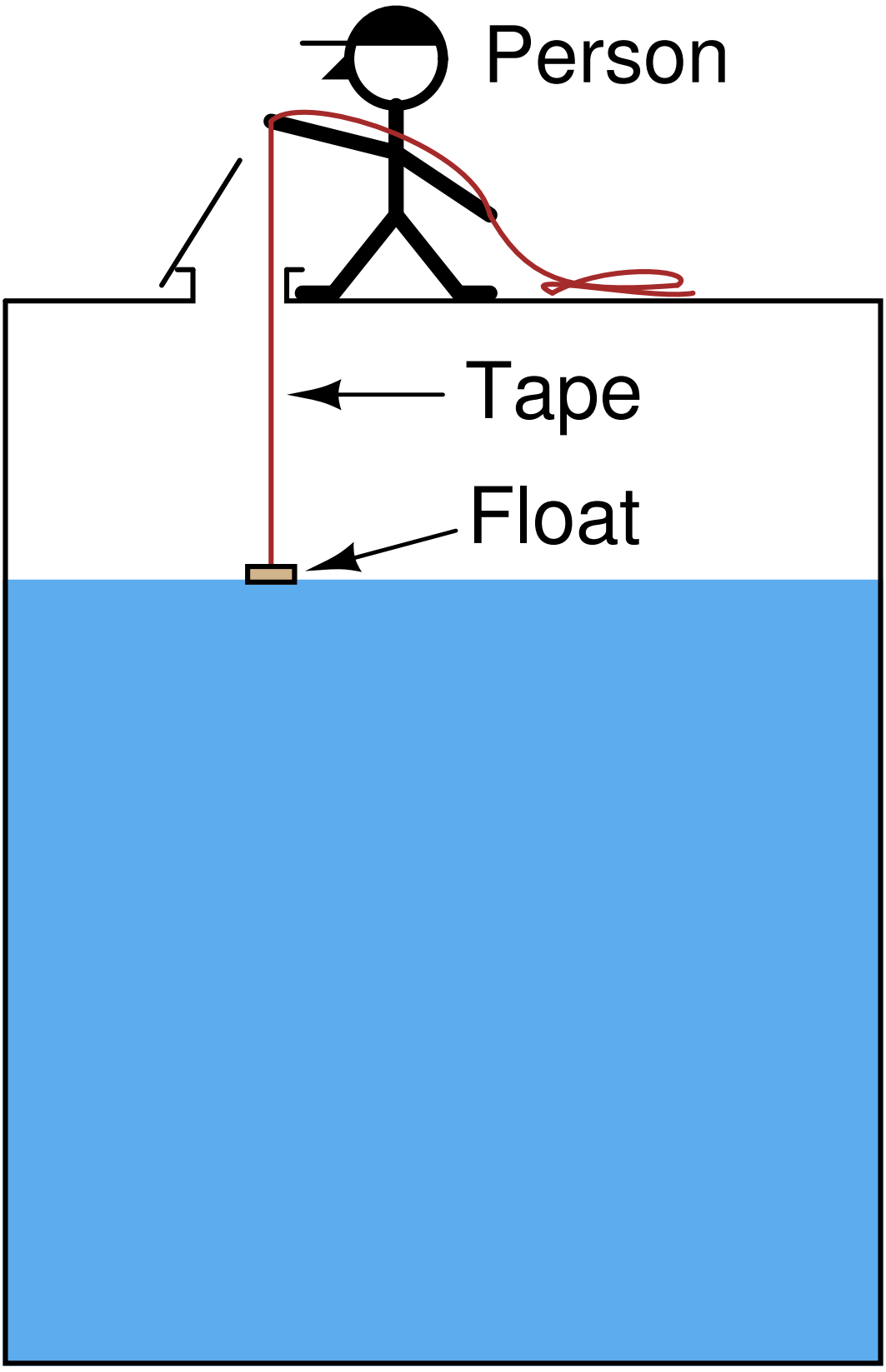

Oil
Water

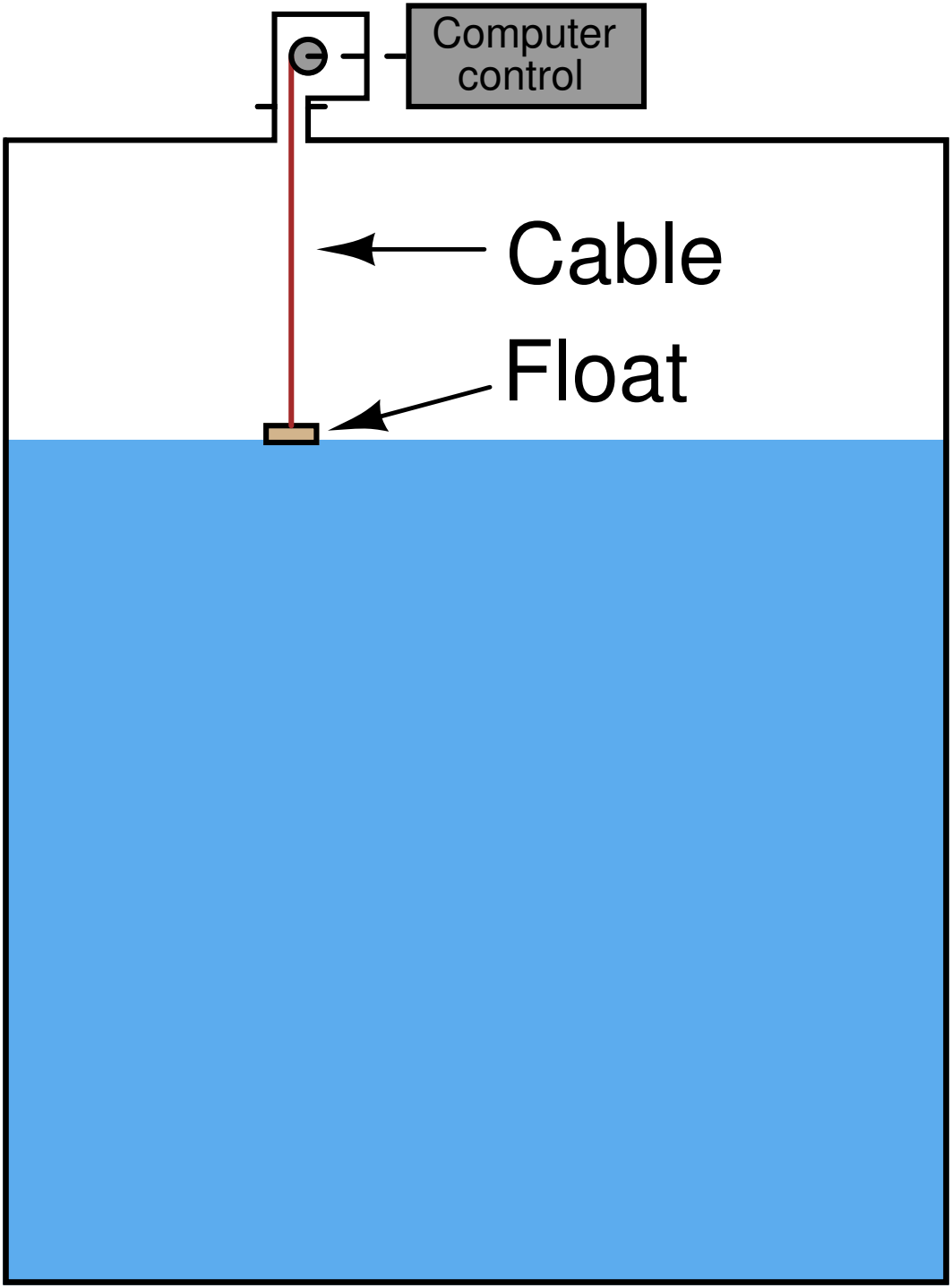

Oil
Water

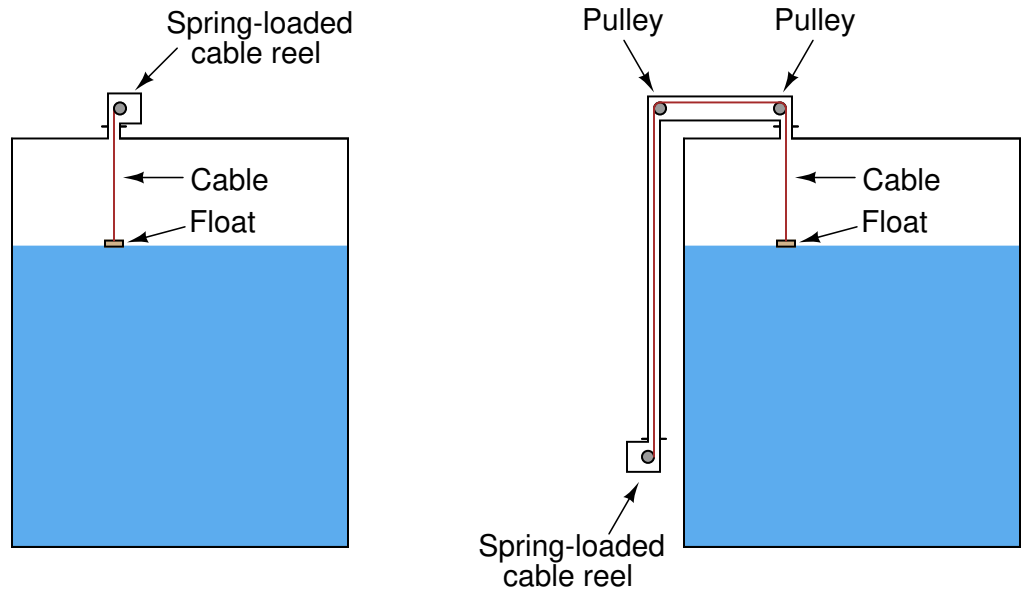

Nozzle is submerged
Oil
Oil
Water
Water
Nozzle is submerged

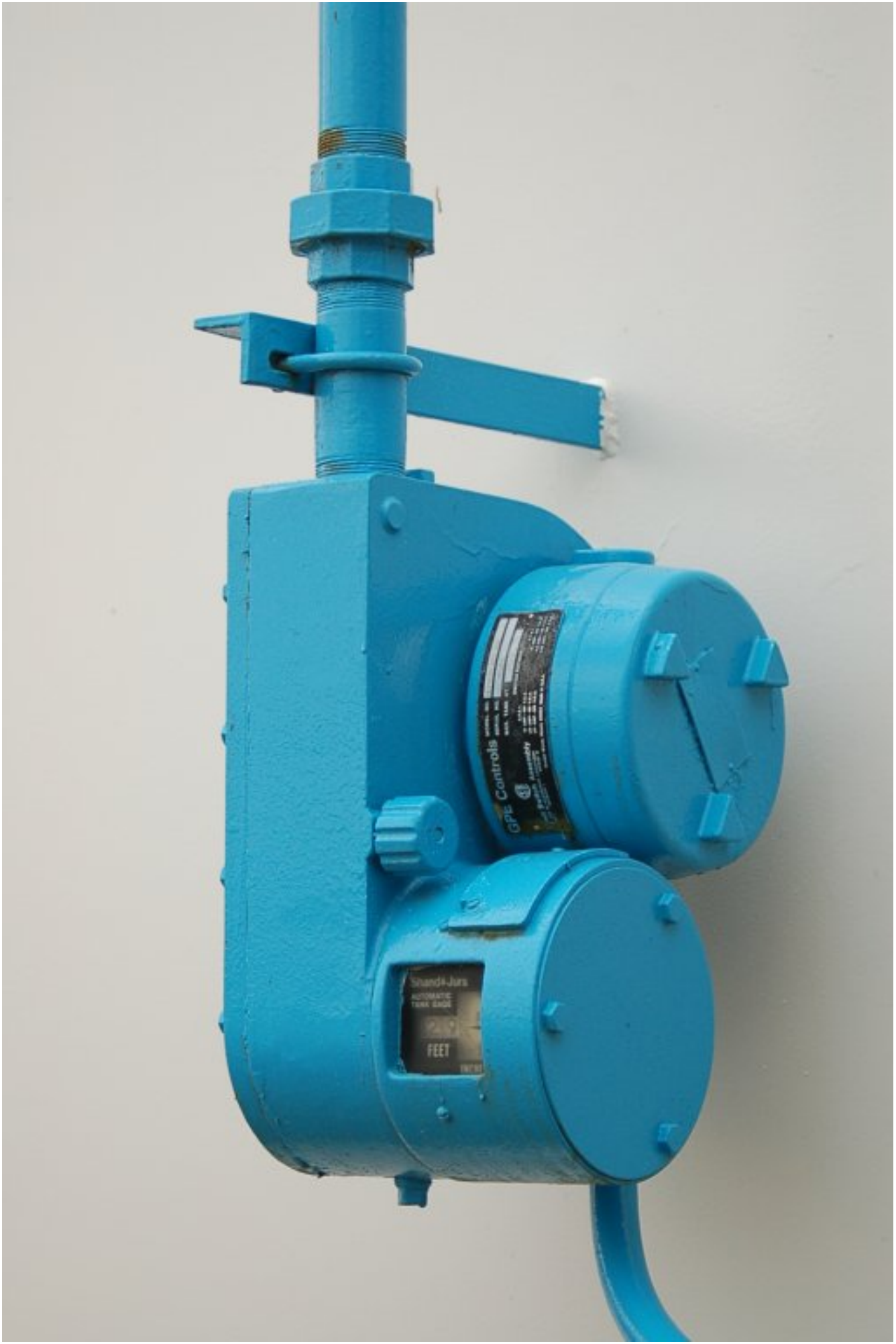

Steam
Water
(hot)
Water
(cold)

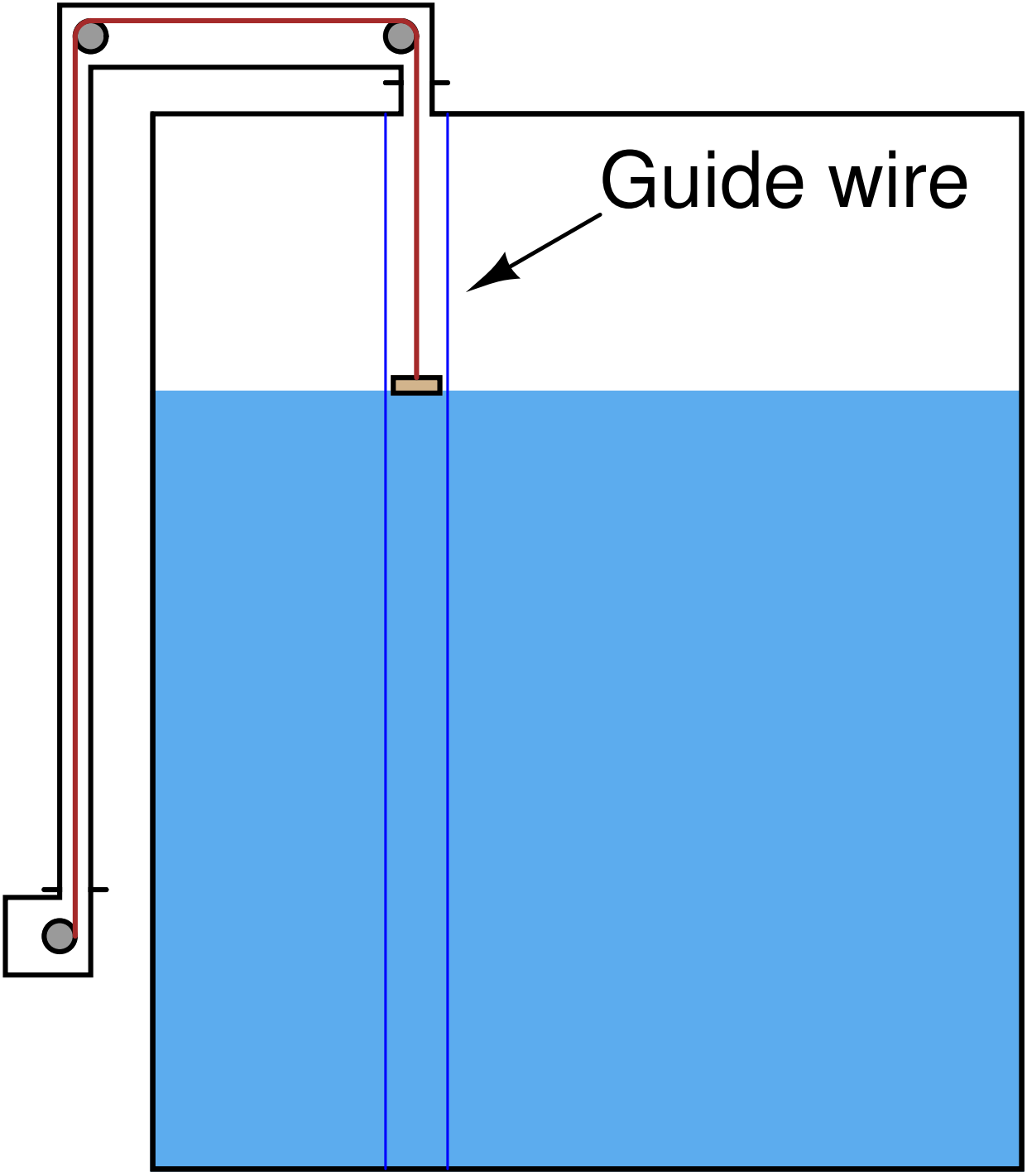
3

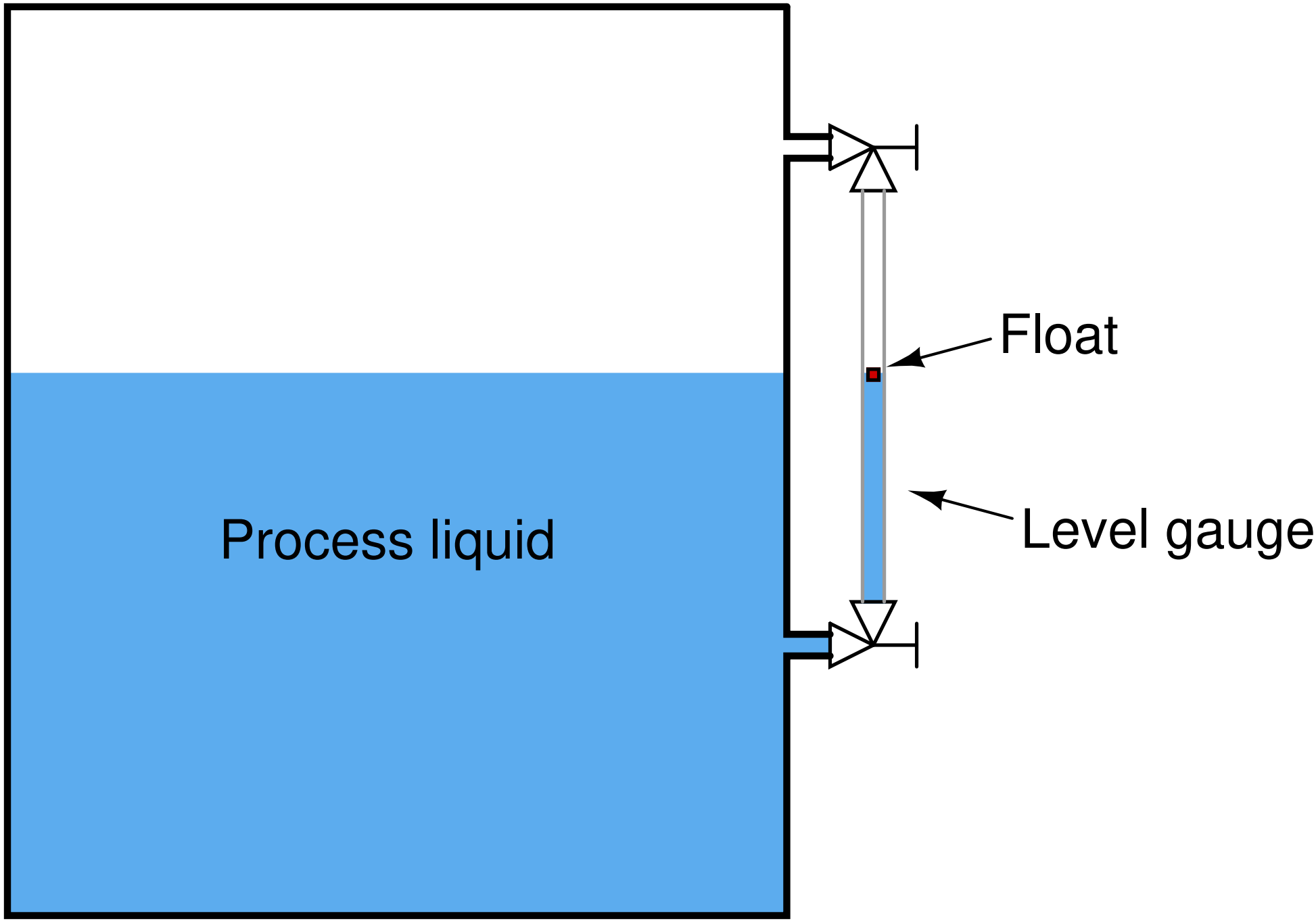

Person
Tape
Float

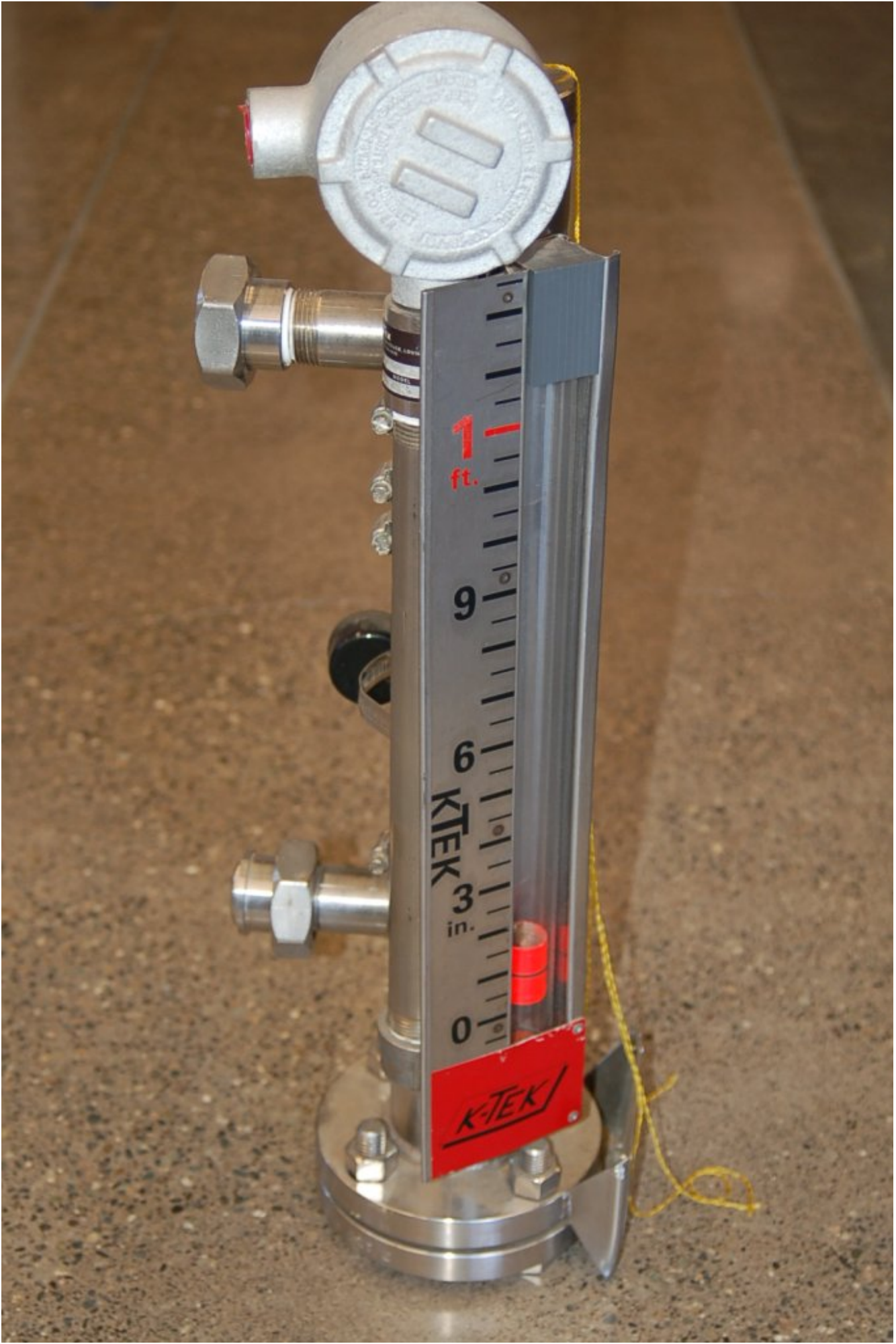

Computer control
Cable
Float


Spring-loaded
cable reel
Cable
Float
Pulley
Pulley
Cable
Float
Spring-loaded
cable reel

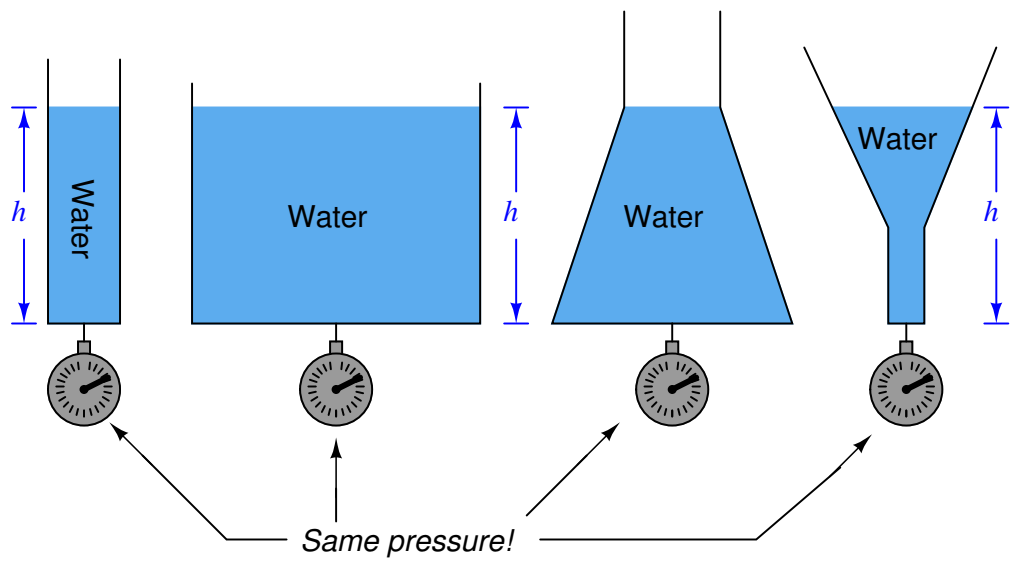

GPE Controls
Shand&Jurs
FEET


Guide wire


Process liquid
Float
Level gauge


1
ft.
9
6
KTEK
3
in.
0
K-TEK


K-TEK
BATON ROUGE


h
Water
Water
h
Water
h
Water
h
Same pressure!

$$P = \rho g h$$

$$P = \gamma h$$

P

ρ

g

h

$$P = \gamma h$$

$$P_{oil} = \left(\frac{40 \text{ lb}}{\text{ft}^3}\right)\left(\frac{12 \text{ ft}}{1}\right) = \frac{480 \text{ lb}}{\text{ft}^2}$$

$$P_{oil} = \left(\frac{480 \text{ lb}}{\text{ft}^2}\right)\left(\frac{1^2 \text{ ft}^2}{12^2 \text{ in}^2}\right)$$

$$P_{oil} = \left(\frac{480 \text{ lb}}{\text{ft}^2}\right)\left(\frac{1 \text{ ft}^2}{144 \text{ in}^2}\right)$$

$$P_{oil} = \frac{3.33 \text{ lb}}{\text{in}^2} = 3.33 \text{ PSI}$$

3.33

$$\text{Specific Gravity of oil} = \frac{\gamma_{oil}}{\gamma_{water}}$$

$$\text{Specific Gravity of oil} = \frac{40 \text{ lb/ft}^3}{62.4 \text{ lb/ft}^3}$$

Specific Gravity of oil = 0.641

$$P_{oil} = (P_{water})(\text{Specific Gravity})$$

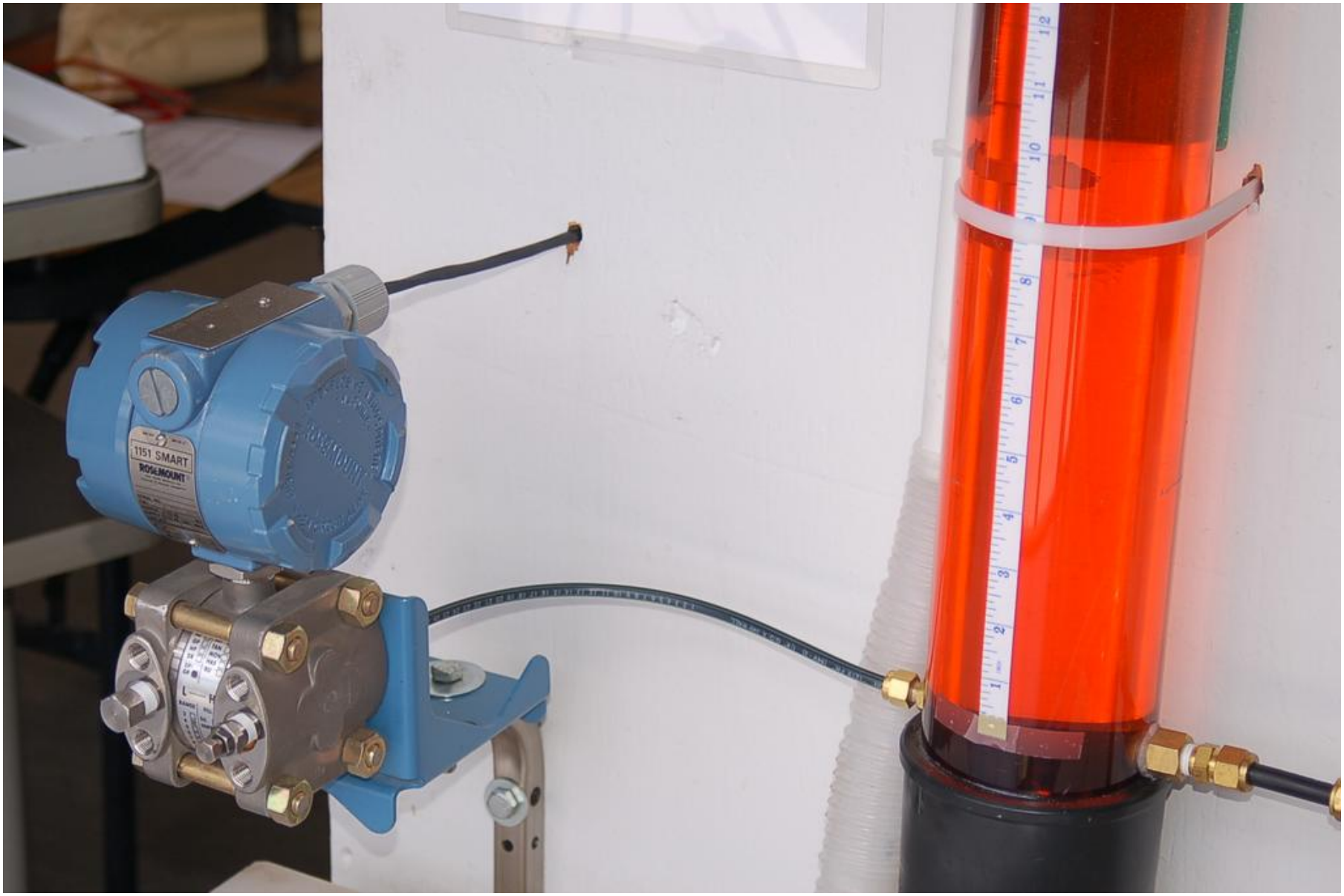
$$P_{oil} = (144\ \text{"W.C.})(0.641)$$

$$P_{oil} = 92.3\ ”\text{W.C.}$$

$$P_{oil} = \left(\frac{92.3\ \text{"W.C.}}{1}\right)\left(\frac{1\ \text{PSI}}{27.68\ \text{"W.C.}}\right)$$

$$P_{oil} = 3.33 \text{ PSI}$$

$$P = \gamma h$$


1151 SMART
ROSEMOUNT

m

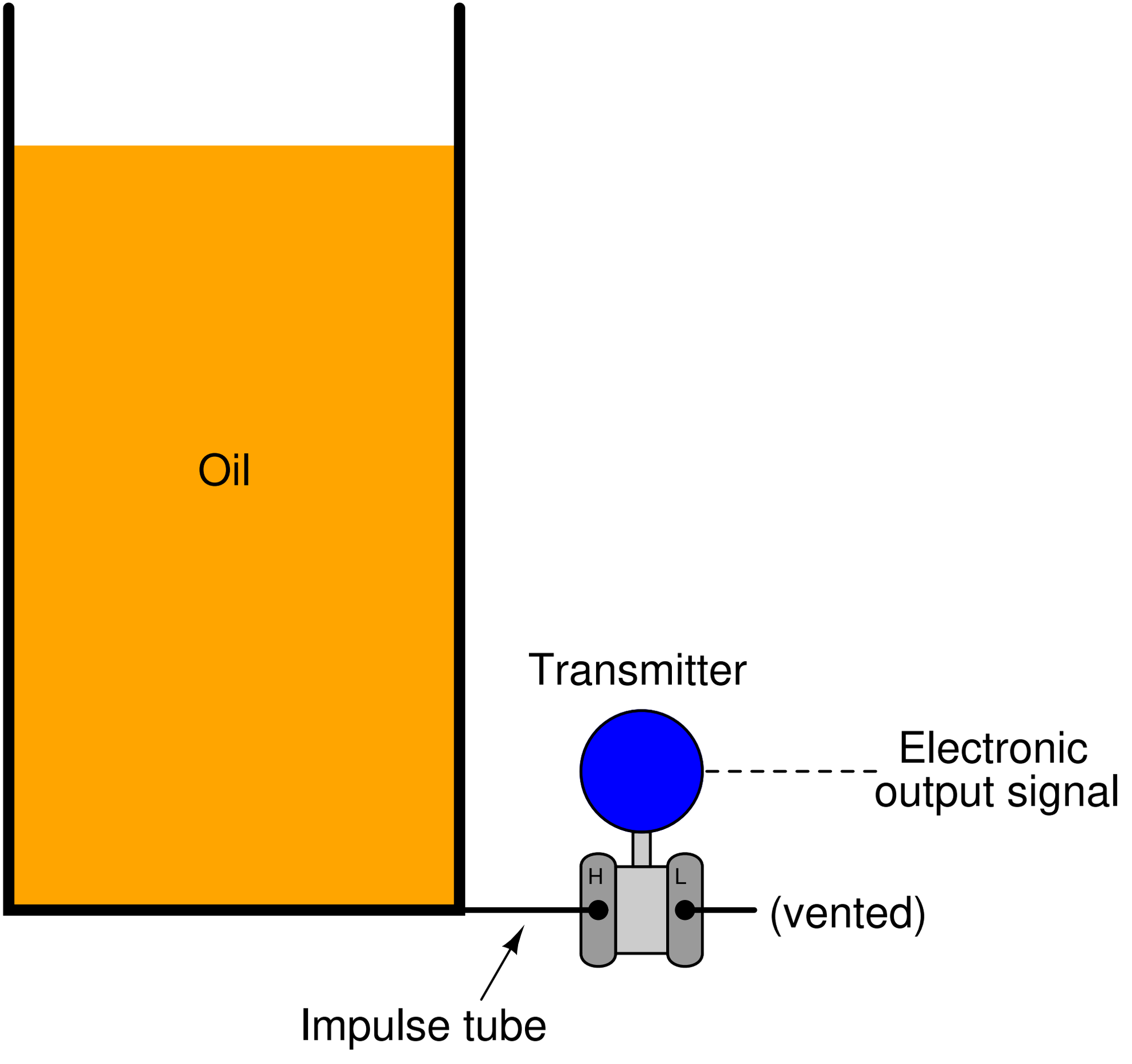
$$m = \rho V$$

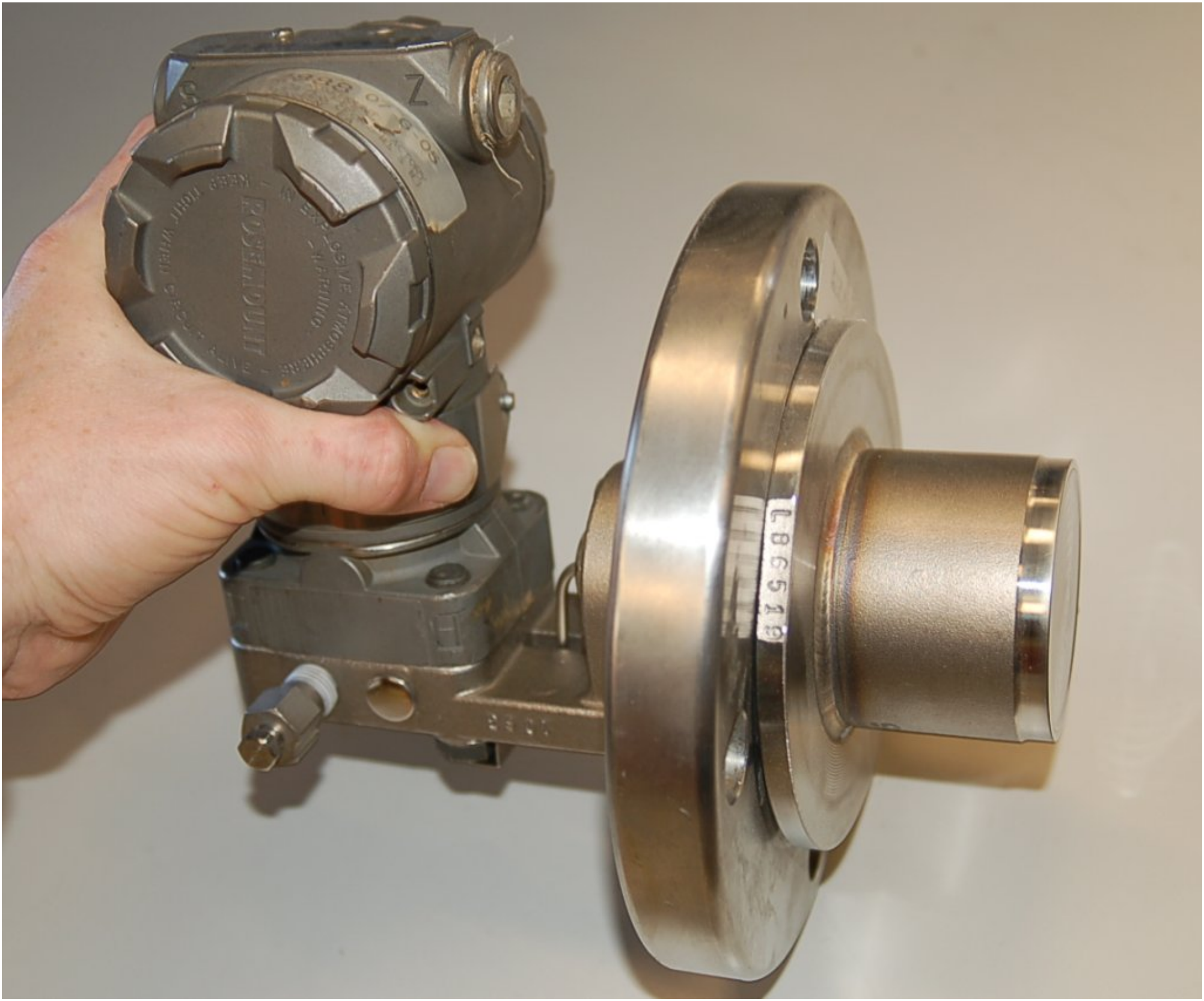
V

$$V = Ah$$

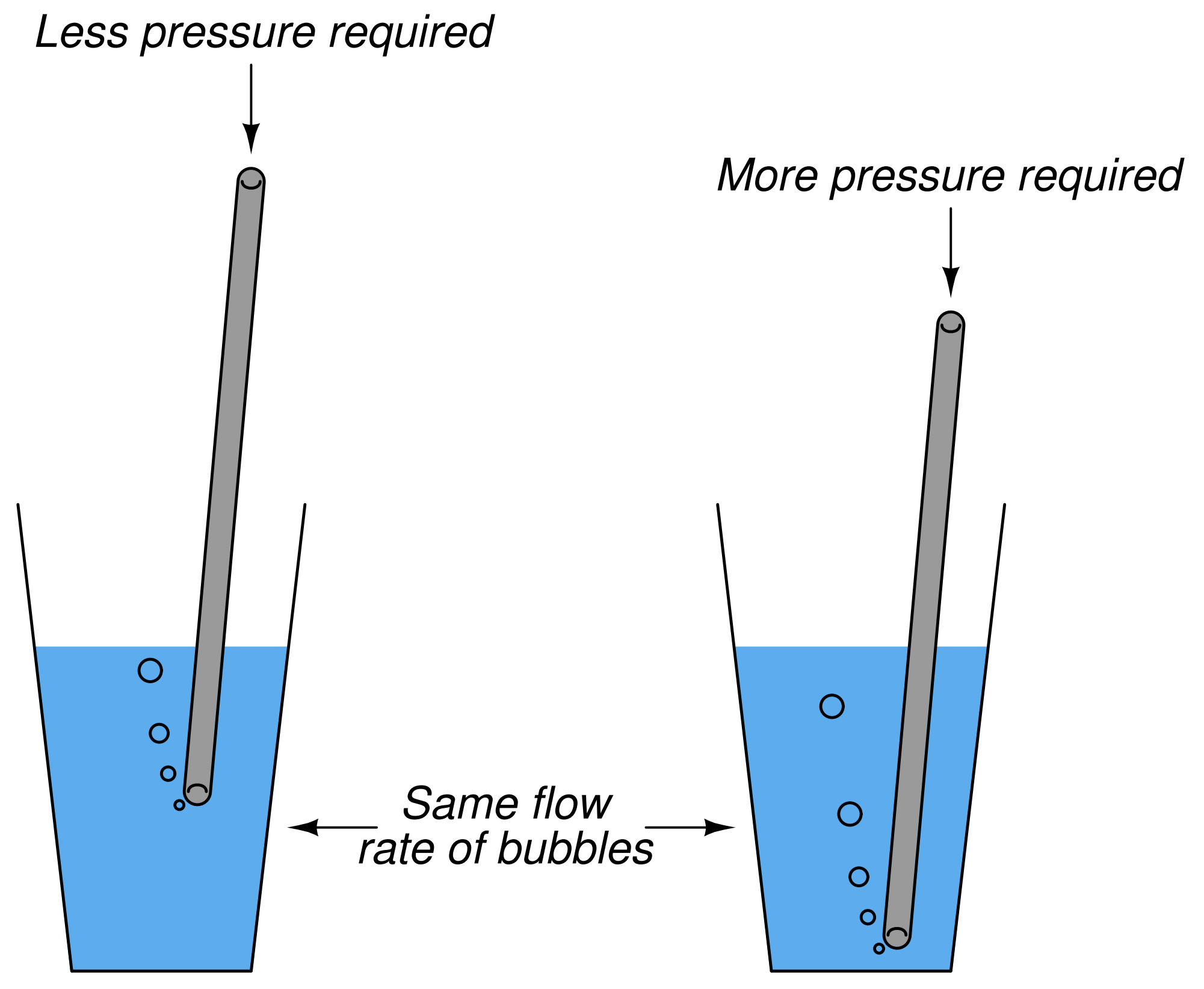
$$P = \rho g h$$

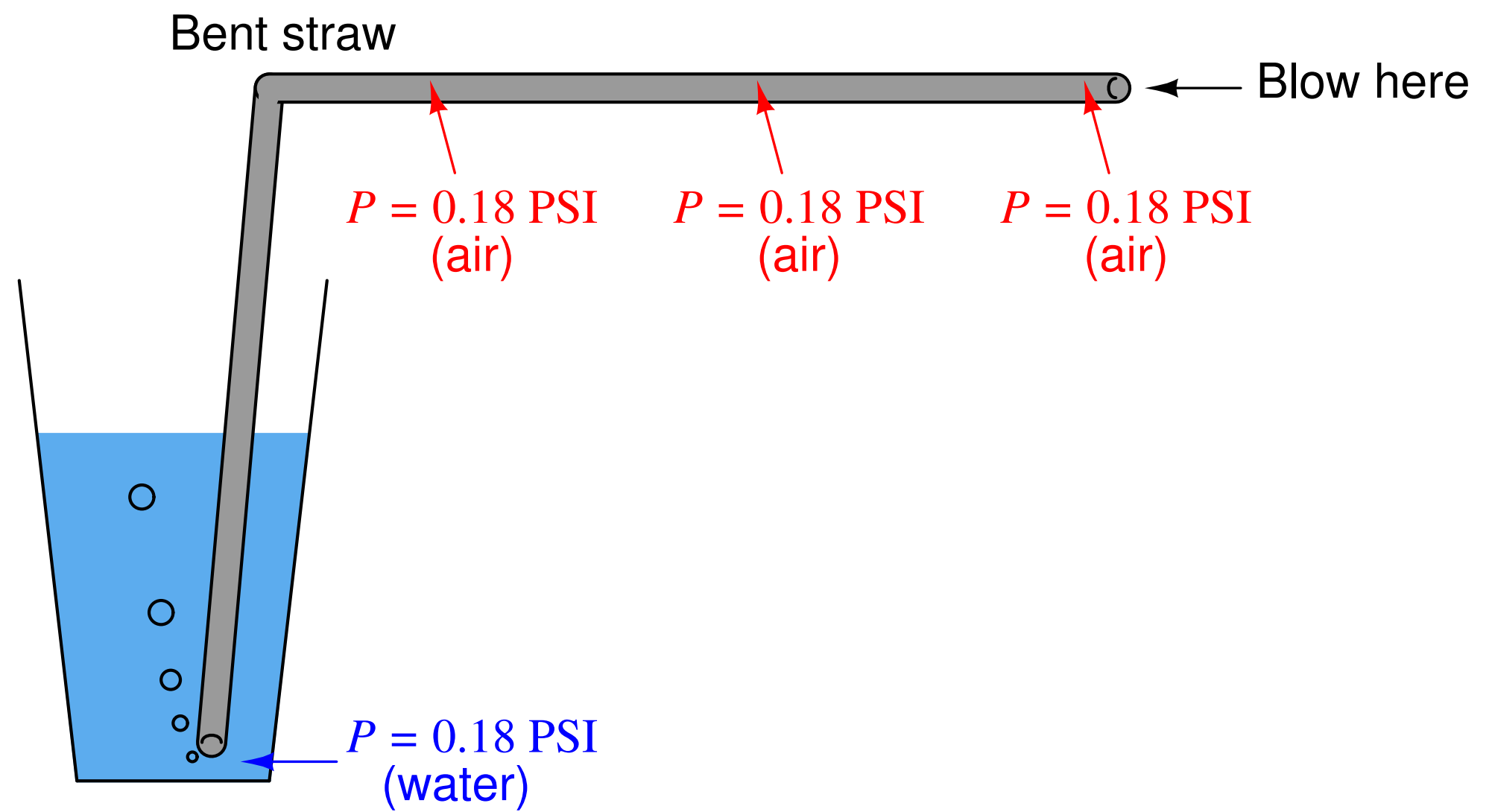
$$m = \frac{AP}{g}$$

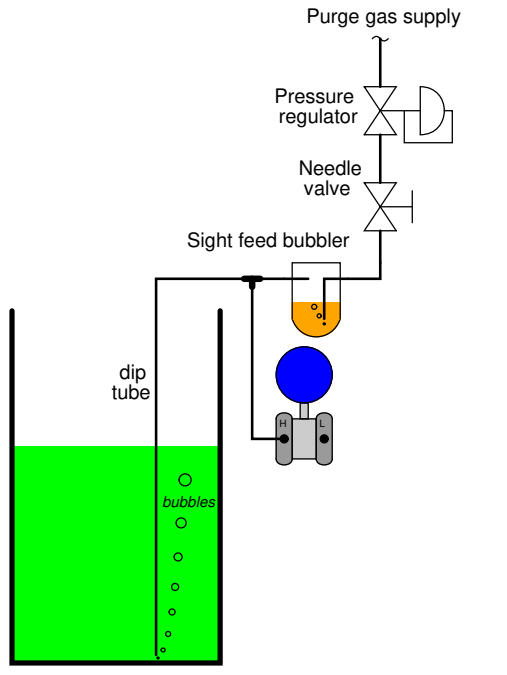

Oil
Transmitter
Electronic
output signal
H
L
(vented)
Impulse tube

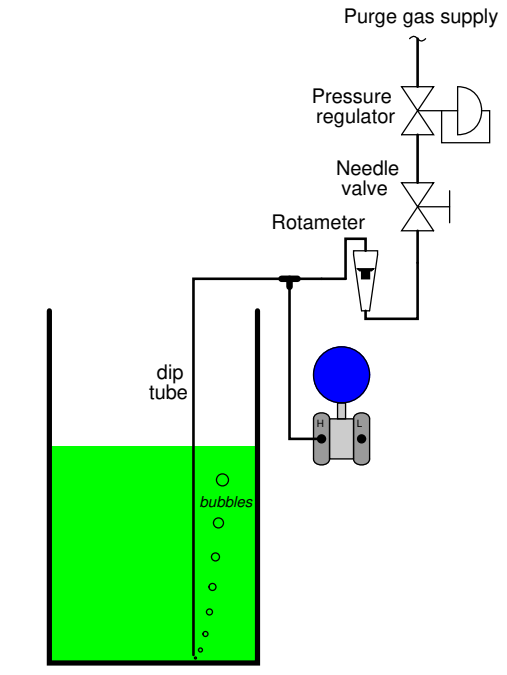

Z
ROSEMOUNT
KEEP TIGHT WHEN ENERGIZED
DO NOT OPEN WHEN ENERGIZED
1165981

Oil level	Percent of range	Hydrostatic pressure	Transmitter output
0 ft	0 %	0 PSI	4 mA
3 ft	25 %	0.833 PSI	8 mA
6 ft	50 %	1.67 PSI	12 mA
9 ft	75 %	2.50 PSI	16 mA
12 ft	100 %	3.33 PSI	20 mA

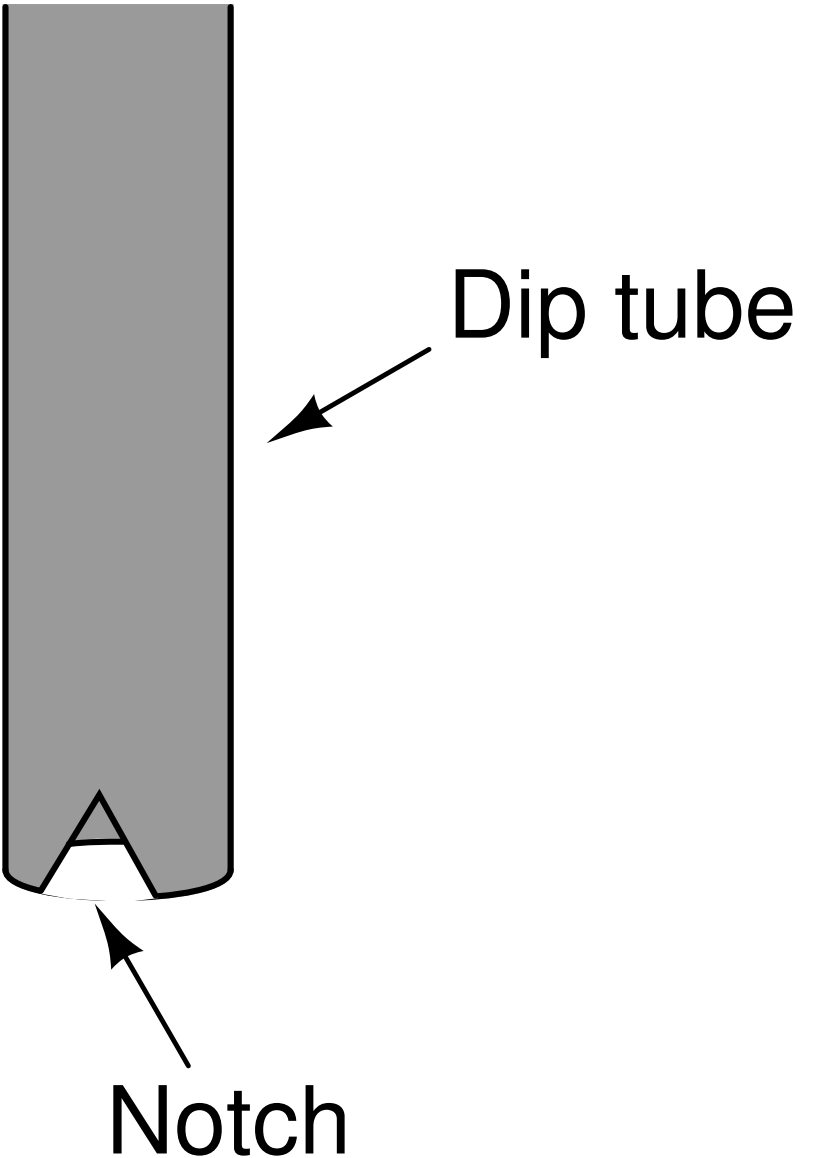

Less pressure required
More pressure required
Same flow
rate of bubbles


Bent straw
Blow here
P = 0.18 PSI
(air)
P = 0.18 PSI
(air)
P = 0.18 PSI
(air)
P = 0.18 PSI
(water)

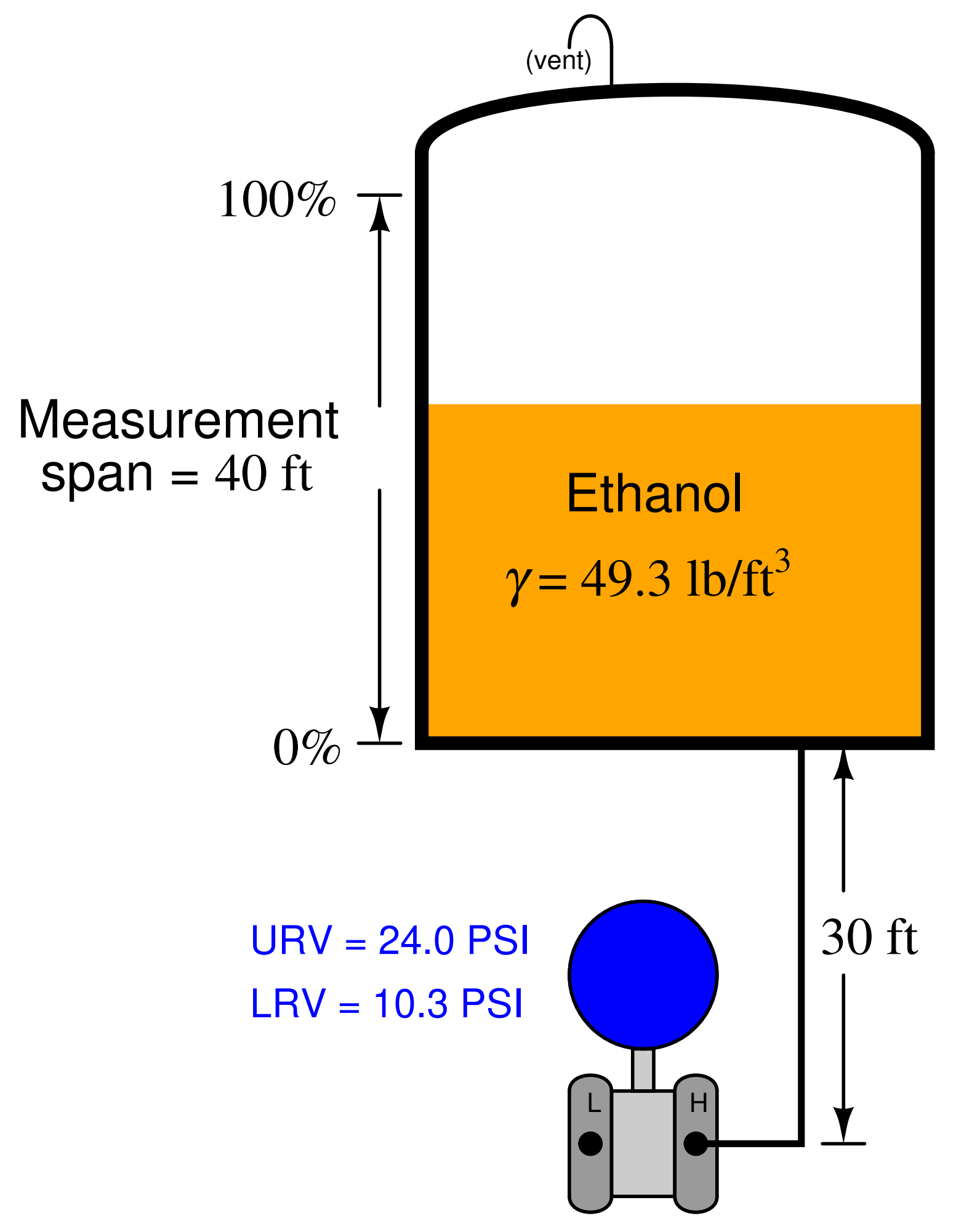

Purge gas supply
Pressure regulator
Needle valve
Sight feed bubbler
dip tube
bubbles
H
L


Purge gas supply
Pressure regulator
Needle valve
Rotameter
dip tube
bubbles
H
L

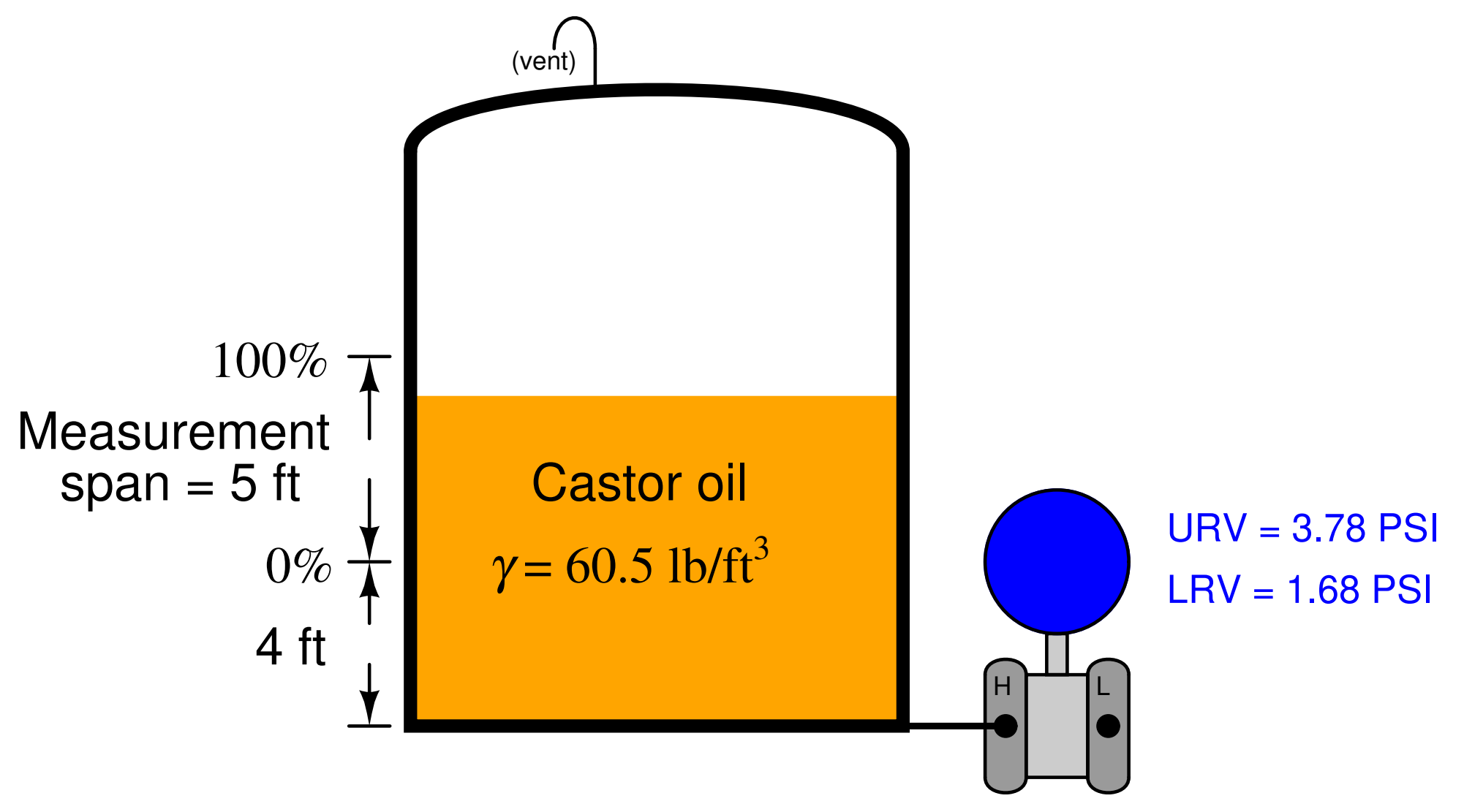
$\frac{1}{4}$

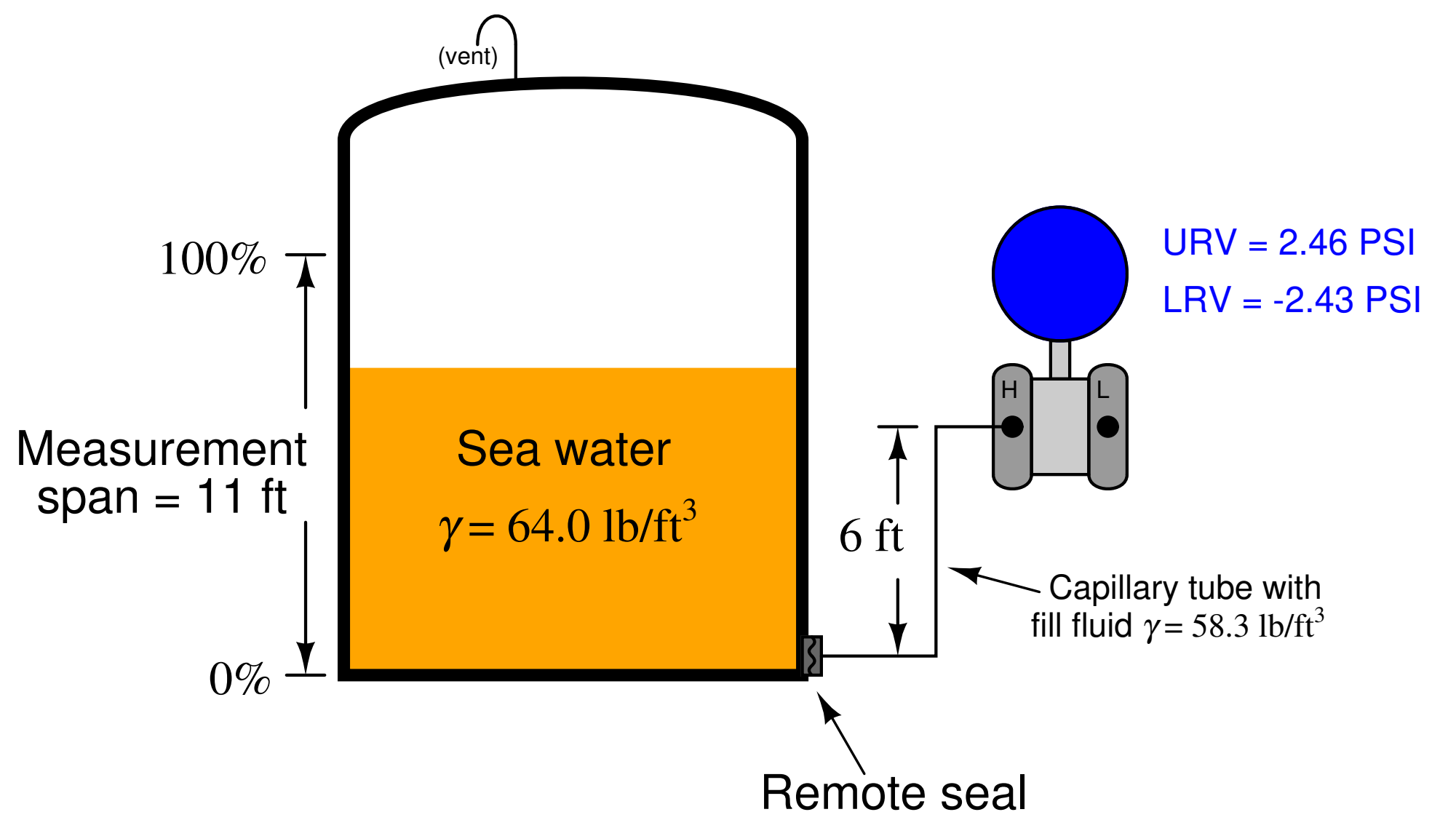

Dip tube
Notch


ROSEMOUNT


(vent)
100%
Measurement
span = 40 ft
Ethanol
$\gamma = 49.3$ lb/ft^3
0%
30 ft
URV = 24.0 PSI
LRV = 10.3 PSI
L
H

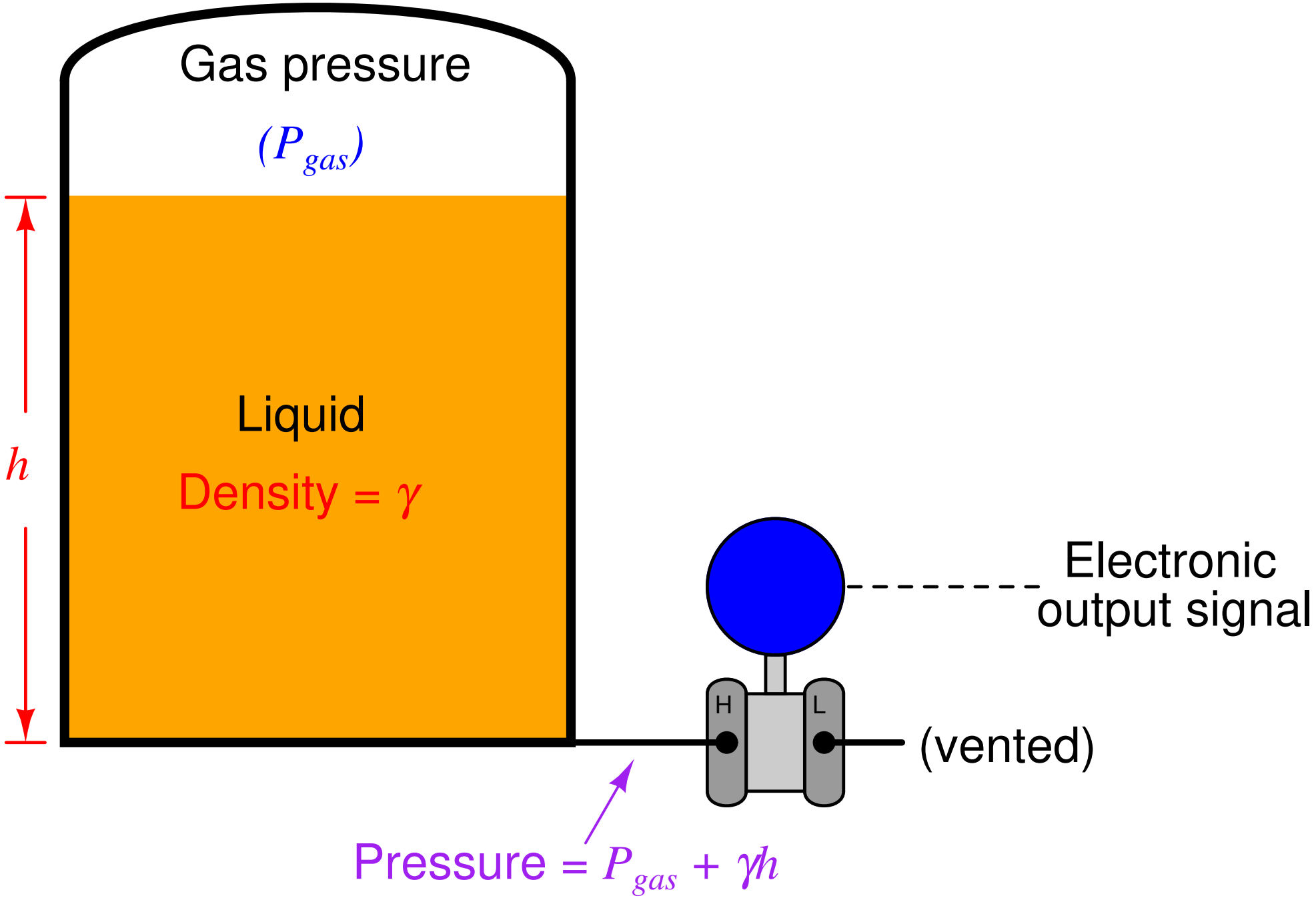
Ethanol level in tank	**Percent of range**	**Pressure** (inches of water)	**Pressure** (PSI)	**Output** (mA)
0 ft	0 %	284 "W.C.	10.3 PSI	4 mA
20 ft	50 %	474 "W.C.	17.1 PSI	12 mA
40 ft	100 %	663 "W.C.	24.0 PSI	20 mA

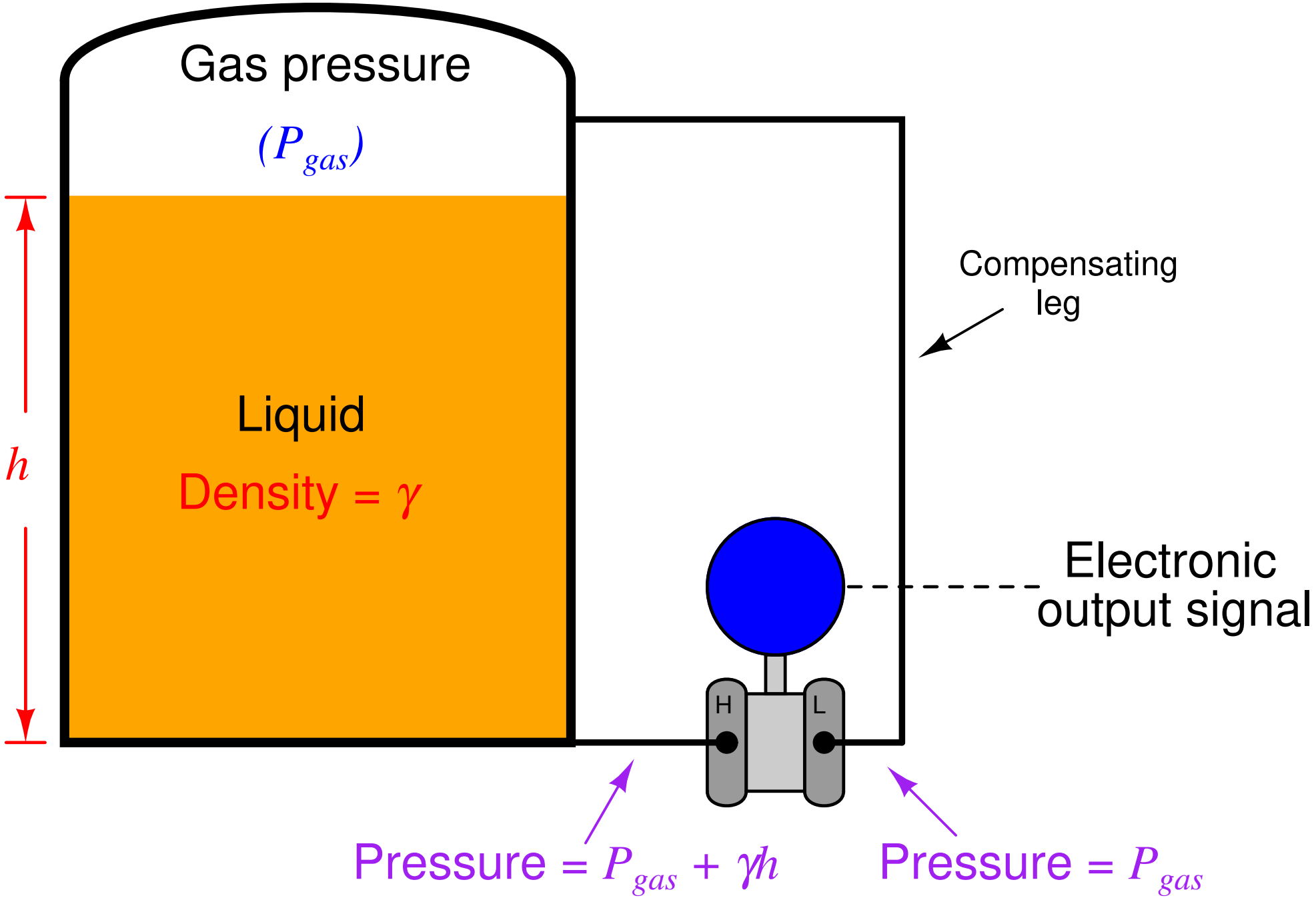

(vent)
100%
Measurement
span = 5 ft
0%
4 ft
Castor oil
$\gamma = 60.5$ lb/ft^3
H
L
URV = 3.78 PSI
LRV = 1.68 PSI


(vent)
100%
Measurement
span = 11 ft
0%
Sea water
$\gamma = 64.0$ lb/ft^3
6 ft
H
L
URV = 2.46 PSI
LRV = -2.43 PSI
Capillary tube with
fill fluid $\gamma = 58.3$ lb/ft^3
Remote seal

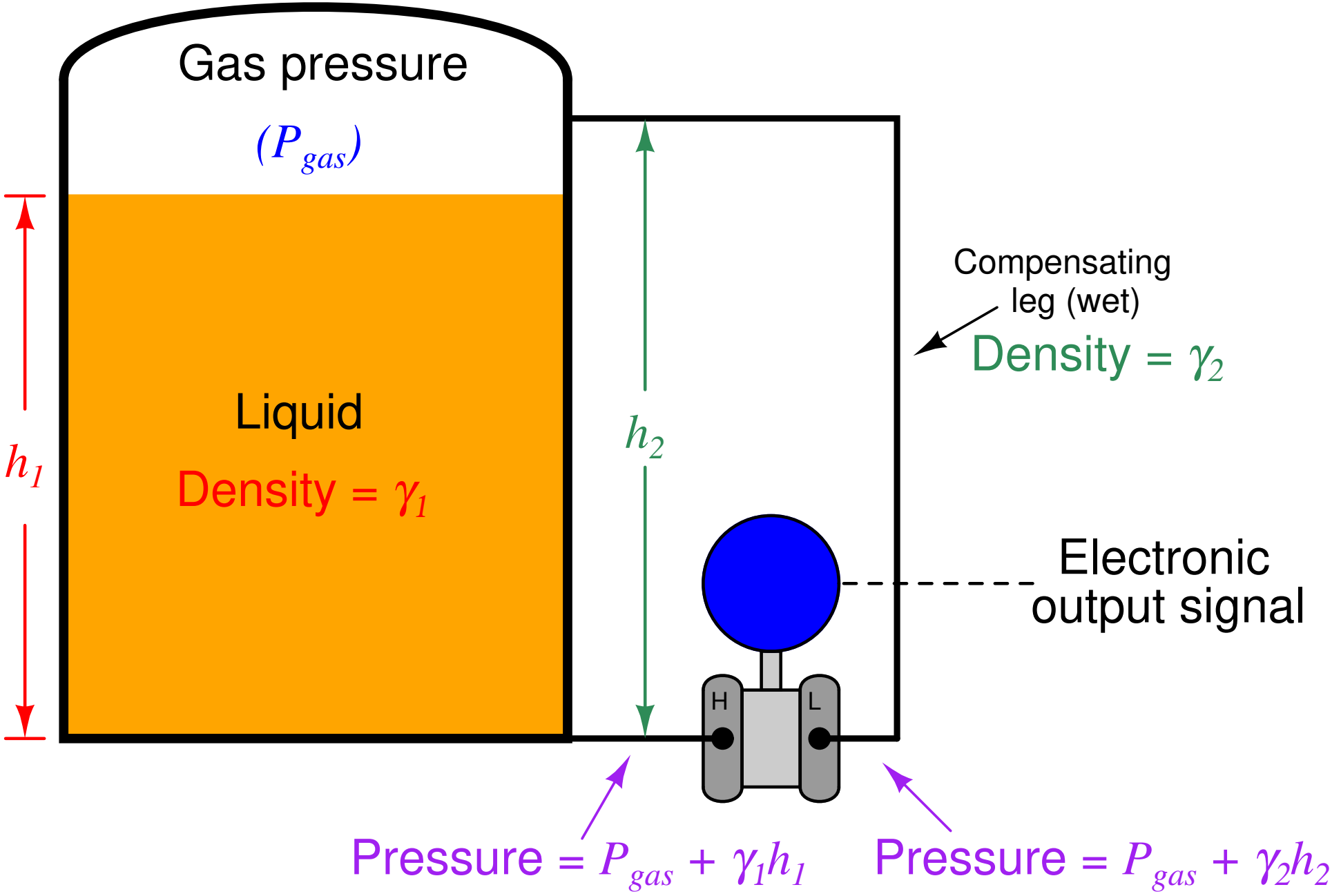
-2.43

-67.2


Gas pressure
(P_{gas})
Liquid
Density = γ
h
H
L
Electronic
output signal
(vented)
Pressure = $P_{gas} + \gamma h$

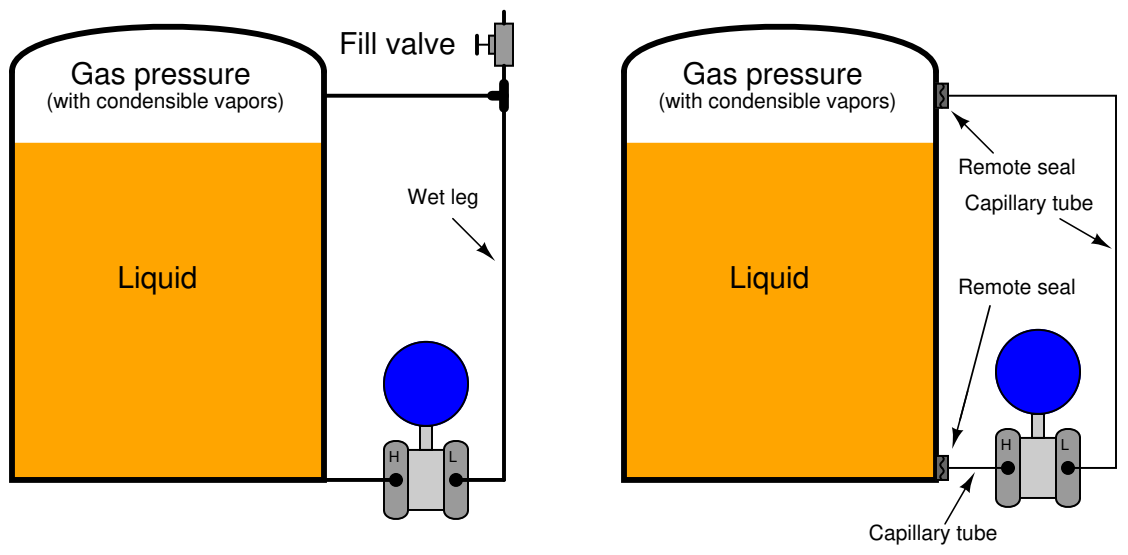

Gas pressure
(P_{gas})
Liquid
Density = γ
h
Compensating leg
Electronic output signal
H
L
Pressure = $P_{gas} + \gamma h$
Pressure = P_{gas}

$$(P_{gas} + \gamma h) - P_{gas} = \gamma h$$

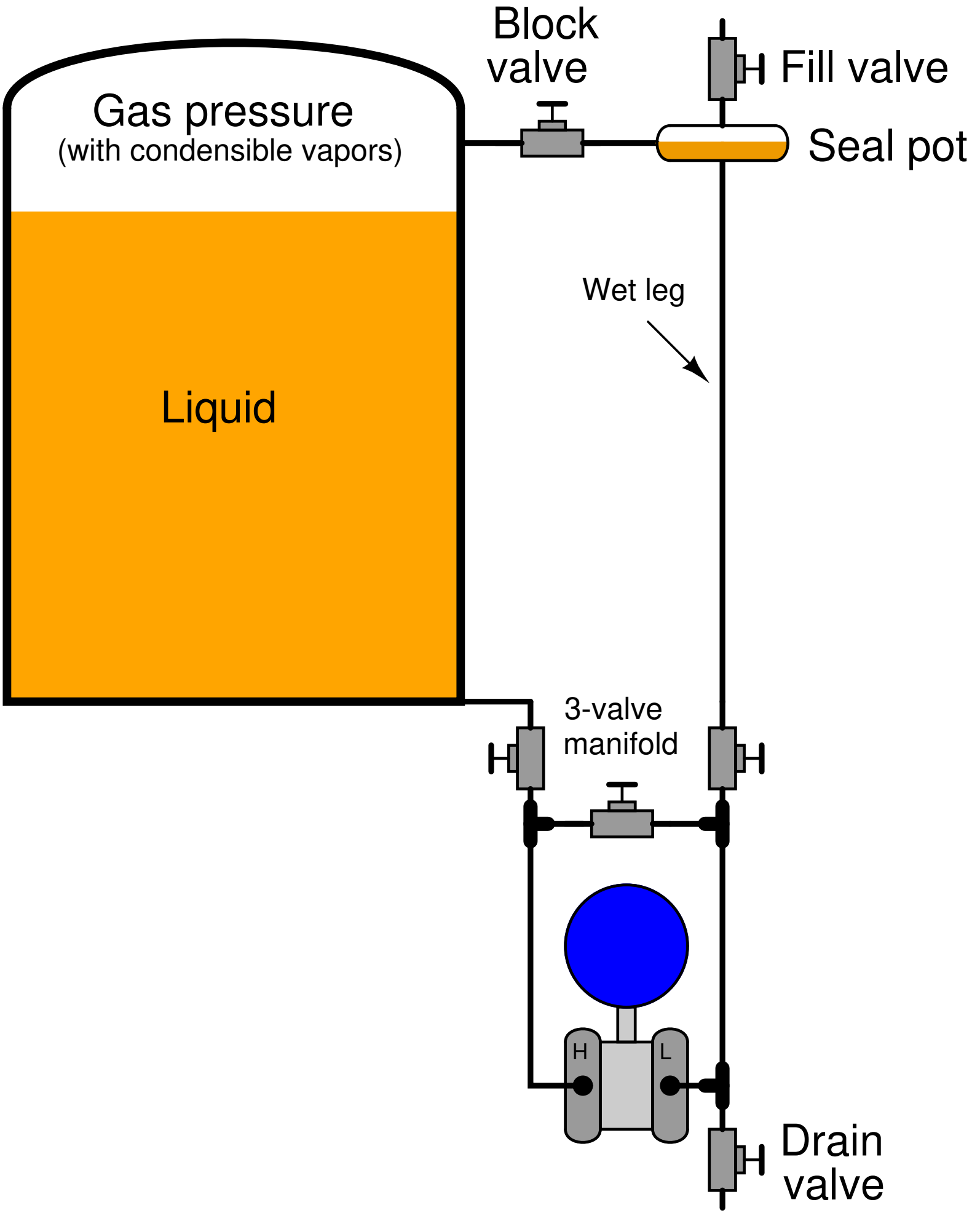

Gas pressure
(P_{gas})
Liquid
Density = γ_1
h_1
h_2
Compensating
leg (wet)
Density = γ_2
Electronic
output signal
H
L
Pressure = $P_{gas} + \gamma_1 h_1$
Pressure = $P_{gas} + \gamma_2 h_2$

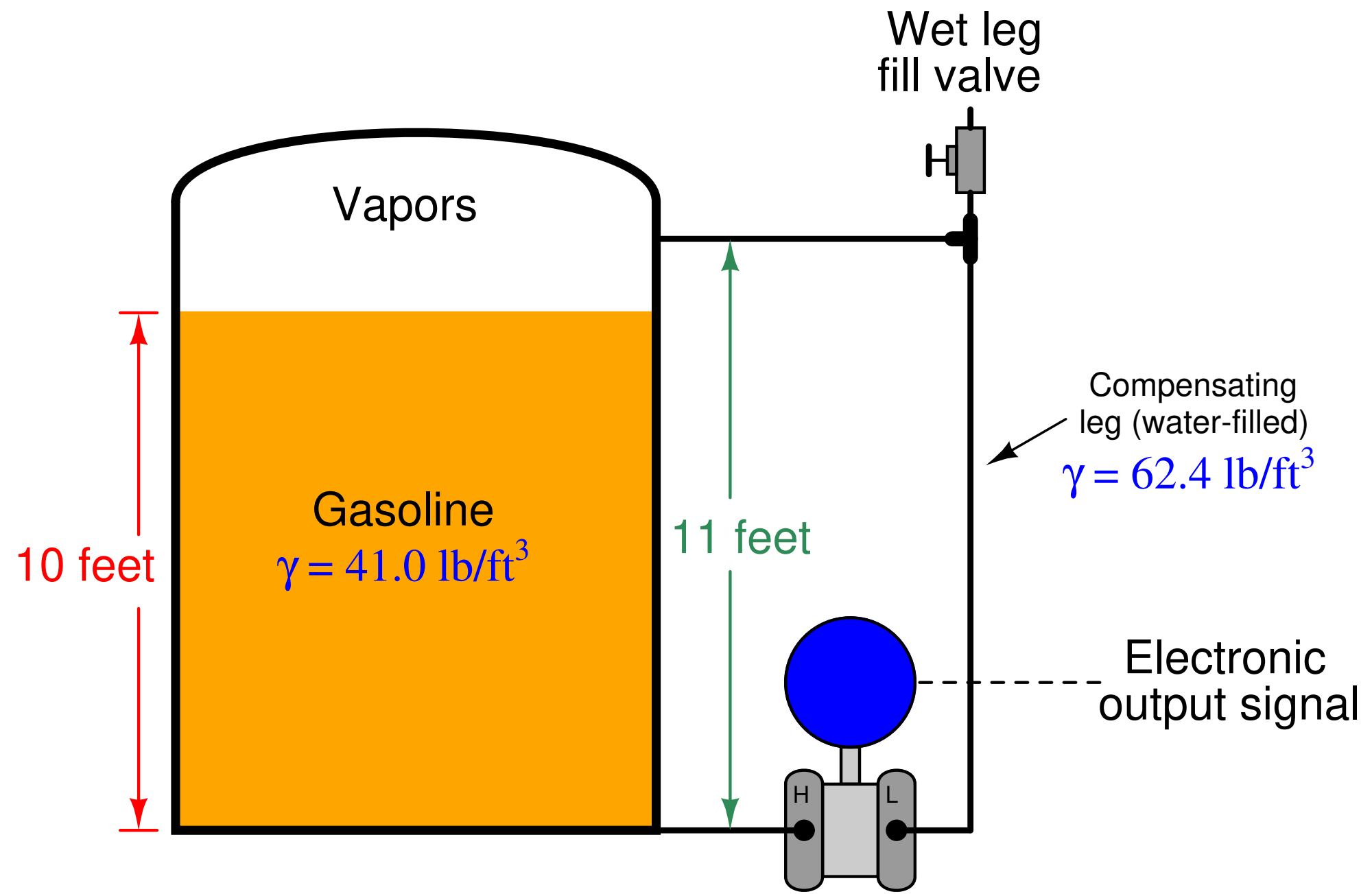
$$(P_{gas} + \gamma_1 h_1) - (P_{gas} + \gamma_2 h_2) = \gamma_1 h_1 - \gamma_2 h_2$$

$$\text{Differential pressure} = \gamma_1 h_1 - \text{Constant}$$


Gas pressure
(with condensible vapors)
Fill valve
Wet leg
Liquid
H
L
Gas pressure
(with condensible vapors)
Remote seal
Capillary tube
Liquid
Remote seal
H
L
Capillary tube

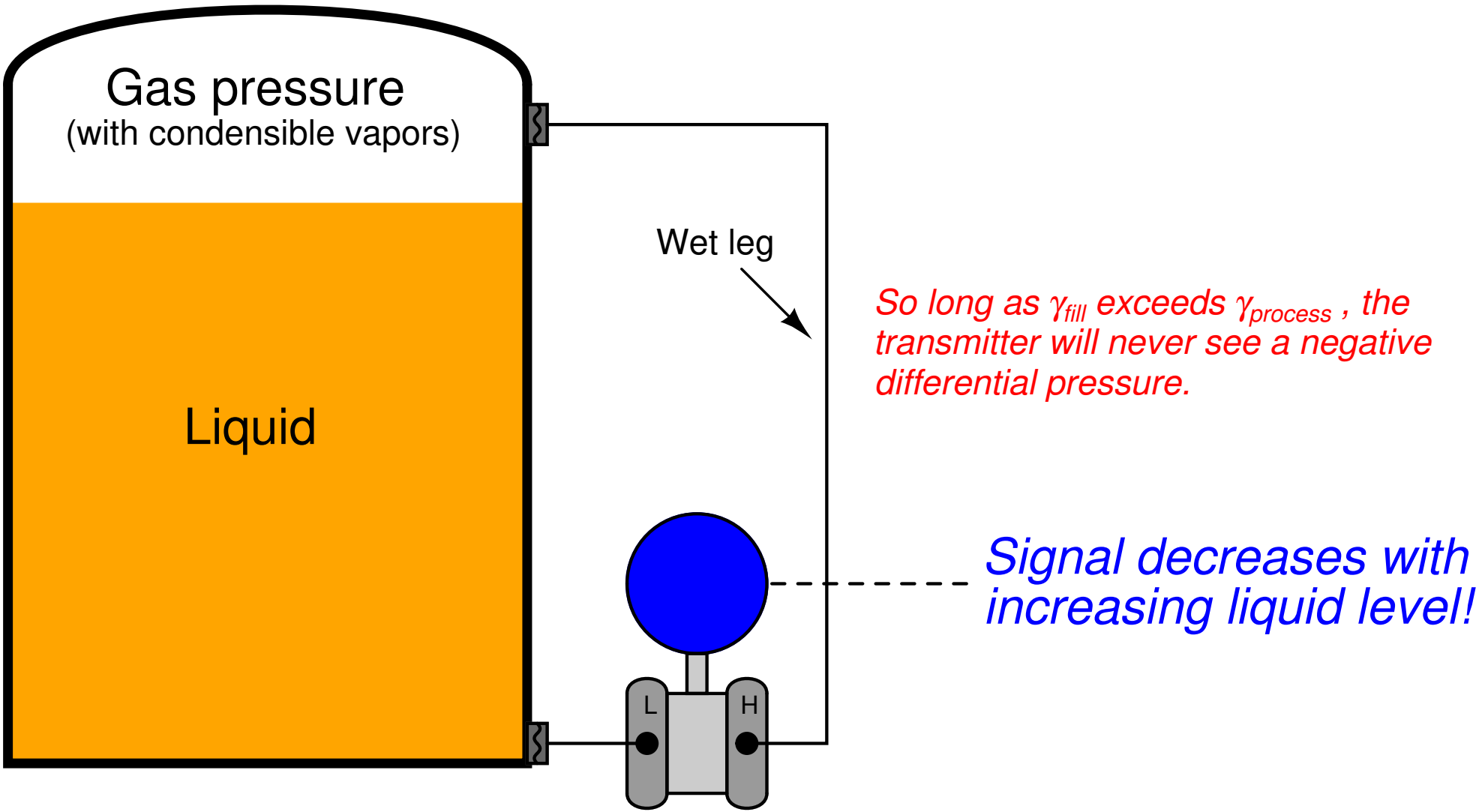

601


Block valve
Fill valve
Gas pressure
(with condensible vapors)
Seal pot
Wet leg
Liquid
3-valve manifold
H
L
Drain valve


Wet leg
fill valve
Vapors
Gasoline
γ = 41.0 lb/ft3
10 feet
11 feet
Compensating
leg (water-filled)
γ = 62.4 lb/ft3
Electronic
output signal
H
L

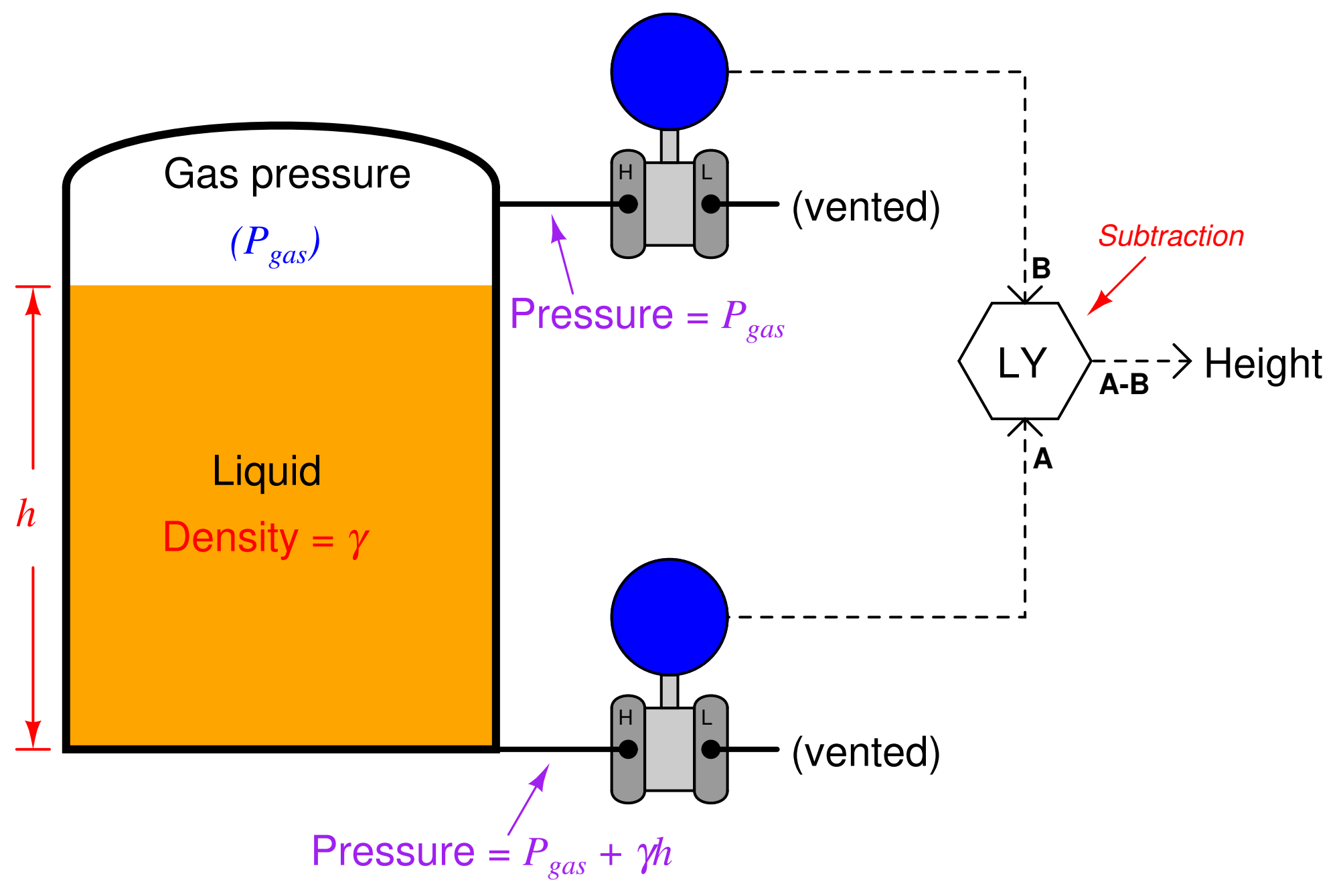
Gasoline level	Percent of range	Differential pressure at transmitter	Transmitter output
0 ft	0 %	−4.77 PSI	4 mA
2.5 ft	25 %	−4.05 PSI	8 mA
5 ft	50 %	−3.34 PSI	12 mA
7.5 ft	75 %	−2.63 PSI	16 mA
10 ft	100 %	−1.92 PSI	20 mA

High side of DP transmitter connected to the compensating impulse leg

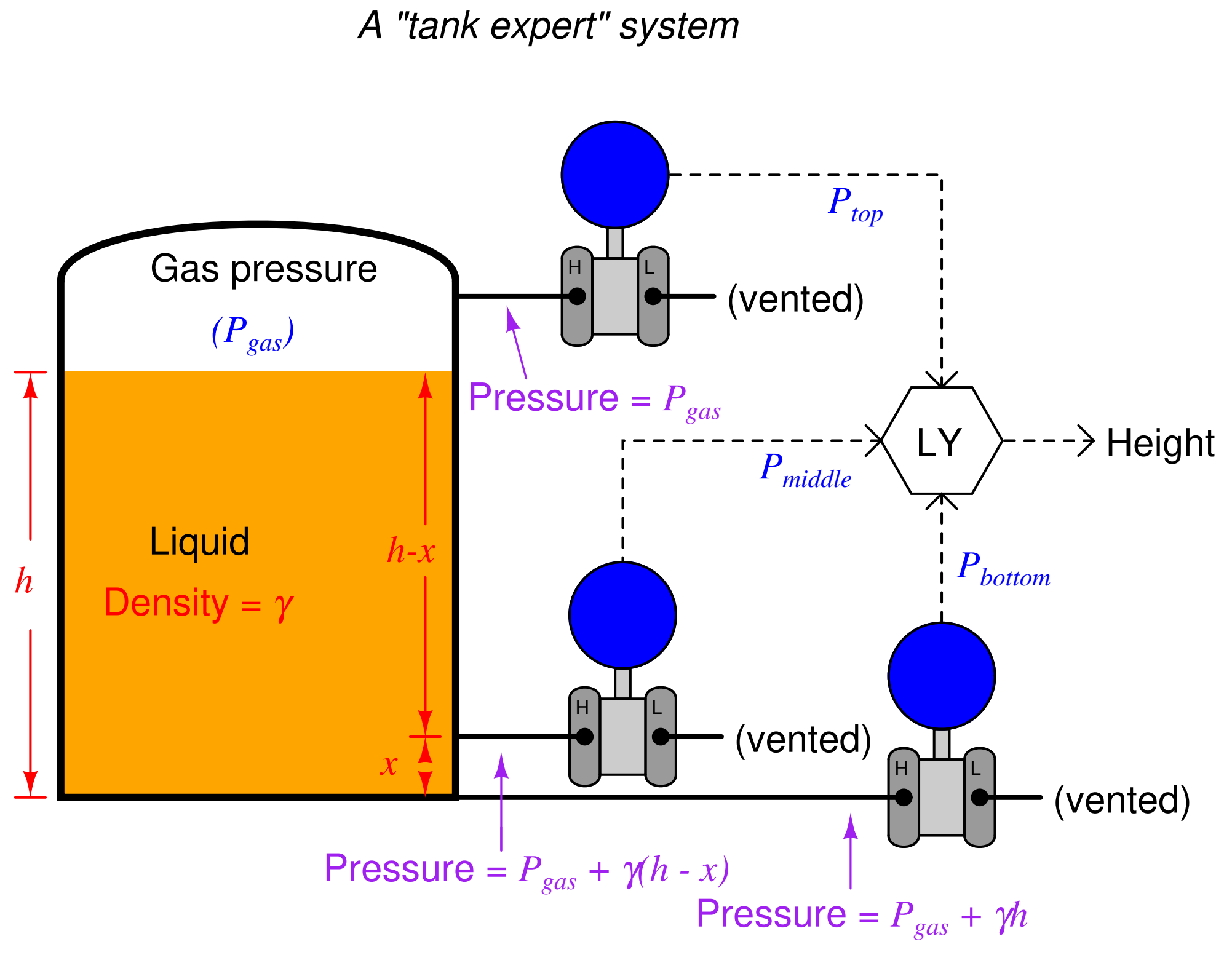


So long as γ_{fill} exceeds $\gamma_{process}$, the transmitter will never see a negative differential pressure.

Signal decreases with increasing liquid level!


Gas pressure
(P_{gas})
Liquid
Density = γ
h
H
L
(vented)
Pressure = P_{gas}
H
L
(vented)
Pressure = $P_{gas} + \gamma h$
Subtraction
B
LY
A-B
Height
A

x


A "tank expert" system
Gas pressure
(P_{gas})
Liquid
Density = γ
h
h-x
x
H
L
(vented)
P_{top}
Pressure = P_{gas}
LY
Height
P_{middle}
P_{bottom}
Pressure = $P_{gas} + \gamma(h - x)$
Pressure = $P_{gas} + \gamma h$


P_{bottom}

$$P_{bottom} - P_{middle} = (P_{gas} + \gamma h) - [P_{gas} + \gamma(h - x)]$$

$$P_{bottom} - P_{middle} = P_{gas} + \gamma h - P_{gas} - \gamma(h - x)$$

$$P_{bottom} - P_{middle} = P_{gas} + \gamma h - P_{gas} - \gamma h + \gamma x$$

$$P_{bottom} - P_{middle} = \gamma x$$

$$\frac{P_{bottom} - P_{middle}}{x} = \gamma$$

$$P_{bottom} - P_{top} = (P_{gas} + \gamma h) - P_{gas}$$

$$P_{bottom} - P_{top} = \gamma h$$

$$\frac{P_{bottom} - P_{top}}{\gamma} = h$$

$$V = \pi r^2 h$$

γ

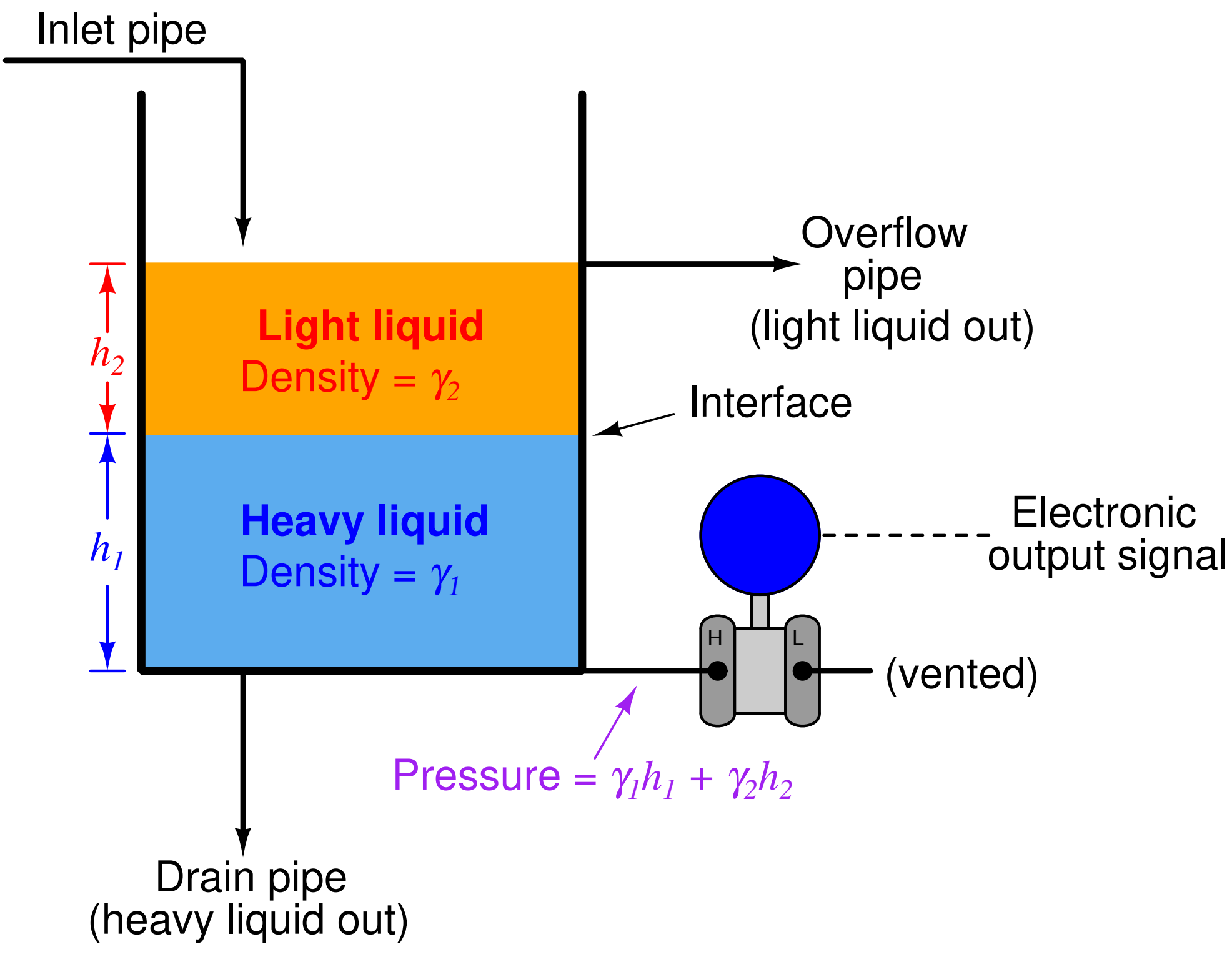
$$\rho g h = \gamma h$$

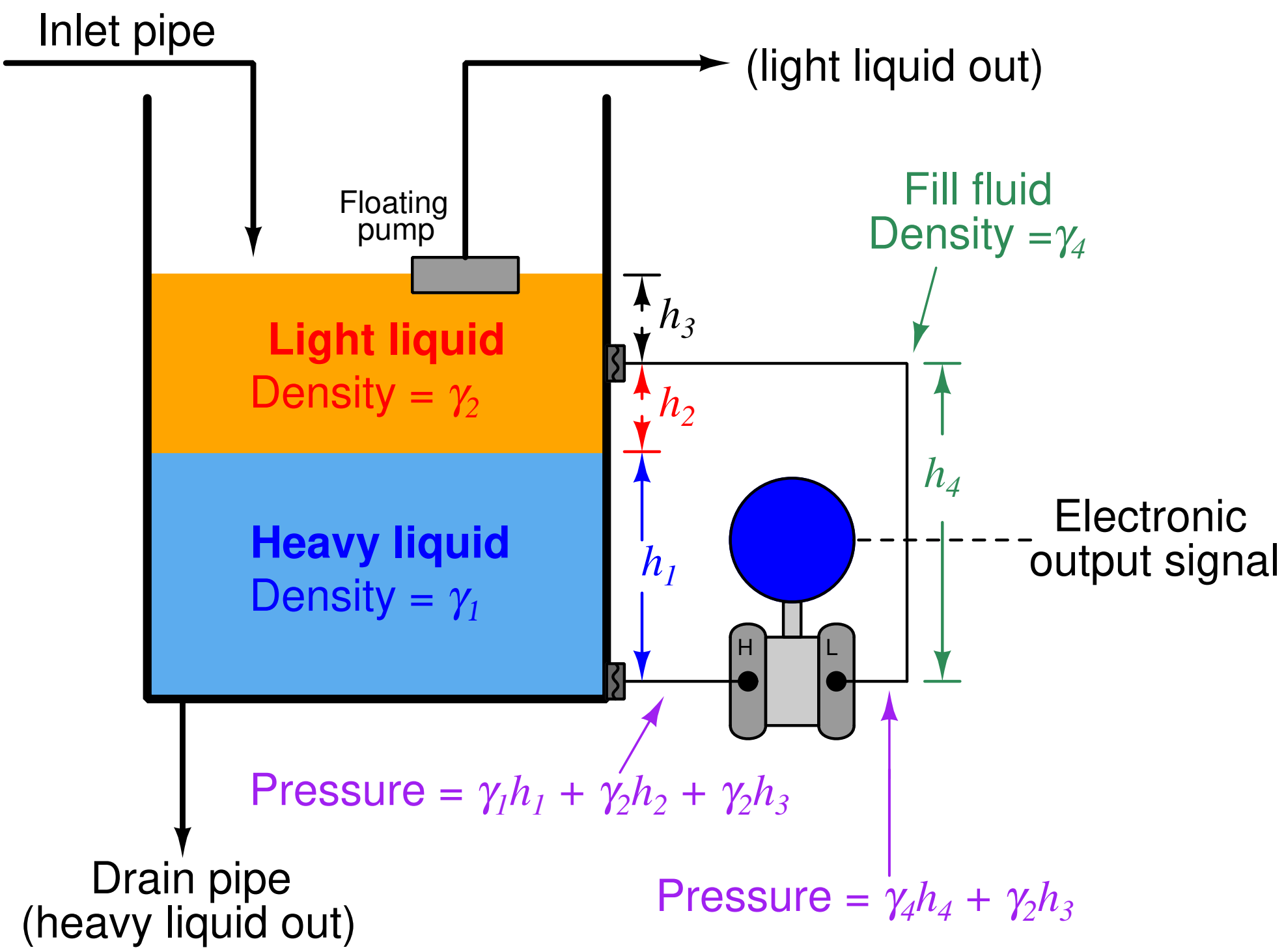
$\rho g = \gamma$

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

$$m = \rho V$$

$$[\mathrm{kg}] = \left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right] \left[\mathrm{m}^3\right]$$


Inlet pipe
Overflow pipe (light liquid out)
Light liquid
Density = γ_2
h_2
Interface
Heavy liquid
Density = γ_1
h_1
Electronic output signal
H
L
(vented)
Pressure = $\gamma_1 h_1 + \gamma_2 h_2$
Drain pipe (heavy liquid out)


Inlet pipe
(light liquid out)
Floating pump
Fill fluid
Density = γ_4
h_3
Light liquid
Density = γ_2
h_2
h_4
Heavy liquid
Density = γ_1
h_1
Electronic output signal
H
L
Pressure = $\gamma_1 h_1 + \gamma_2 h_2 + \gamma_2 h_3$
Drain pipe
(heavy liquid out)
Pressure = $\gamma_4 h_4 + \gamma_2 h_3$

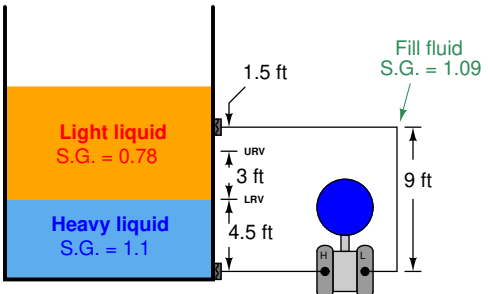
$$(\gamma_1 h_1 + \gamma_2 h_2 + \gamma_2 h_3) - (\gamma_4 h_4 + \gamma_2 h_3)$$

$$\gamma_1 h_1 + \gamma_2 h_2 + \gamma_2 h_3 - \gamma_4 h_4 - \gamma_2 h_3$$

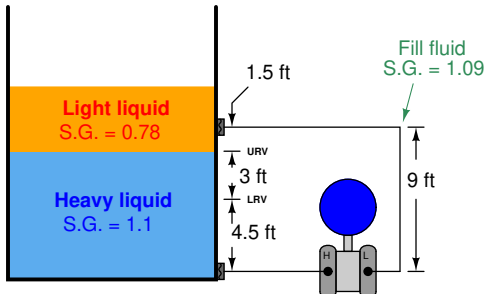
$$\gamma_1 h_1 + \gamma_2 h_2 - \gamma_4 h_4$$

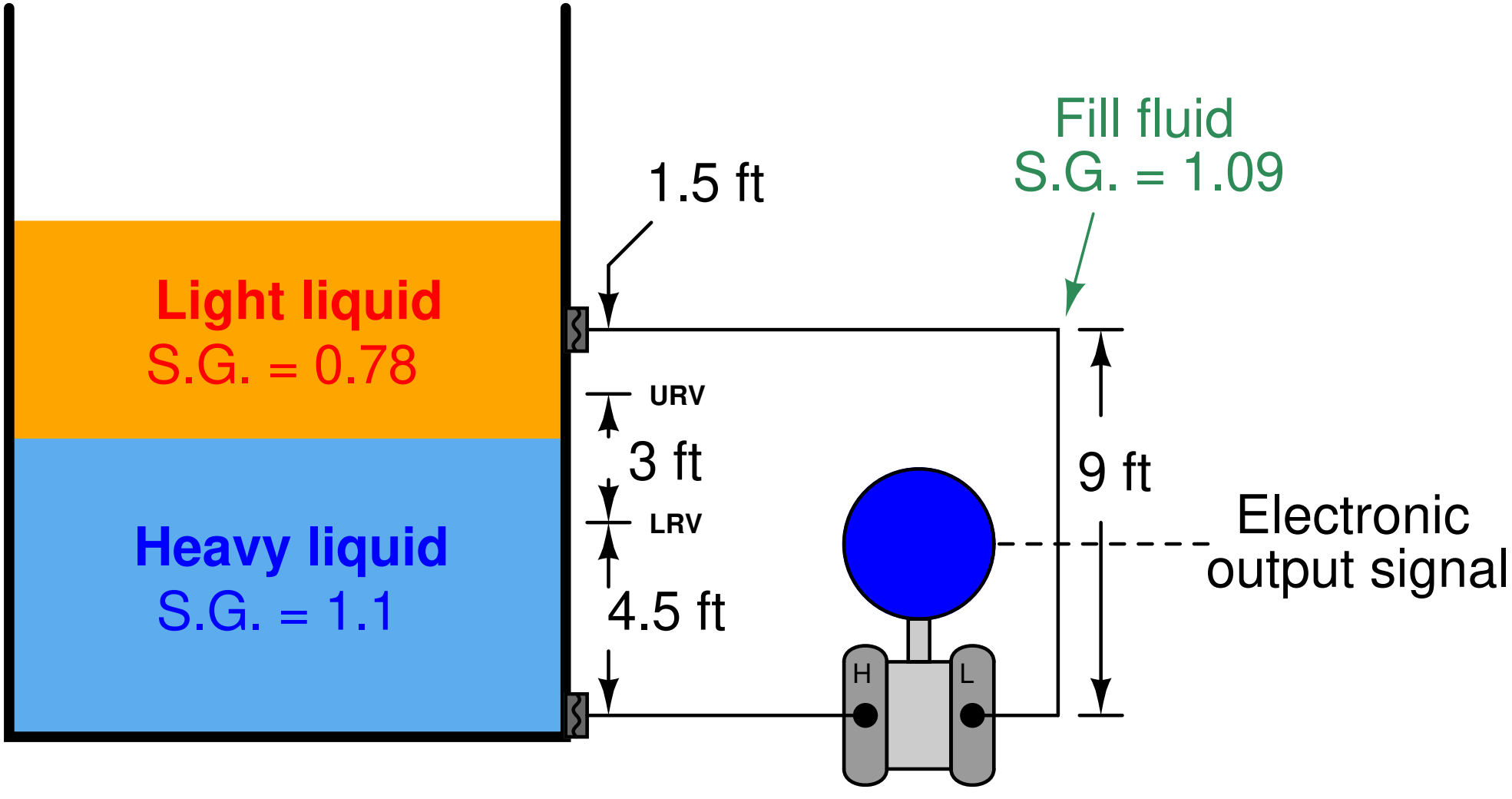
$\gamma_1 h_1 + \gamma_2 h_2 - \text{Constant}$

Interface level = LRV

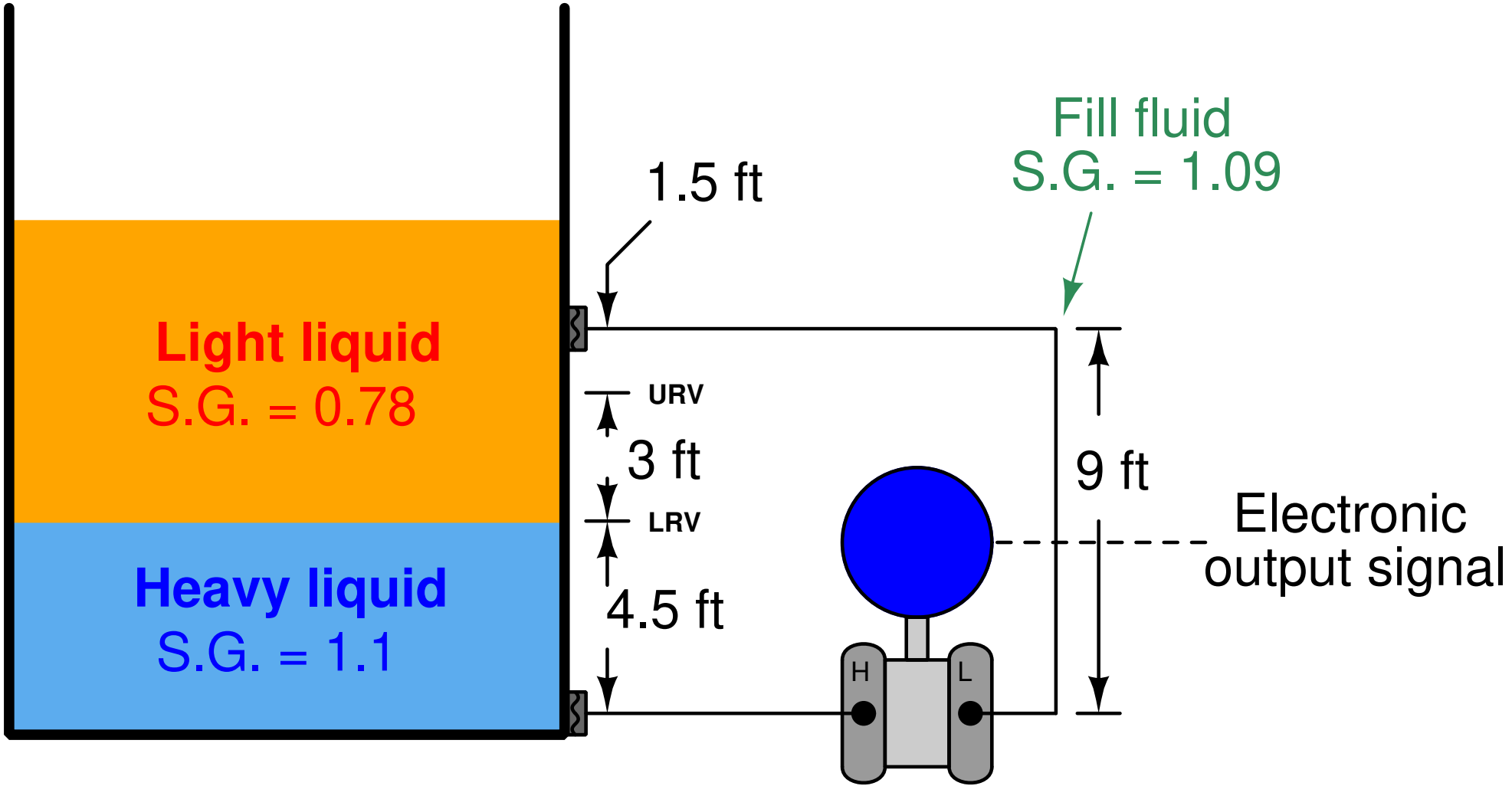


Interface level = URV




Light liquid
S.G. = 0.78
Heavy liquid
S.G. = 1.1
1.5 ft
Fill fluid
S.G. = 1.09
URV
3 ft
LRV
4.5 ft
9 ft
Electronic
output signal
H
L

LRV interface level condition



$$P_{high} = 4.5 \text{ feet of heavy liquid} + 4.5 \text{ feet of light liquid}$$

$P_{high} = 54 \text{ inches of heavy liquid} + 54 \text{ inches of light liquid}$

P_{high} "W.C. = (54 inches of heavy liquid)(1.1) + (54 inches of light liquid)(0.78)

$$P_{high}\ \text{"W.C.} = 59.4\ \text{"W.C.} + 42.12\ \text{"W.C.}$$

$P_{high} = 101.52$ ”W.C.

$P_{low} = 9$ feet of fill fluid

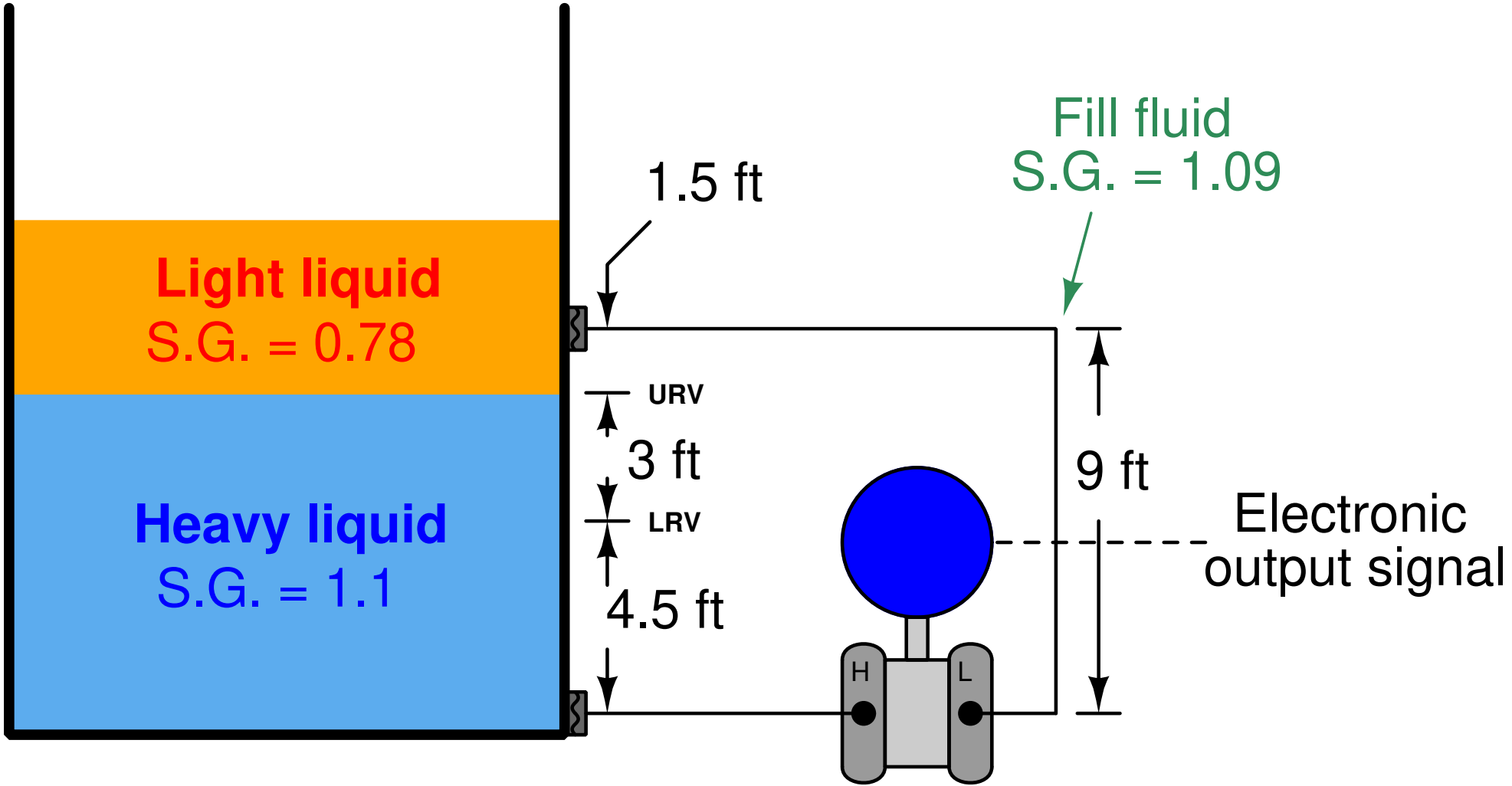
$P_{low} = 108$ inches of fill fluid

$$P_{low}\ \text{"W.C.} = (108\ \text{inches of fill fluid})(1.09)$$

$P_{low} = 117.72$ ”W.C.

$$P_{LRV} = 101.52\ \text{”W.C.} - 117.72\ \text{”W.C.} = -16.2\ \text{”W.C.}$$

URV interface level condition



$$P_{high} = 7.5 \text{ feet of heavy liquid} + 1.5 \text{ feet of light liquid}$$

$$P_{high} = 90 \text{ inches of heavy liquid} + 18 \text{ inches of light liquid}$$

P_{high} "W.C. = (90 inches of heavy liquid)(1.1) + (18 inches of light liquid)(0.78)

$$P_{high}\ \text{”W.C.} = 99\ \text{”W.C.} + 14.04\ \text{”W.C.}$$

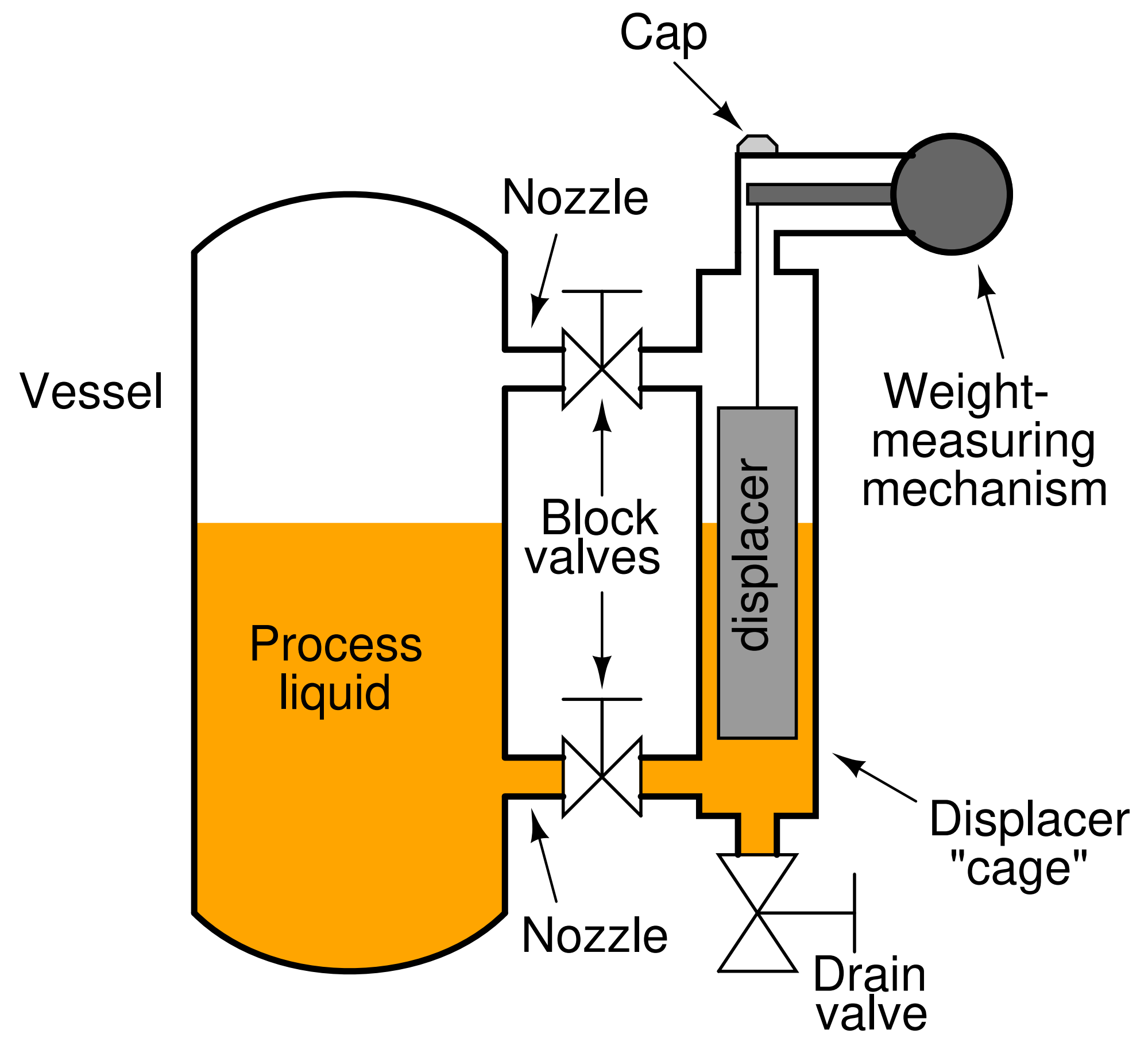
$P_{high} = 113.04$ ”W.C.

$$P_{URV} = 113.04\ \text{”W.C.} - 117.72\ \text{”W.C.} = -4.68\ \text{”W.C.}$$

Interface level	Percent of range	Differential pressure at transmitter	Transmitter output
4.5 ft	0 %	−16.2 "W.C.	4 mA
5.25 ft	25 %	−13.32 "W.C.	8 mA
6 ft	50 %	−10.44 "W.C.	12 mA
6.75 ft	75 %	−7.56 "W.C.	16 mA
7.5 ft	100 %	−4.68 "W.C.	20 mA

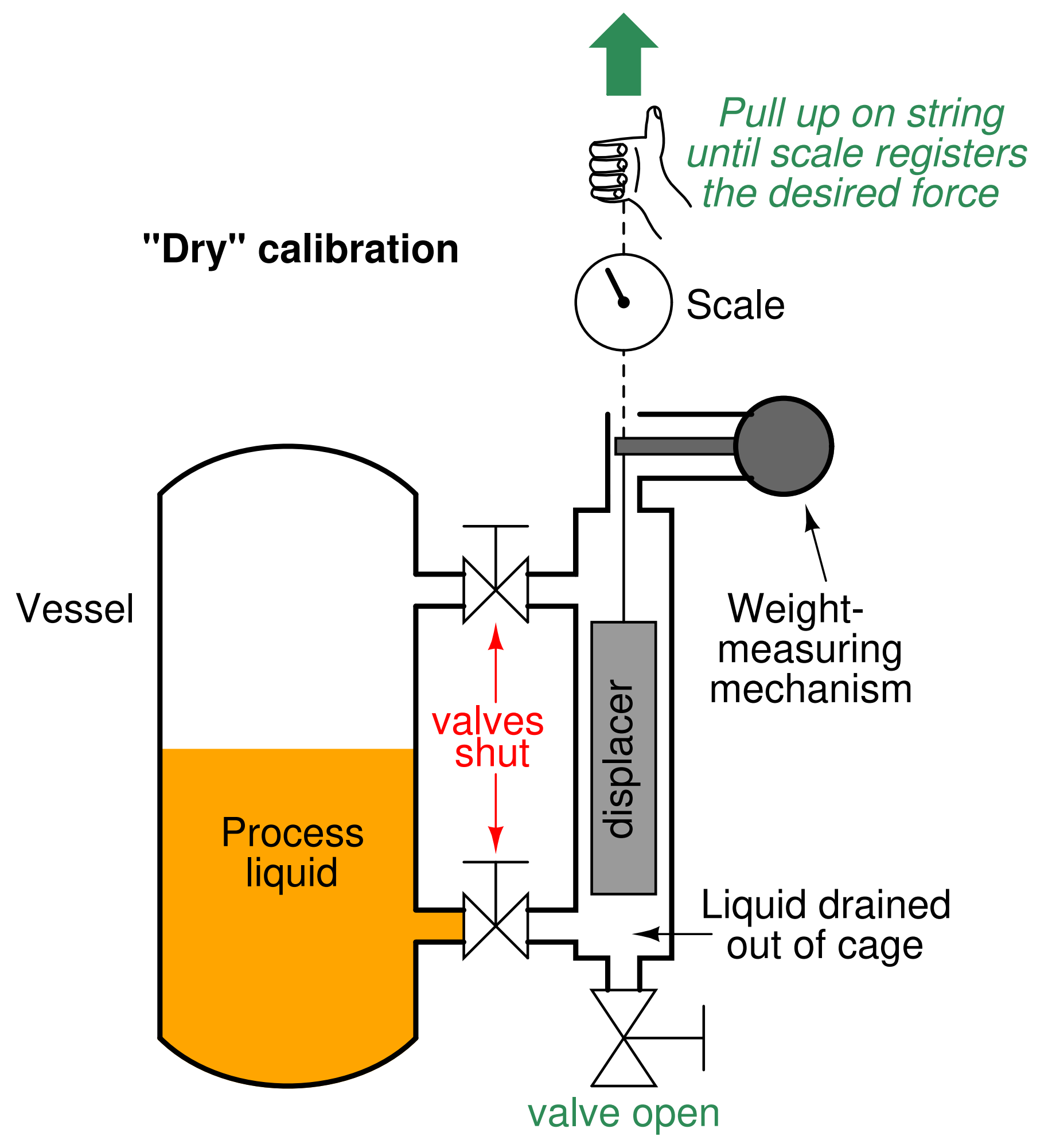
$$\text{Span in "W.C.} = (36 \text{ inches})(1.1 - 0.78)$$

$\text{Span} = 11.52\text{ ”W.C.}$


Cap
Nozzle
Vessel
Weight-
measuring
mechanism
Block
valves
displacer
Process
liquid
Displacer
"cage"
Nozzle
Drain
valve

$$F = \gamma V$$


FISHER


Pull up on string
until scale registers
the desired force
"Dry" calibration
Scale
Vessel
Weight-
measuring
mechanism
valves
shut
displacer
Process
liquid
Liquid drained
out of cage
valve open

$$V = \pi r^2 l$$

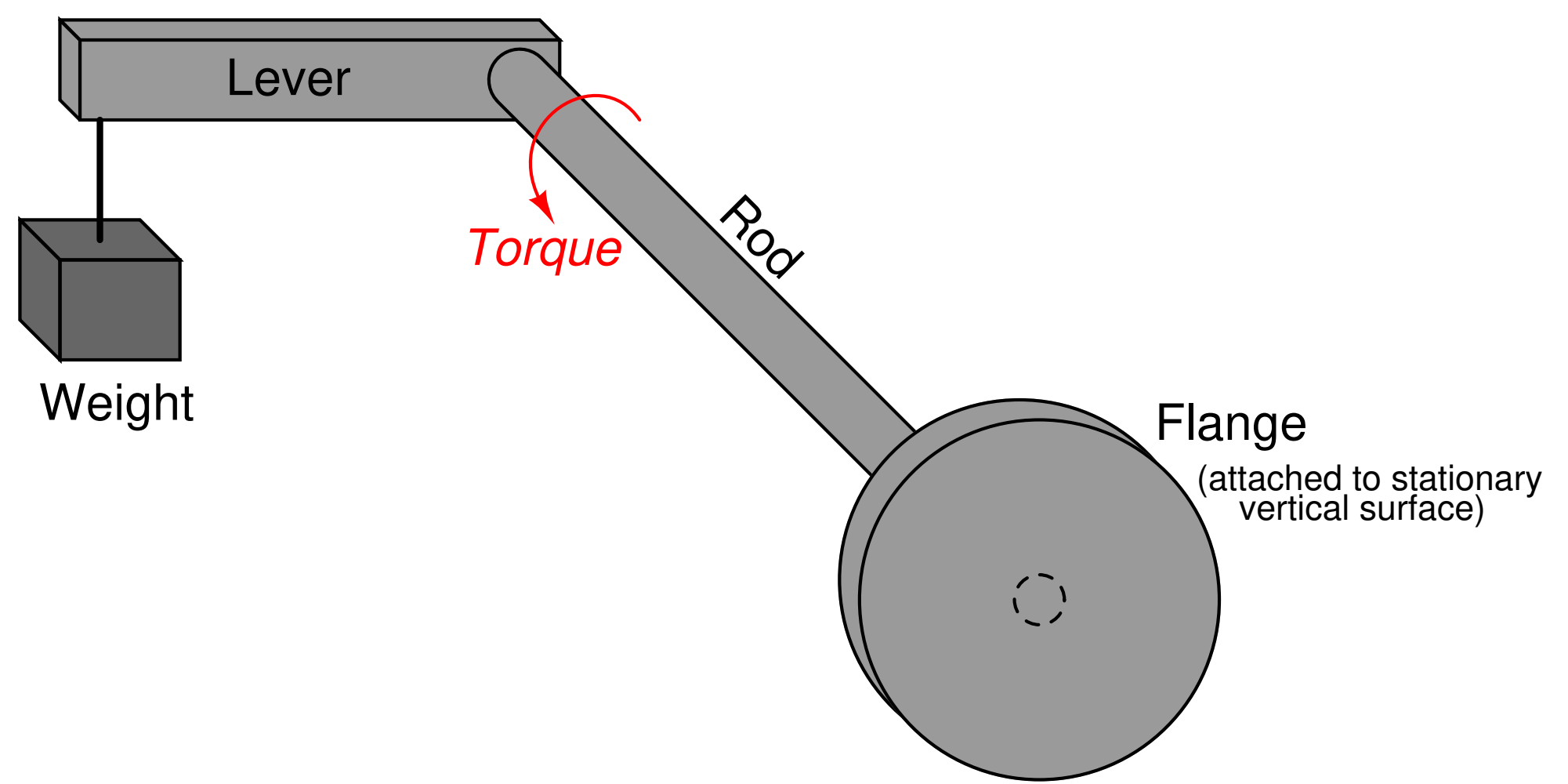
$$F_{buoyant} = \gamma V$$

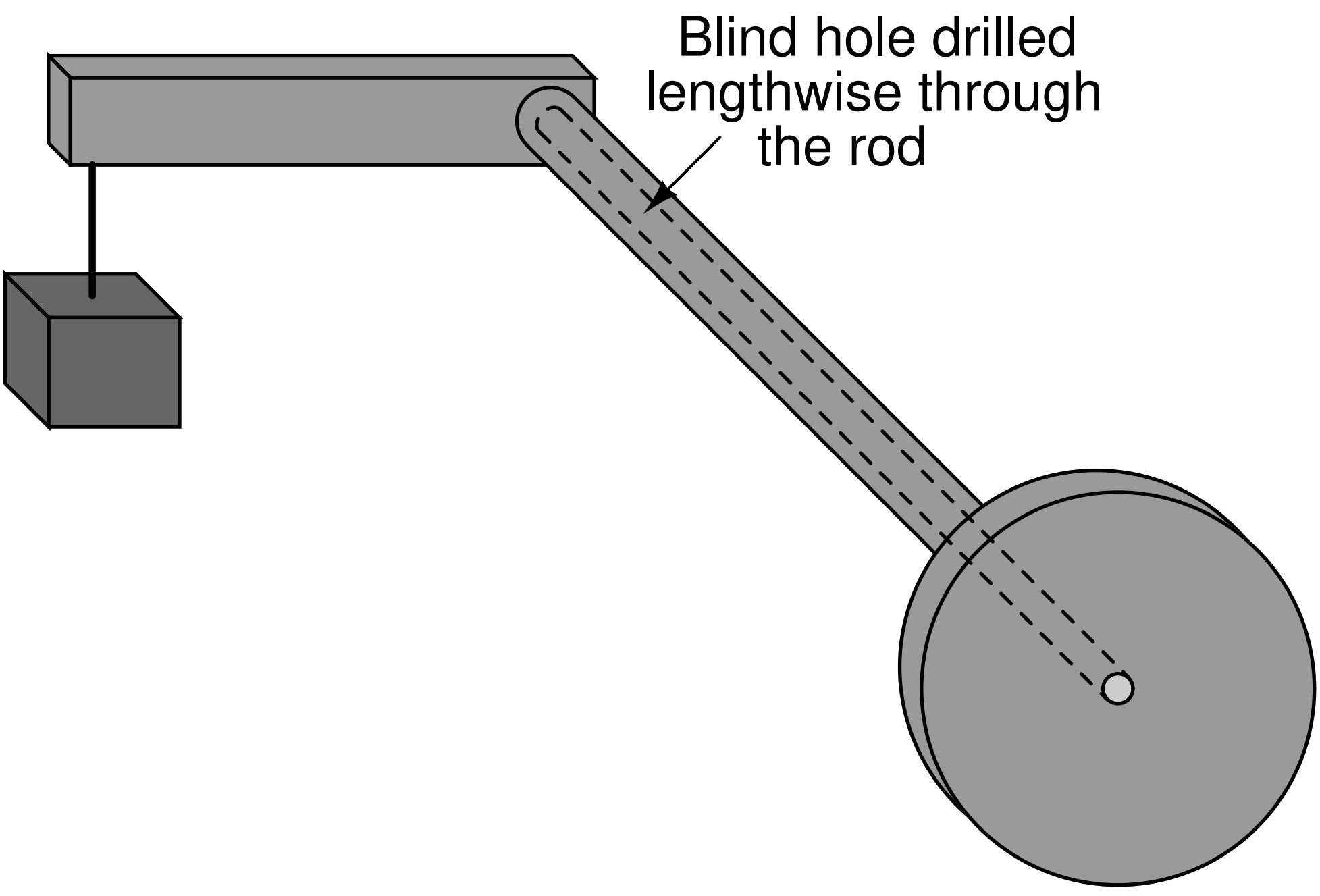
$$F_{buoyant} = \gamma \pi r^2 l$$

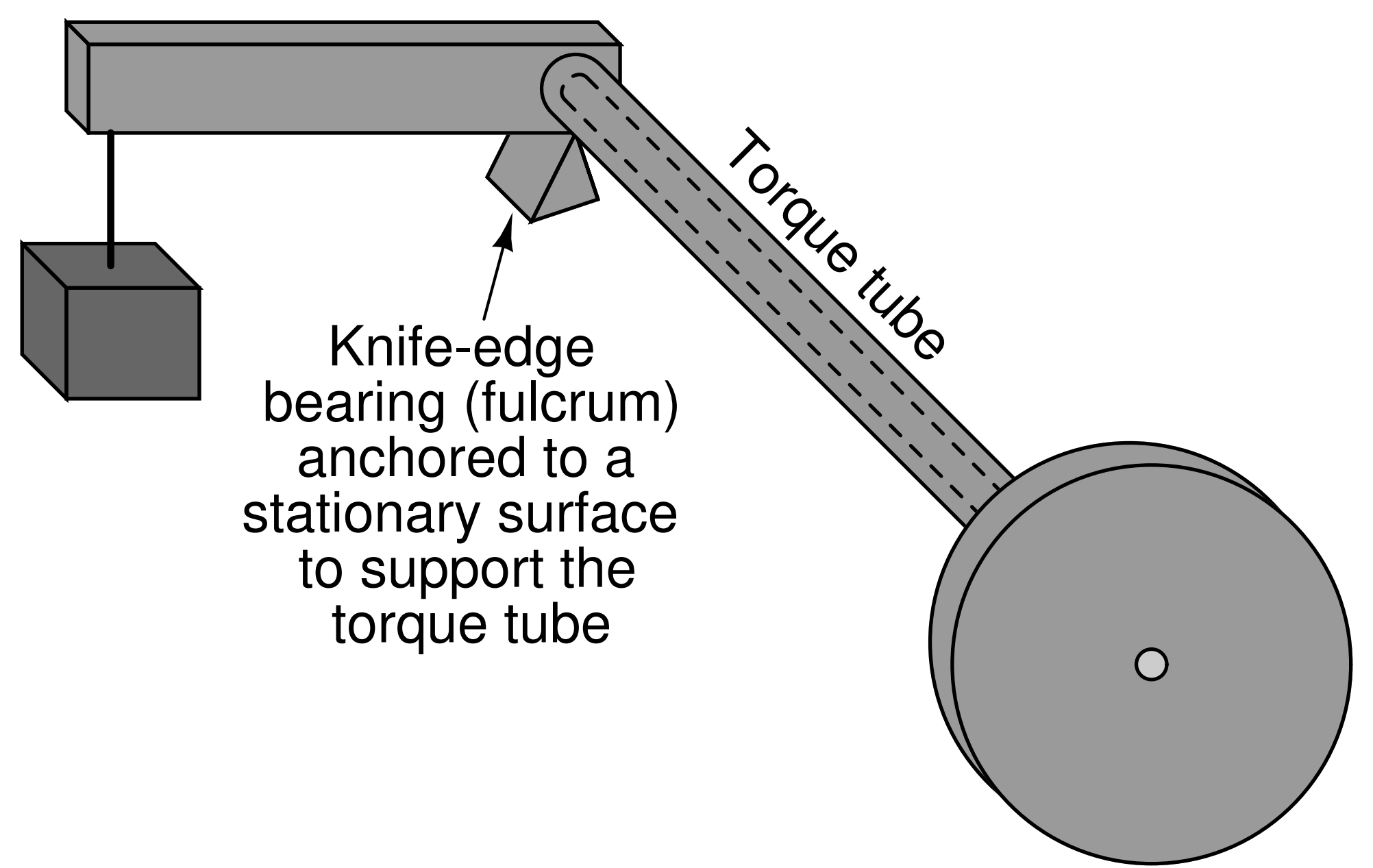
$$\gamma = \left(\frac{57.3 \text{ lb}}{\text{ft}^3}\right)\left(\frac{1 \text{ ft}^3}{12^3 \text{ in}^3}\right) = 0.0332\frac{\text{lb}}{\text{in}^3}$$

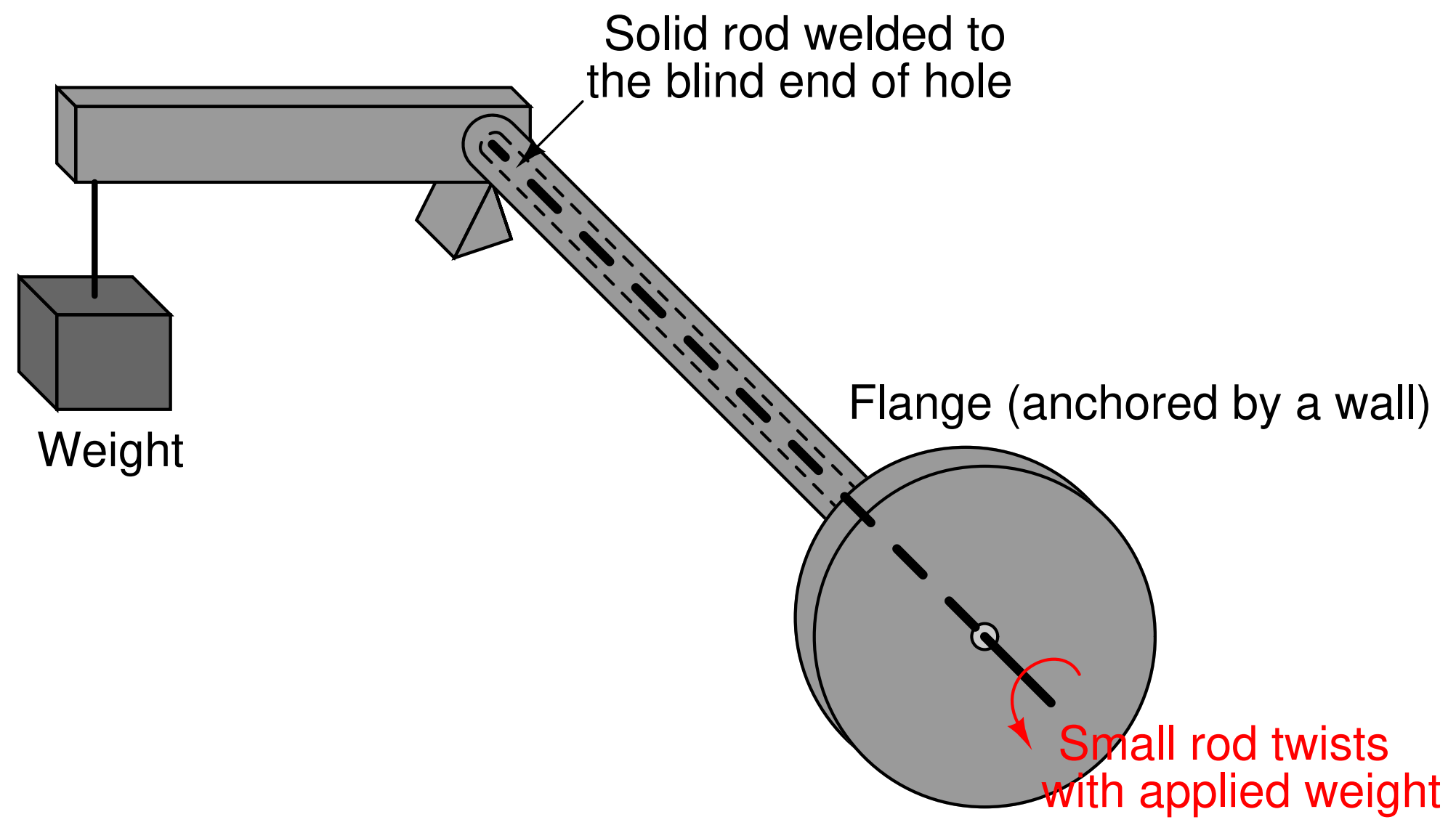
$$V = \pi r^2 l = \pi(1.5 \text{ in})^2(24 \text{ in}) = 169.6 \text{ in}^3$$

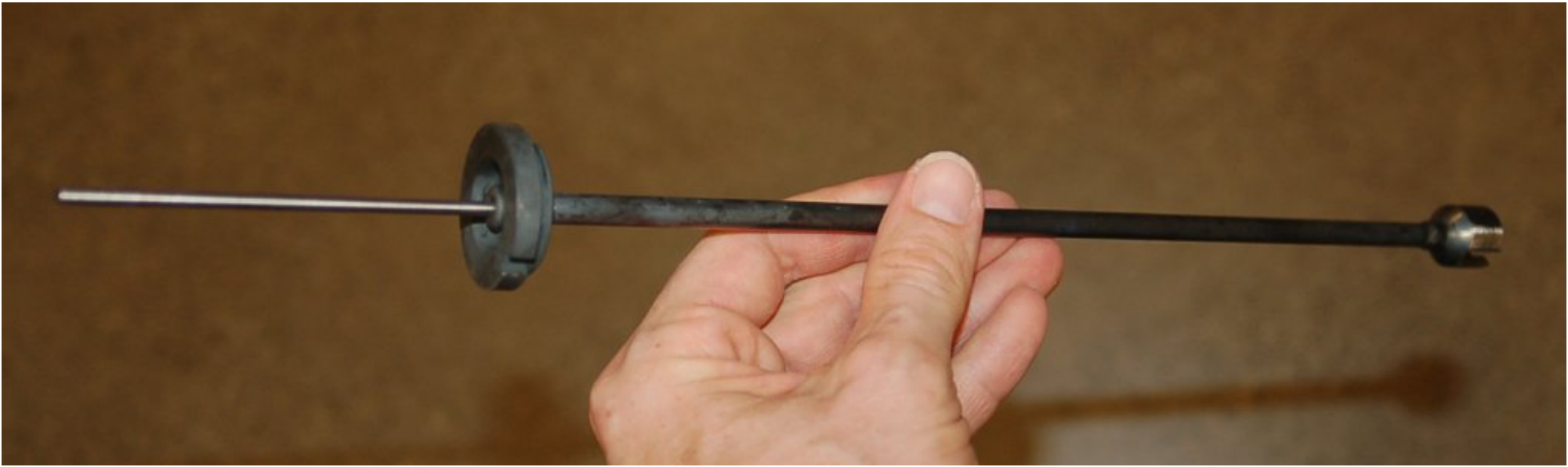
$$F_{buoyant} = \gamma V = \left(0.0332 \frac{\text{lb}}{\text{in}^3}\right)\left(169.6 \text{ in}^3\right) = 5.63 \text{ lb}$$

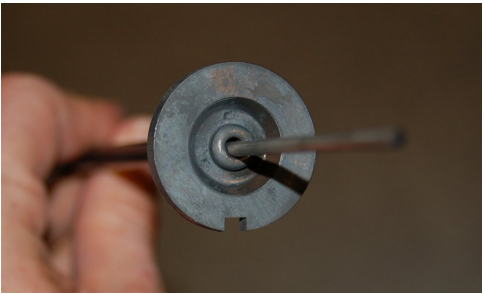

Lever
Torque
Rod
Weight
Flange
(attached to stationary
vertical surface)

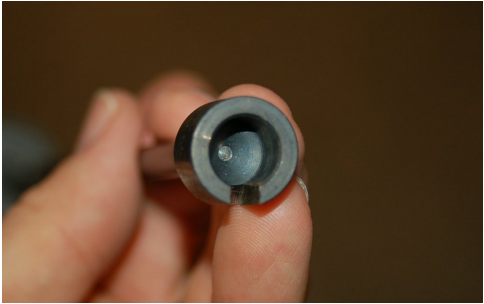

Blind hole drilled
lengthwise through
the rod

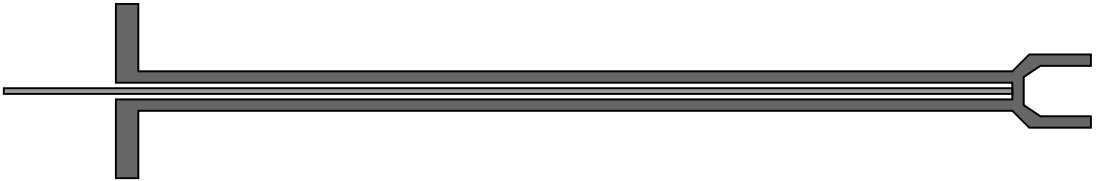

Torque tube
Knife-edge
bearing (fulcrum)
anchored to a
stationary surface
to support the
torque tube

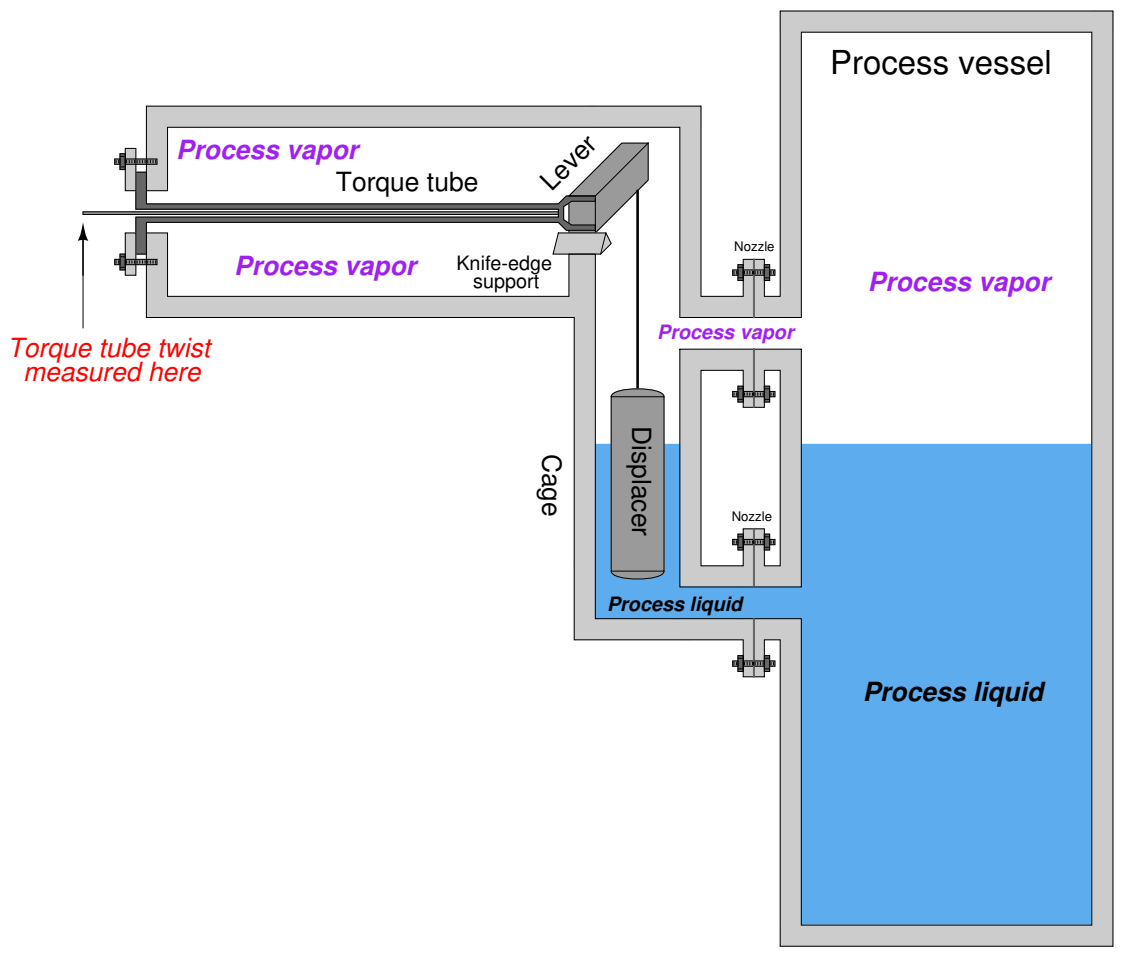

Solid rod welded to
the blind end of hole
Weight
Flange (anchored by a wall)
Small rod twists
with applied weight







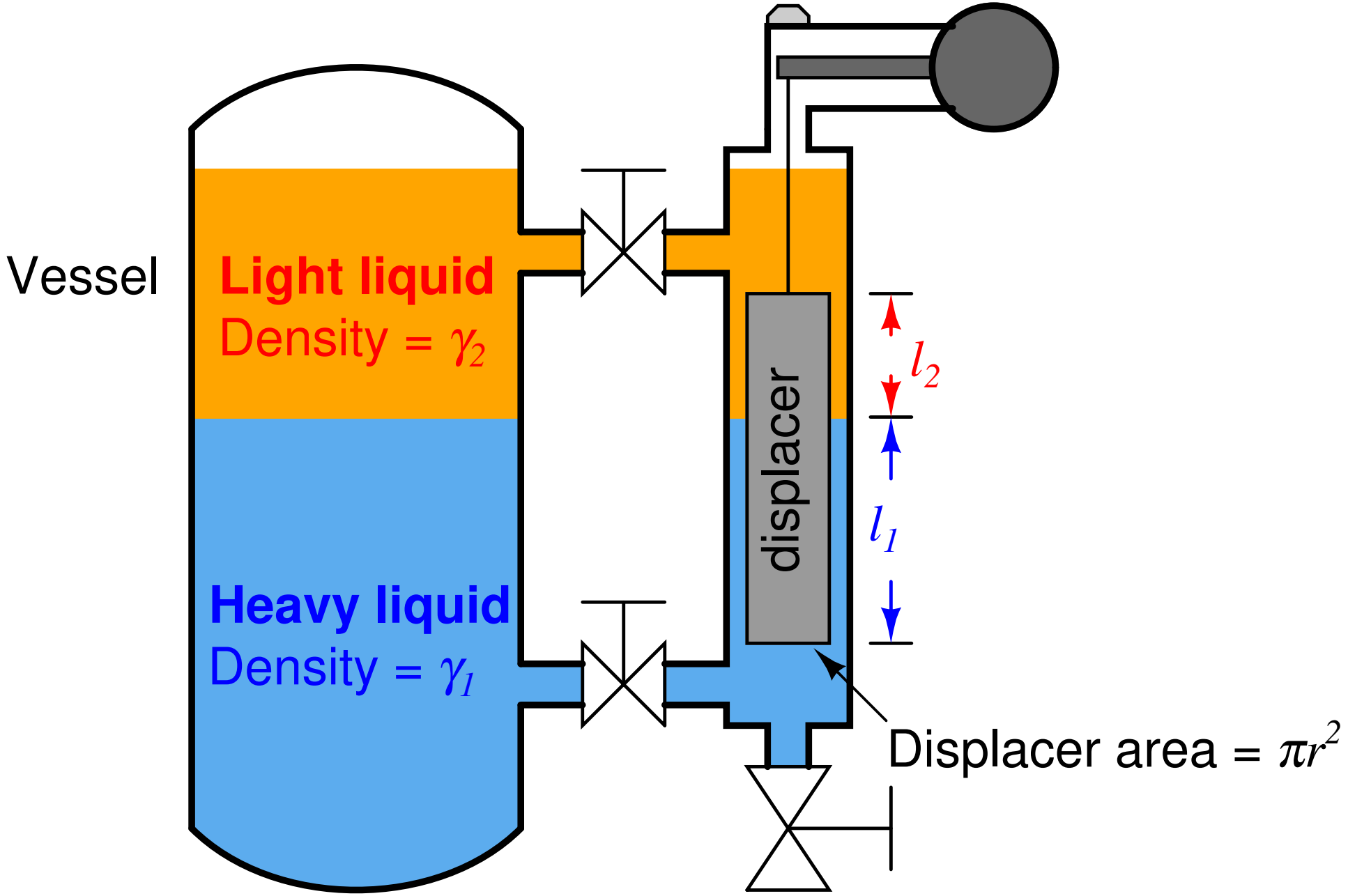



Process vessel
Process vapor
Torque tube
Lever
Process vapor
Knife-edge support
Nozzle
Process vapor
Process vapor
Torque tube twist measured here
Cage
Displacer
Nozzle
Process liquid
Process liquid


6
7
8
9
10

$$F_{buoyant} = \gamma_1 V_1 + \gamma_2 V_2$$

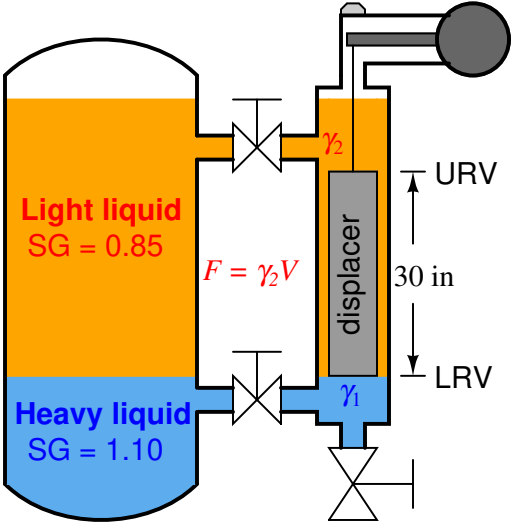
πr^2


Vessel
Light liquid
Density = γ_2
Heavy liquid
Density = γ_1
displacer
l_2
l_1
Displacer area = πr^2

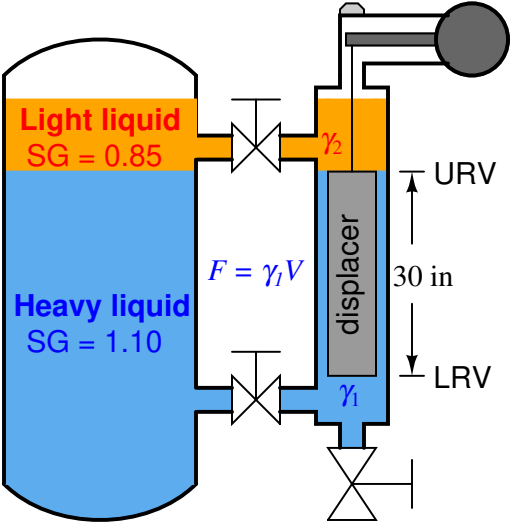
$$F_{buoyant} = \gamma_1 \pi r^2 l_1 + \gamma_2 \pi r^2 l_2$$

$$F_{buoyant} = \pi r^2(\gamma_1 l_1 + \gamma_2 l_2)$$

LRV interface level condition



URV interface level condition



$$F_{buoyant}\ (\text{LRV}) = \gamma_2 V = \gamma_2 \pi r^2 l$$

$$F_{buoyant}\ (\text{URV}) = \gamma_1 V = \gamma_1 \pi r^2 l$$

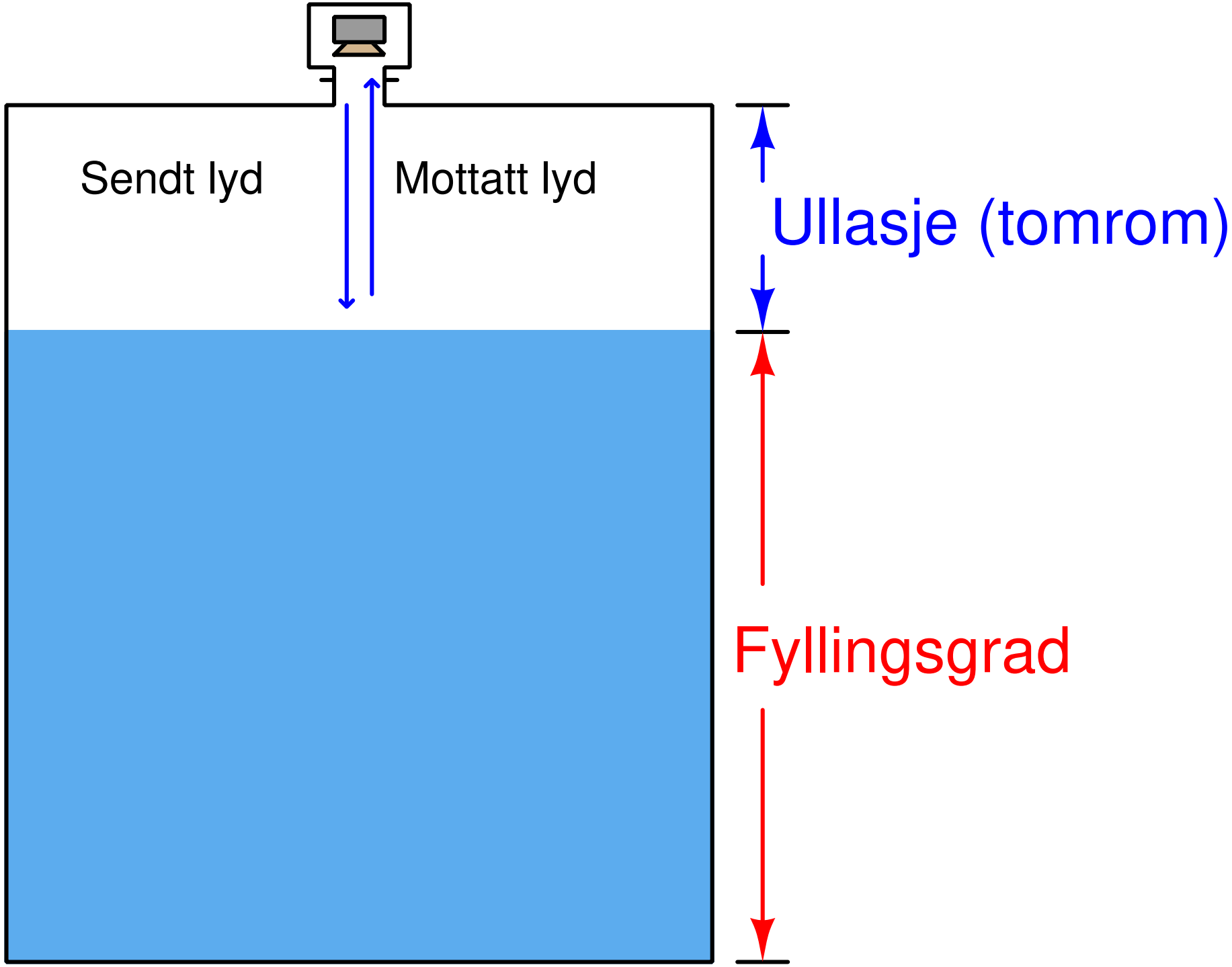
$$\gamma_1 = \left(62.4\,\frac{\text{lb}}{\text{ft}^3}\right)(1.10) = 68.6\,\frac{\text{lb}}{\text{ft}^3} = 0.0397\,\frac{\text{lb}}{\text{in}^3}$$

$$\gamma_2 = \left(62.4\ \frac{\text{lb}}{\text{ft}^3}\right)(0.85) = 53.0\ \frac{\text{lb}}{\text{ft}^3} = 0.0307\ \frac{\text{lb}}{\text{in}^3}$$

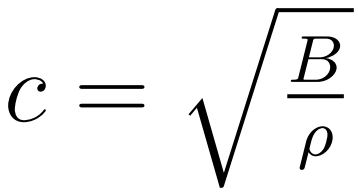
$$F_{buoyant}\ (\text{LRV}) = \left(0.0307\ \frac{\text{lb}}{\text{in}^3}\right)\pi(1.375\ \text{in})^2(30\ \text{in}) = 5.47\ \text{lb}$$

$$F_{buoyant}\ (\text{URV}) = \left(0.0397\ \frac{\text{lb}}{\text{in}^3}\right)\pi(1.375\ \text{in})^2(30\ \text{in}) = 7.08\ \text{lb}$$

Interface level (inches)	**Buoyant force** (pounds)
0	5.47
7.5	5.87
15	6.27
22.5	6.68
30	7.08


Sendt lyd
Mottatt lyd
Ullasje (tomrom)
Fyllingsgrad

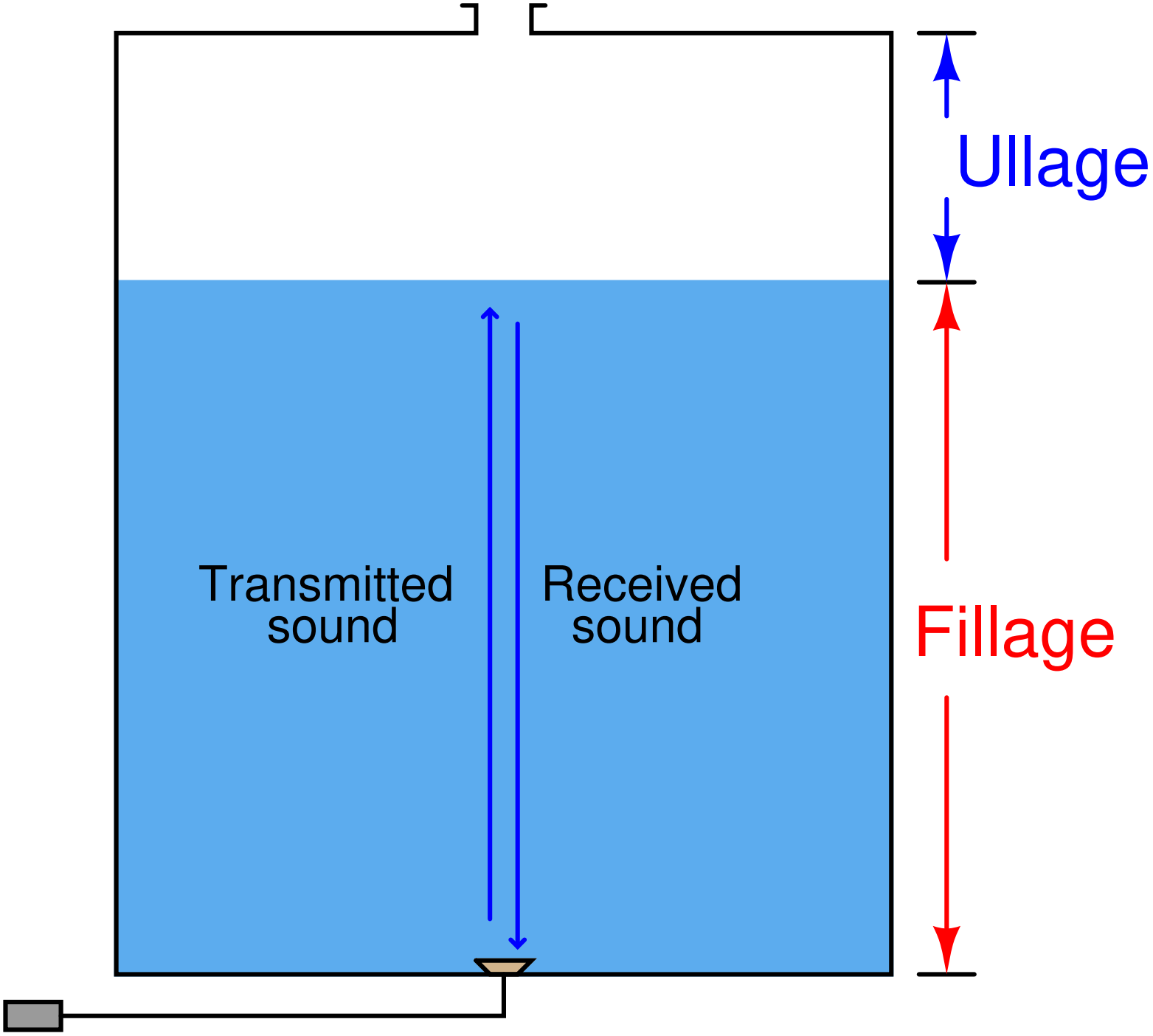
$$\text{Nivå} = \text{Tankens totale høyde} - \text{Ullasje}$$



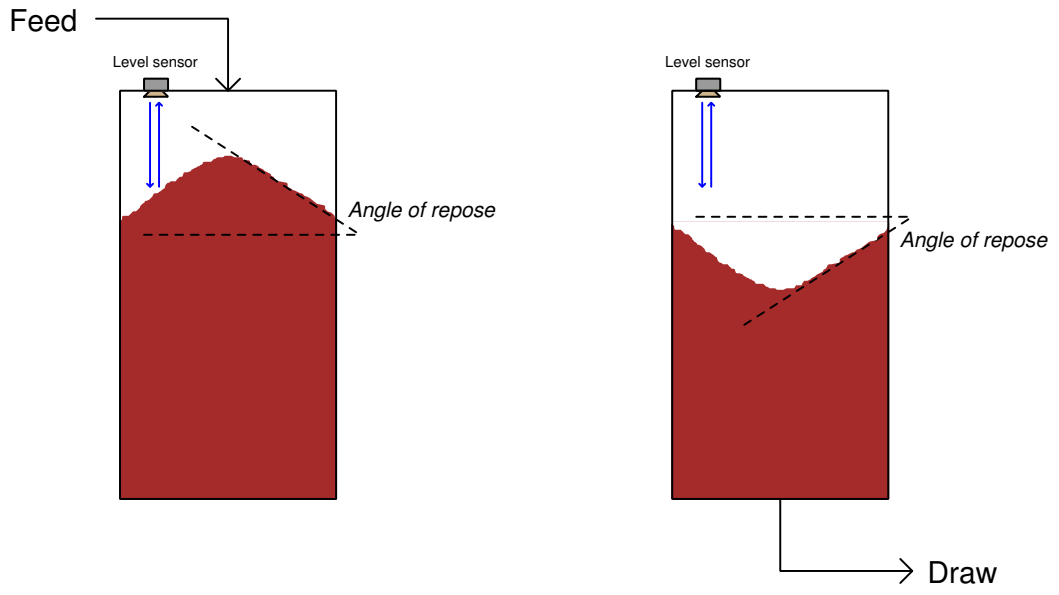
C


RELAY 1
RELAY 2
RELAY 3
RELAY 4
RELAY 5
LC-I Level Commander™
HI. TO
LO. TO
HEAD
FLOW
1
2
3
4
R1. HR
R2. HR
R3. HR
5
6
7
8
R1. ST
R2. ST
R3. ST
9
0
R5. HR
CE
#
MODE
TEST
R5. ST
DSP
ENT
Kay-Ray/Sensall, Inc.

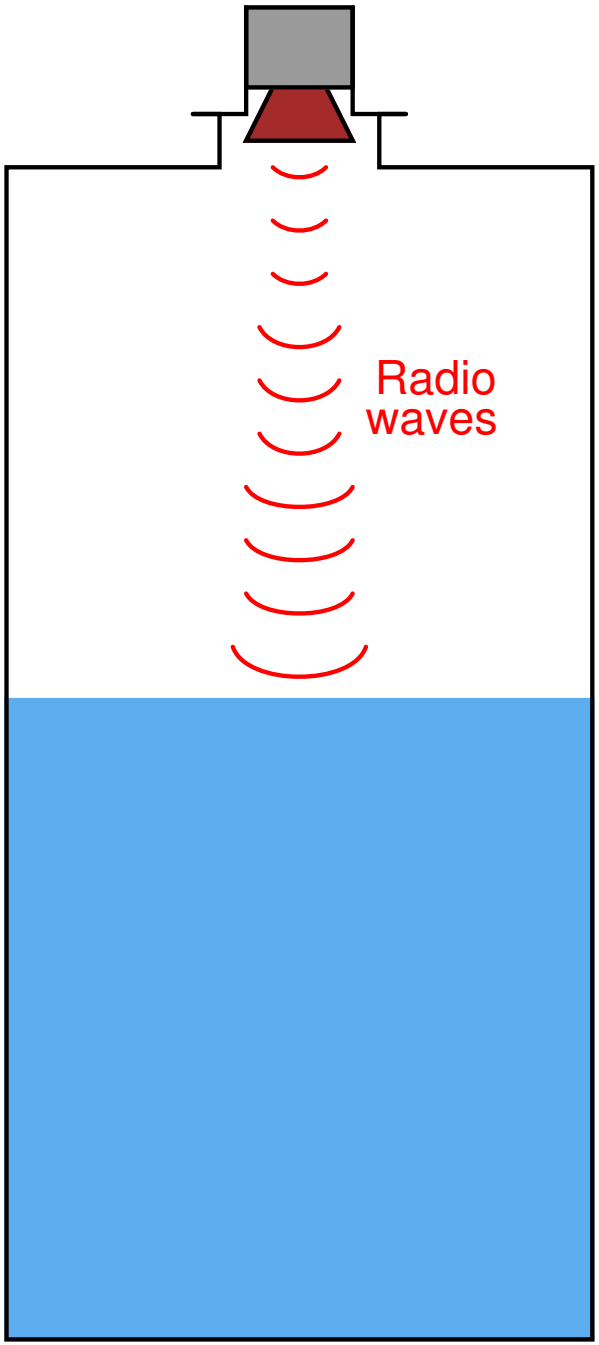

MILLTRONICS
ST-25C
SERIAL #
MADE IN CANADA


Ullage
Transmitted sound
Received sound
Fillage

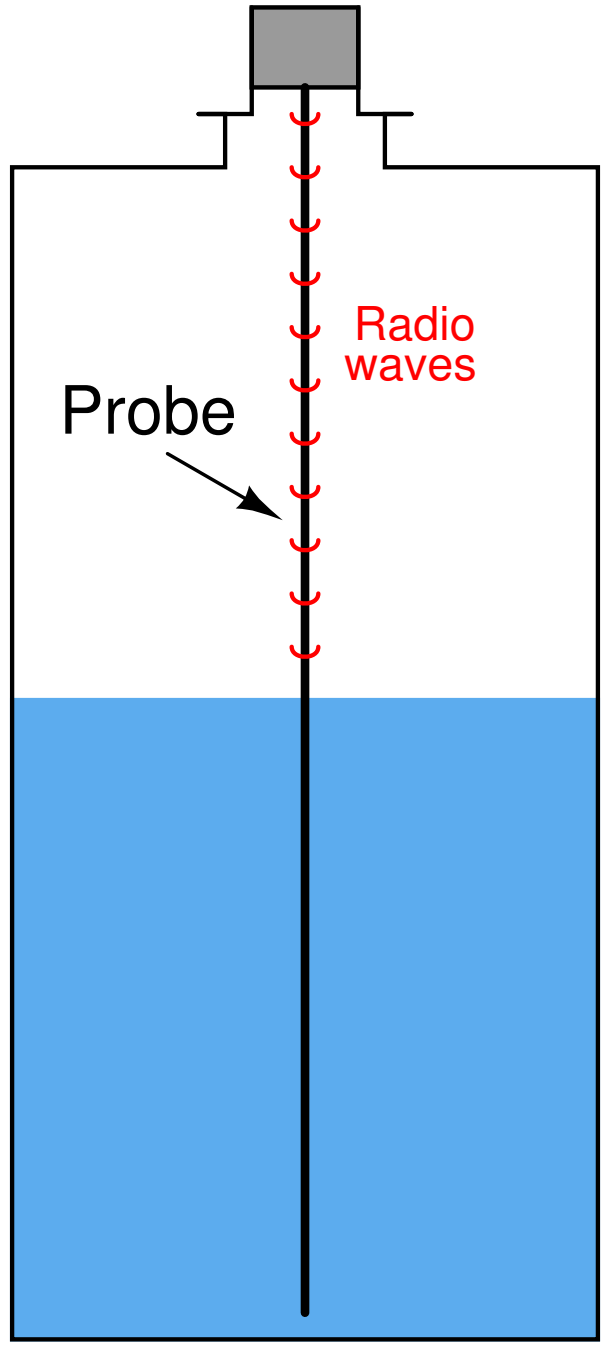
$$\text{Ullage} = \text{Total height} - \text{Fillage}$$


Feed
Level sensor
Angle of repose
Level sensor
Angle of repose
Draw

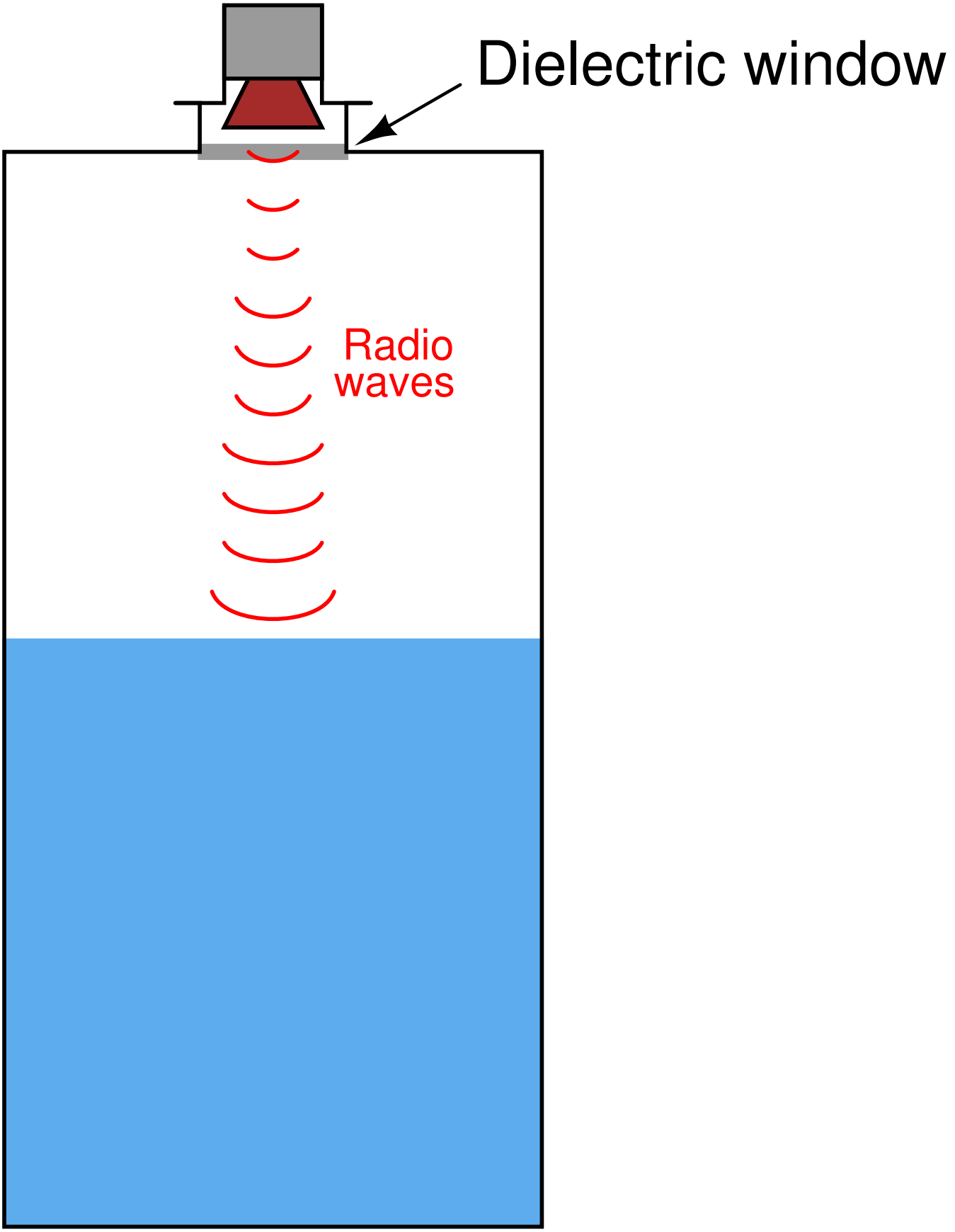
Non-contact radar liquid level measurement



Guided-wave radar (GWR) liquid level measurement



Non-contact radar liquid level measurement



2.9979×10^8

ϵ

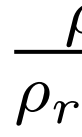
v

ϵ_r

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

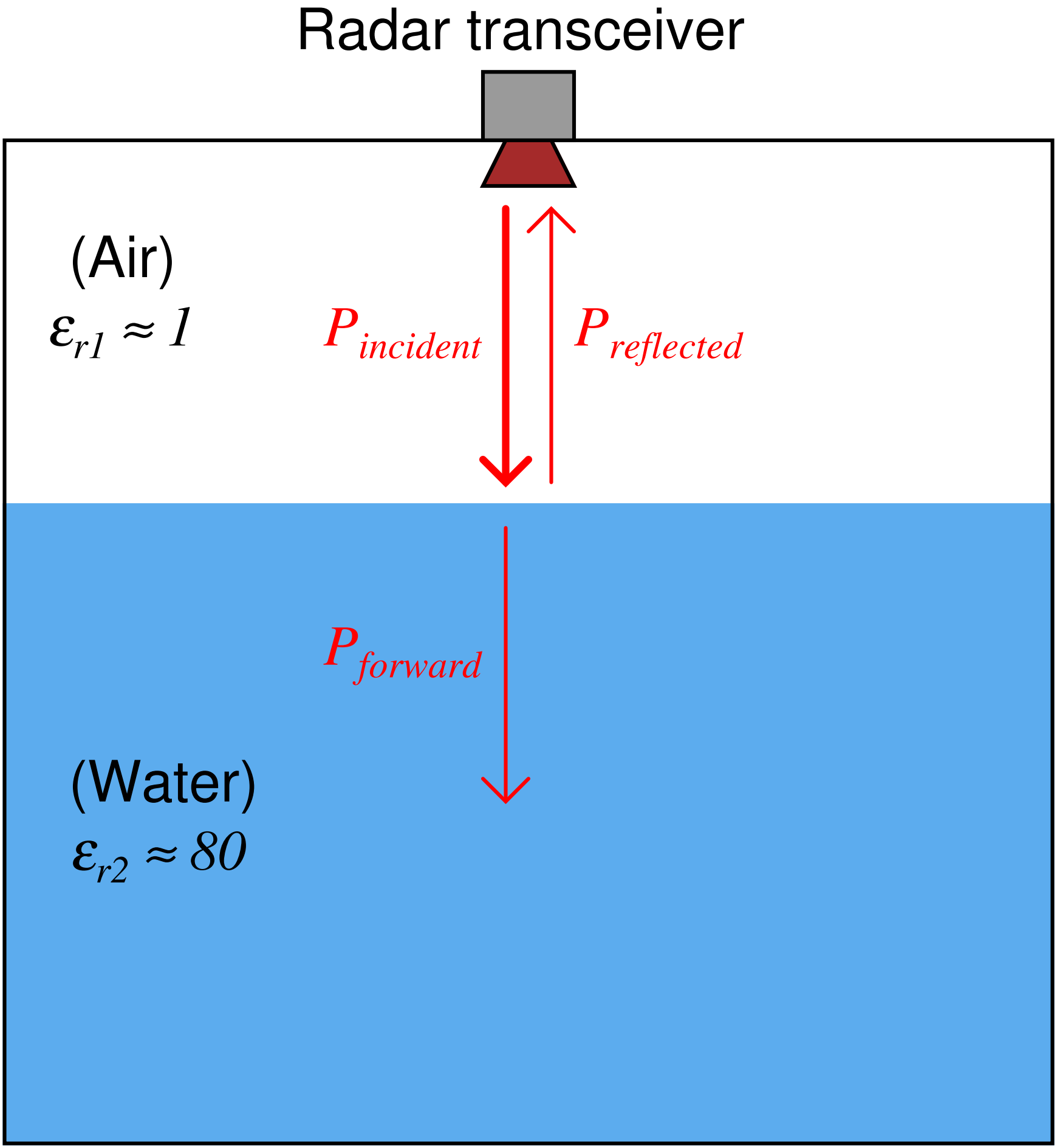
$$PV = nRT$$

$$\rho = \frac{n}{V} = \frac{P}{RT}$$



$$\epsilon_r = 1 + (\epsilon_{ref} - 1)\frac{PT_{ref}}{P_{ref}T}$$

T


Radar transceiver
(Air)
$\varepsilon_{r1} \approx 1$
$P_{incident}$
$P_{reflected}$
$P_{forward}$
(Water)
$\varepsilon_{r2} \approx 80$

R

$$R = \frac{\left(\sqrt{\epsilon_{r2}} - \sqrt{\epsilon_{r1}}\right)^2}{\left(\sqrt{\epsilon_{r2}} + \sqrt{\epsilon_{r1}}\right)^2}$$


$$\frac{P_{forward}}{P_{incident}}$$

$1 - R$

$$R = \frac{\left(\sqrt{\epsilon_r} - 1\right)^2}{\left(\sqrt{\epsilon_r} + 1\right)^2}$$

$\epsilon_r \approx 1$

$\epsilon_r \approx 80$

-1.95

-15.3

$\epsilon_r \approx 42$

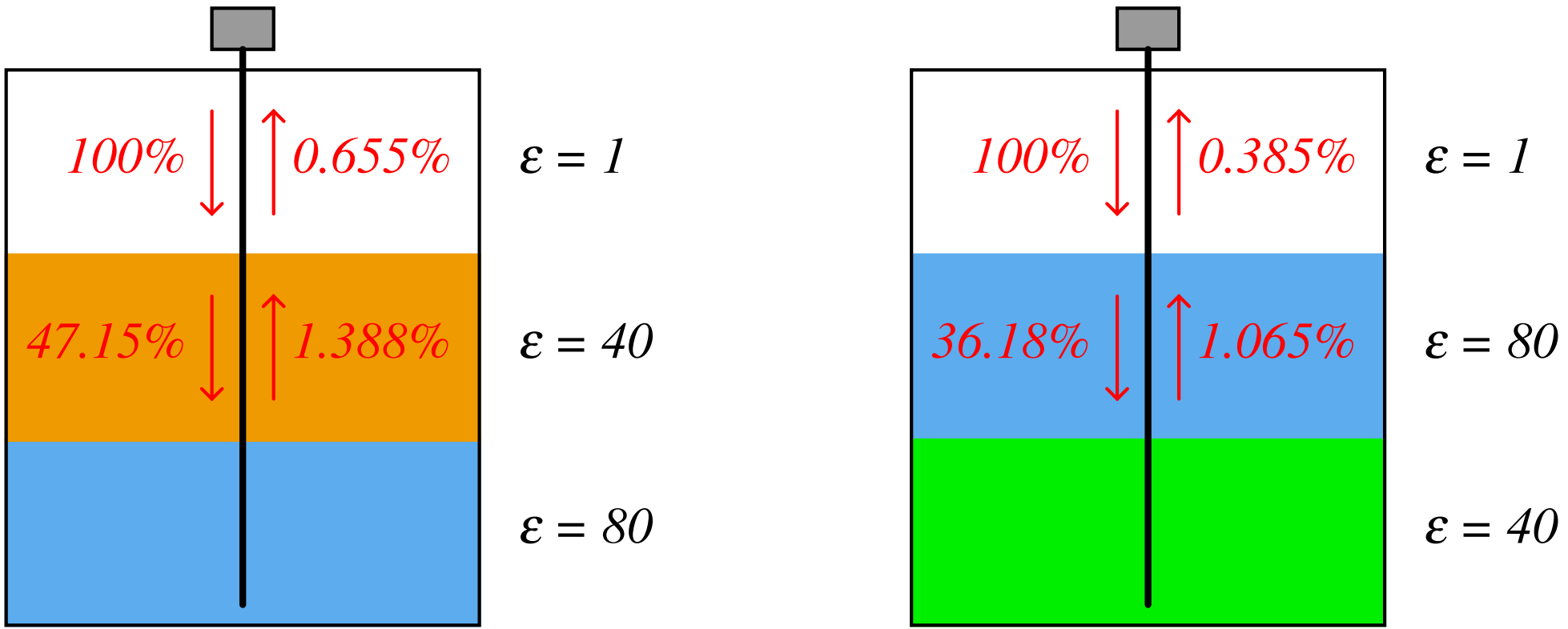
$R = 0.5285$

$R = 0.02944$

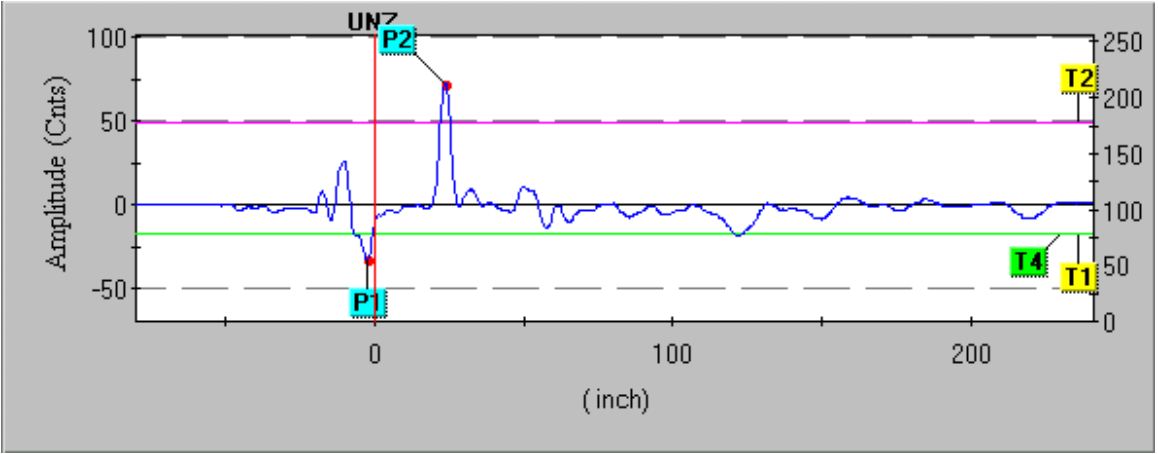
$$R = 0.6382$$

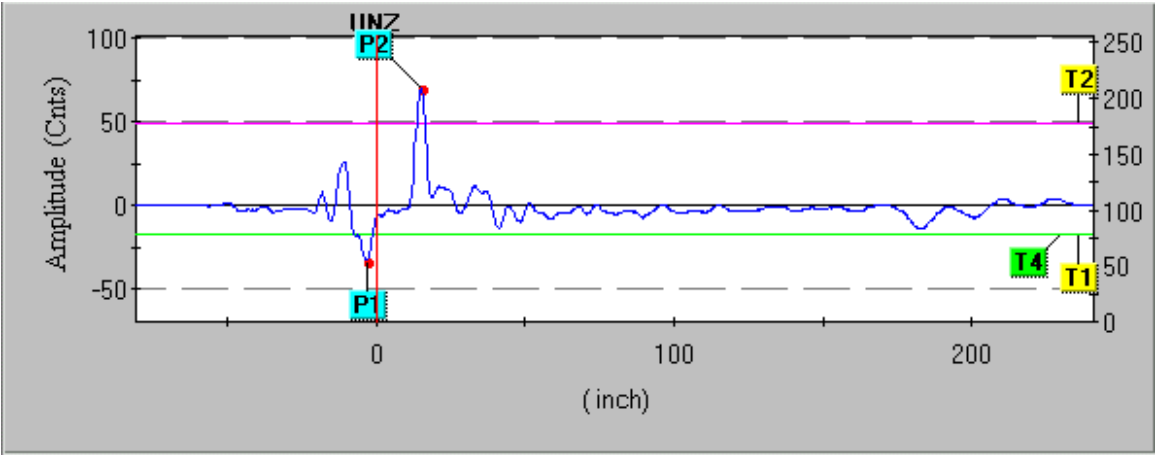
$$R = \frac{\left(\sqrt{\epsilon_r}-1\right)^2}{\left(\sqrt{\epsilon_r}+1\right)^2}$$

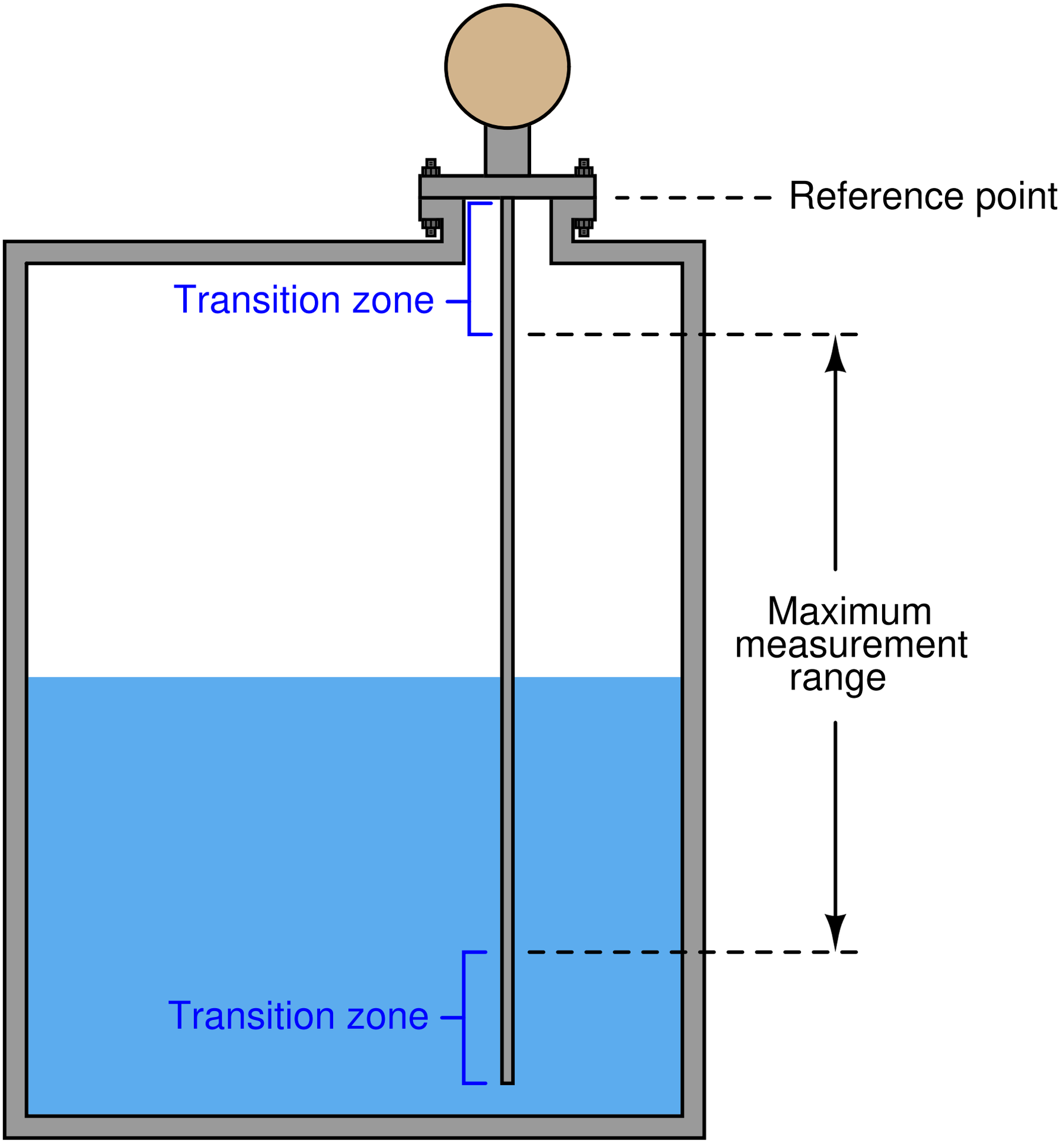
Signal power strengths en route and reflected off of the liquid-liquid interface



$\approx 3 \times 10^8$


UNZ
P2
P1
T2
T4
T1
100
50
0
-50
250
200
150
100
50
0
Amplitude (Cnts)
0
100
200
(inch)


UNZ
P2
P1
T2
T4
T1
100
50
0
-50
250
200
150
100
50
0
Amplitude (Cnts)
0
100
200
(inch)


Reference point
Transition zone
Maximum measurement range
Transition zone

Magnetostrictive
level transmitter

Sensing head

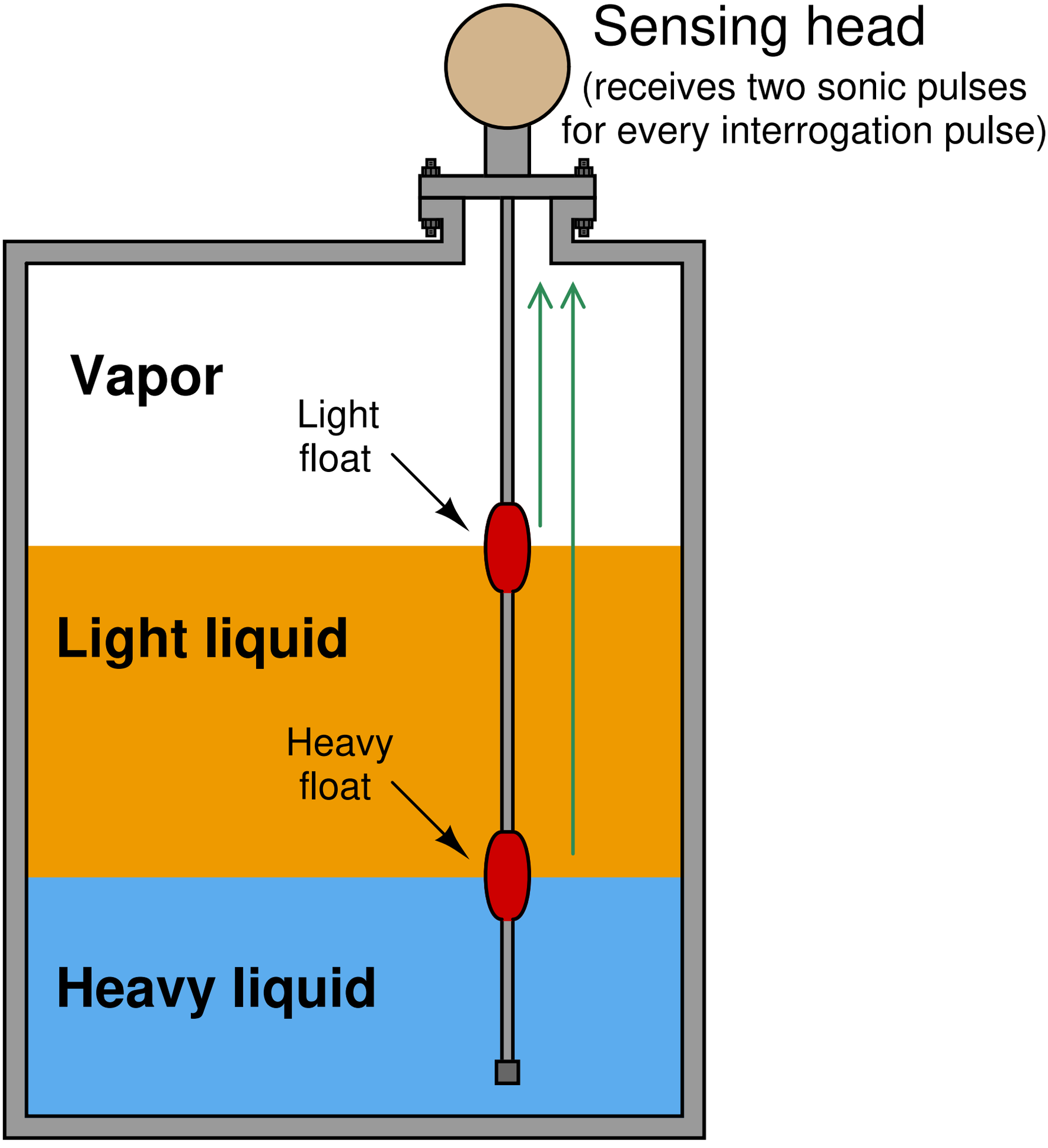
The time required for the torsional stress wave to travel from the float to the sensing head is proportional to the vessel's ullage.

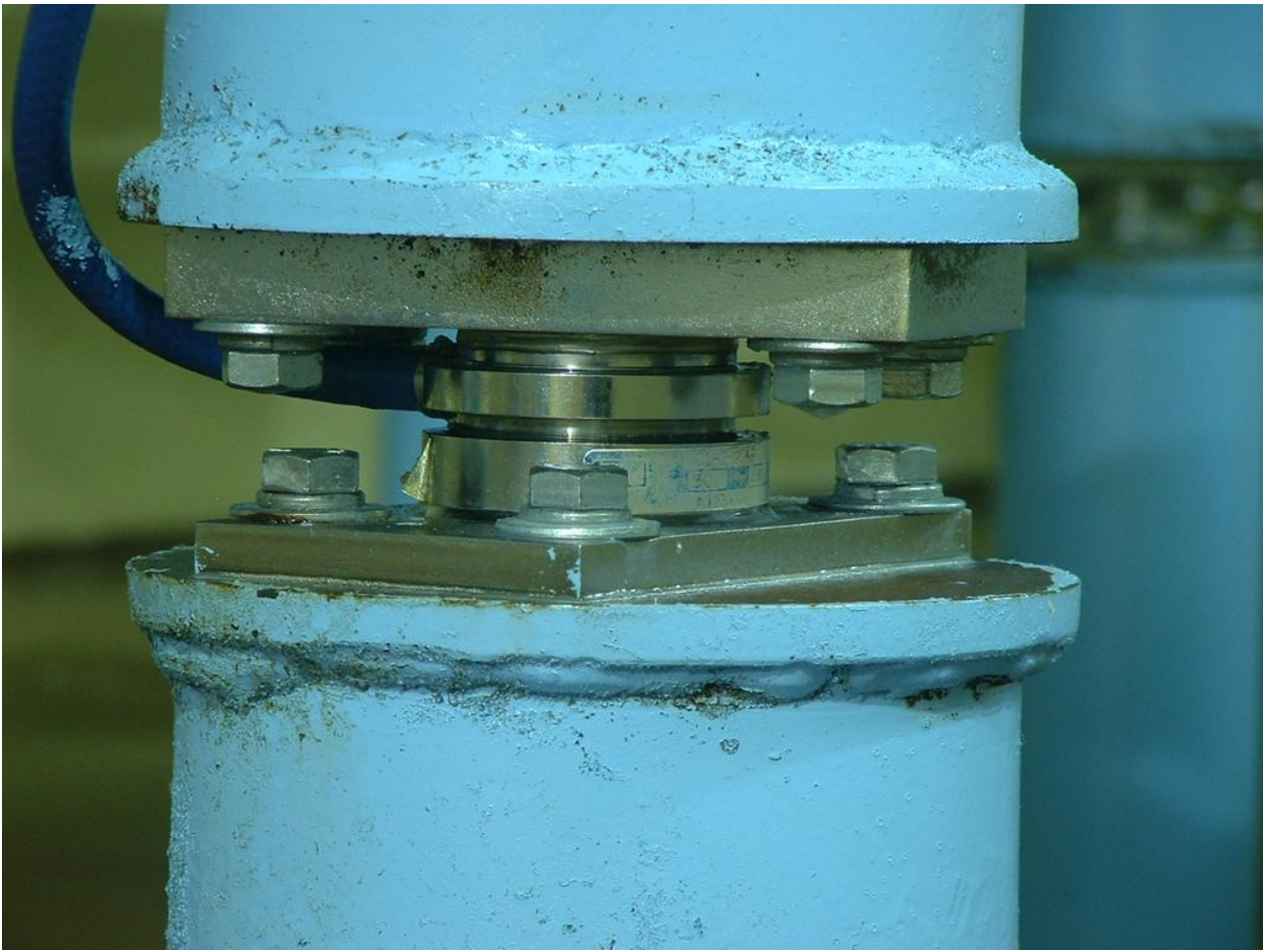
Magnetic
float

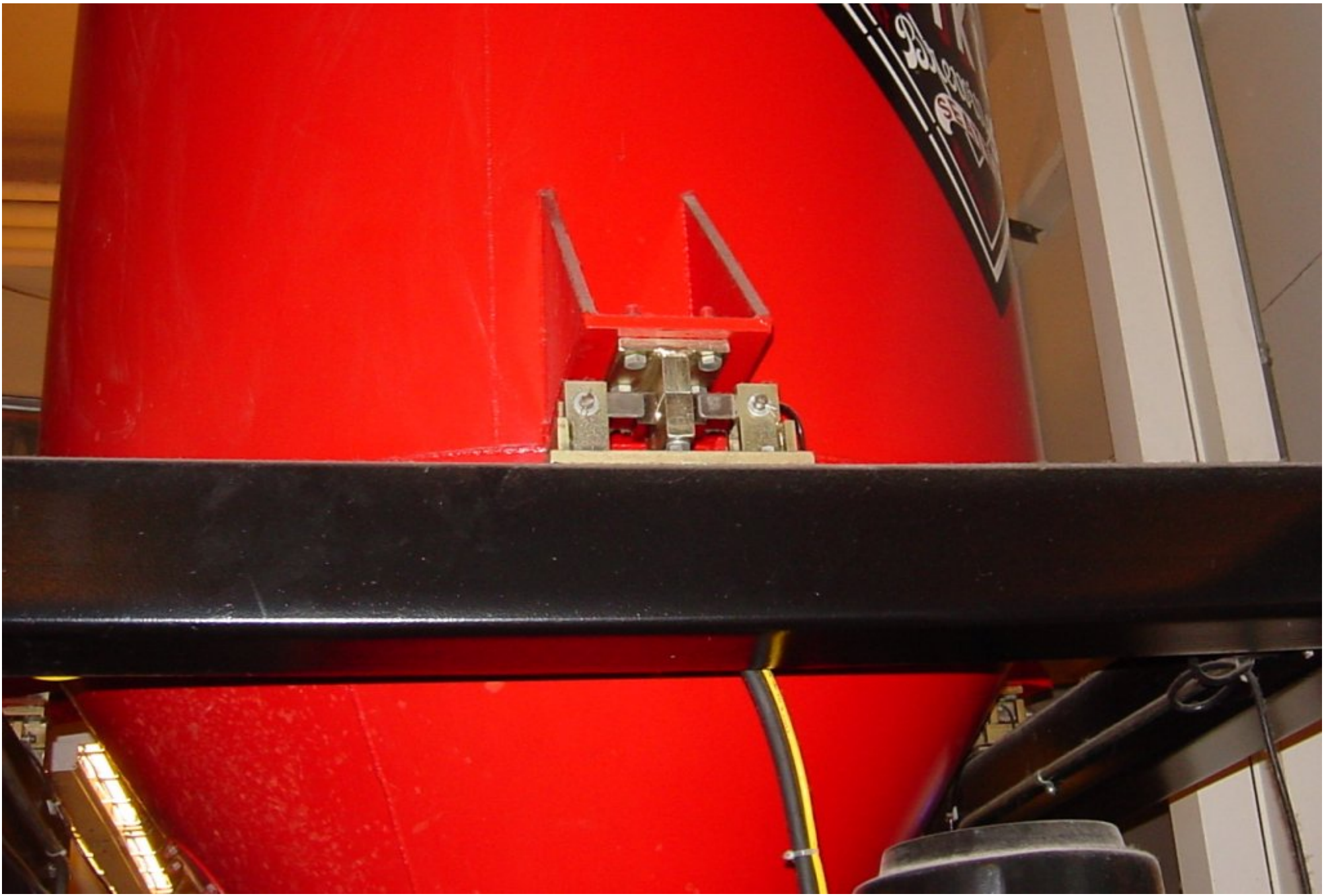
Dampener

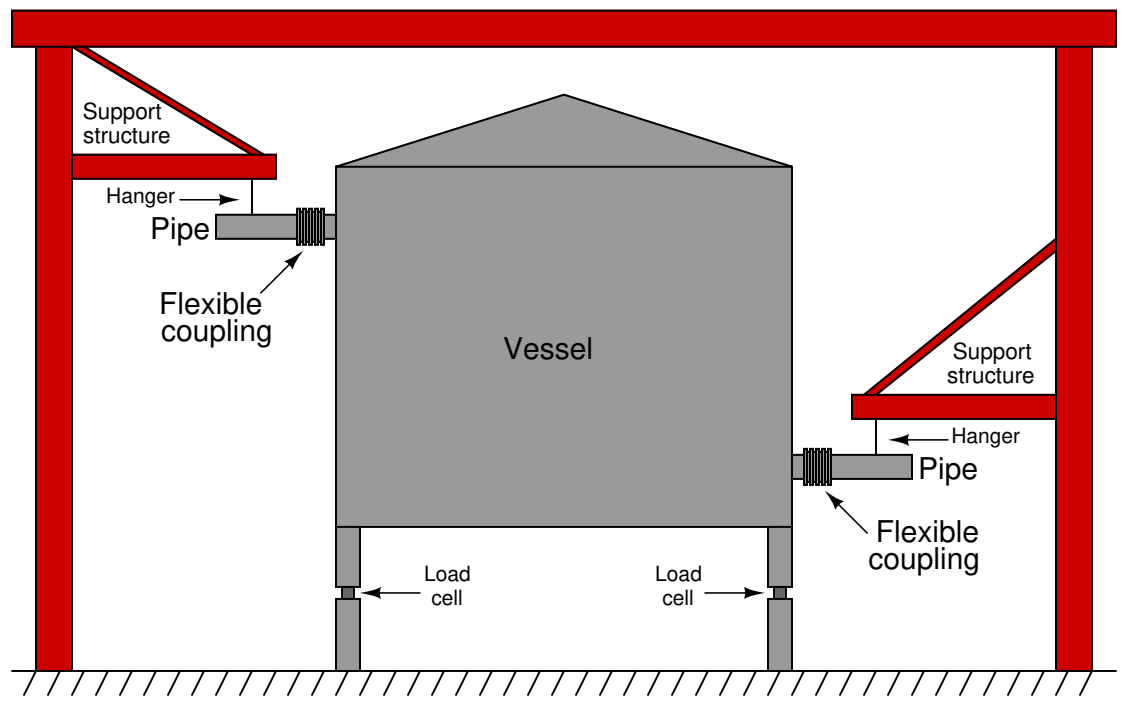
3×10^3

3×10^8


Sensing head
(receives two sonic pulses
for every interrogation pulse)
Vapor
Light
float
Light liquid
Heavy
float
Heavy liquid



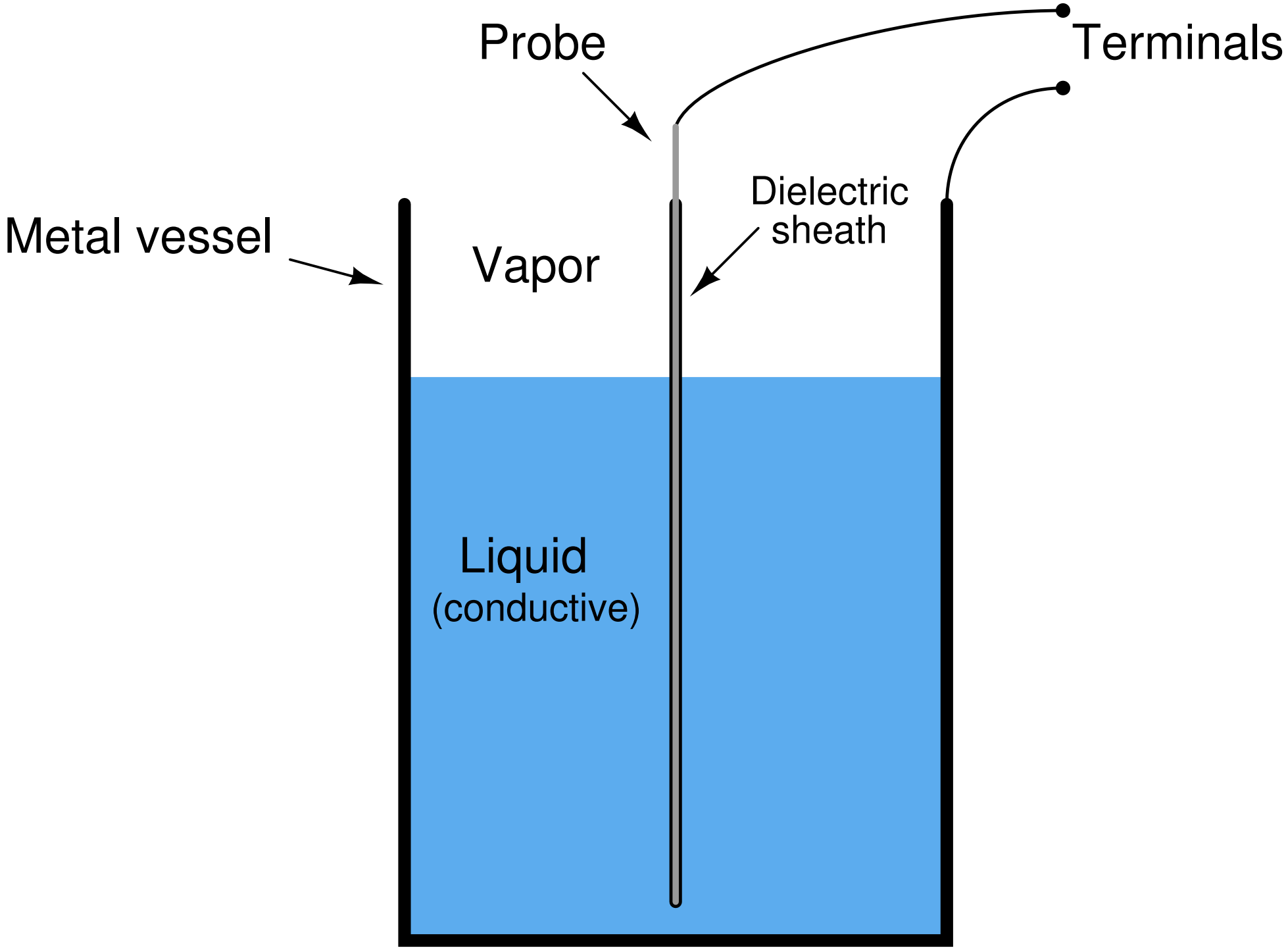


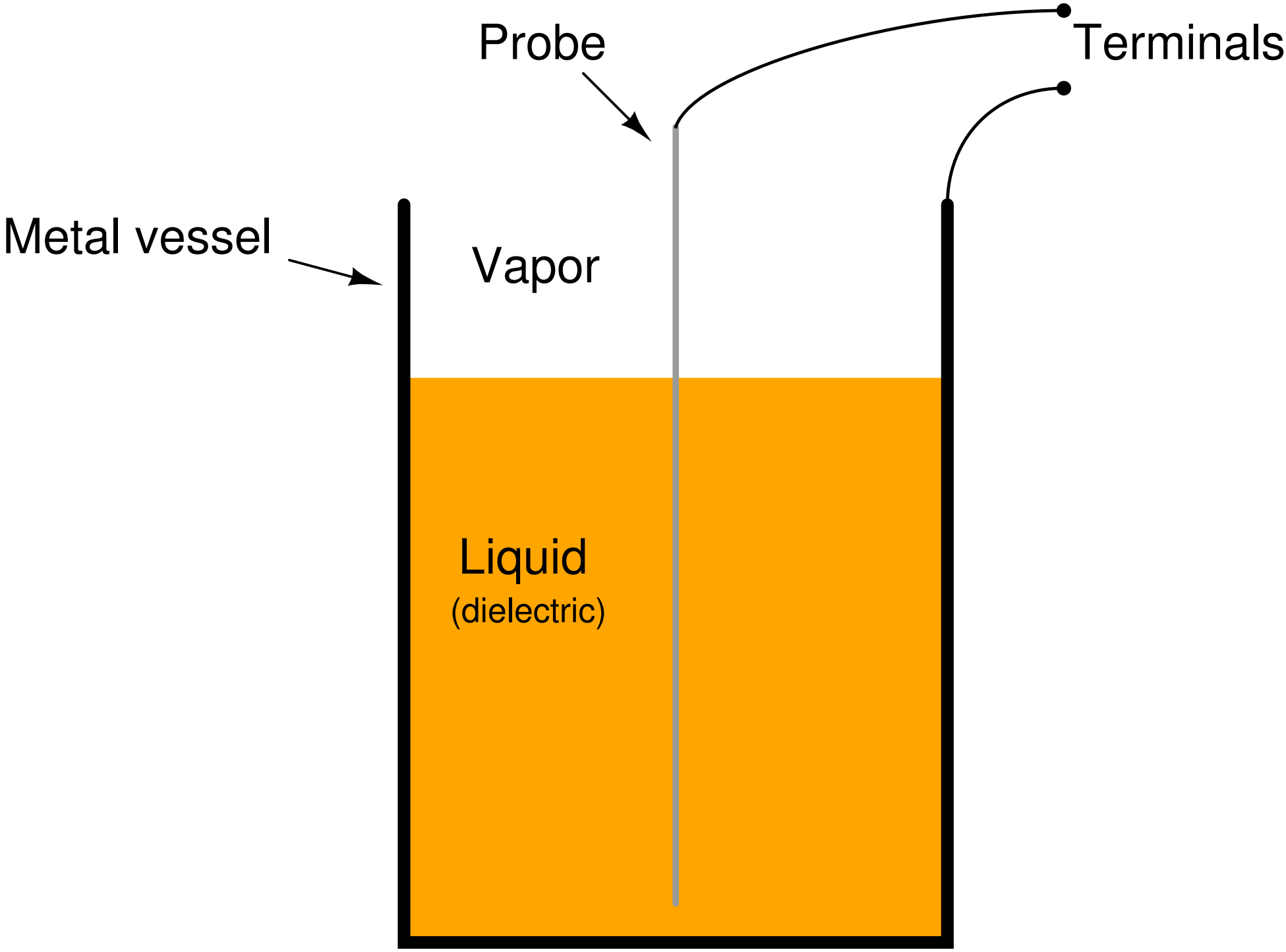

Support structure
Hanger
Pipe
Flexible coupling
Vessel
Support structure
Hanger
Pipe
Flexible coupling
Load cell
Load cell

$$F = ma$$

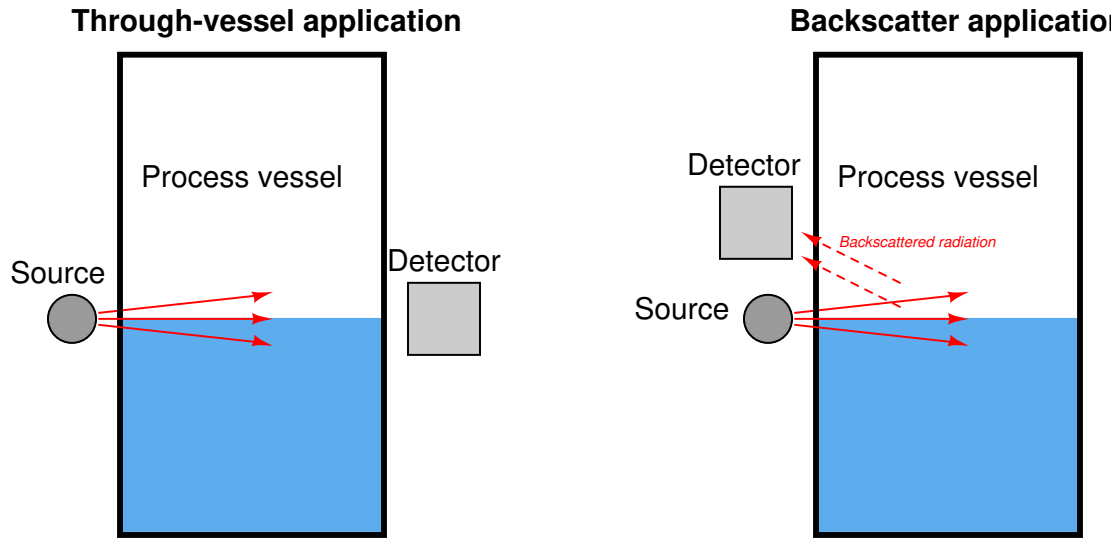
$$C = \frac{\epsilon A}{d}$$

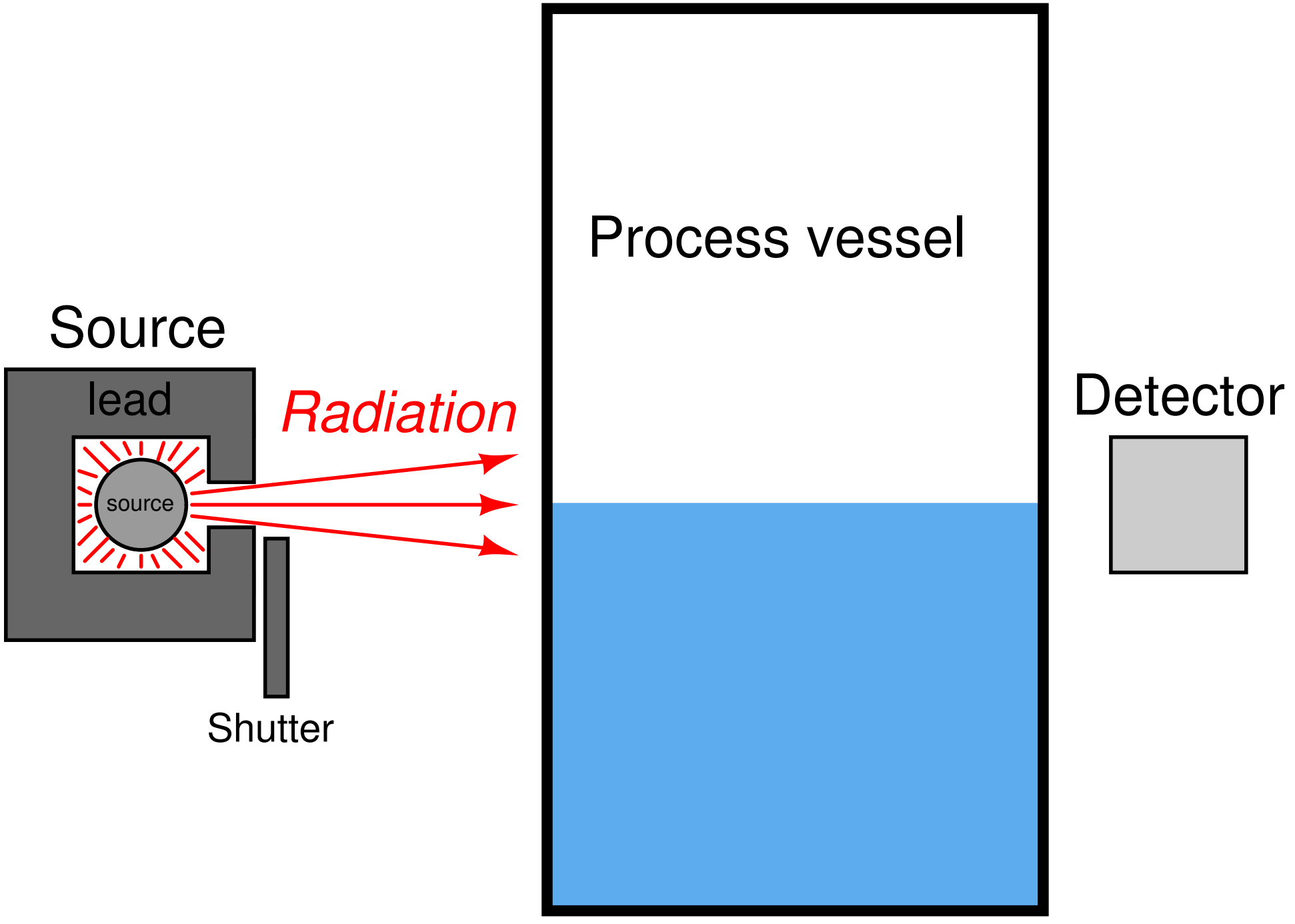
d


Probe
Terminals
Dielectric
sheath
Metal vessel
Vapor
Liquid
(conductive)

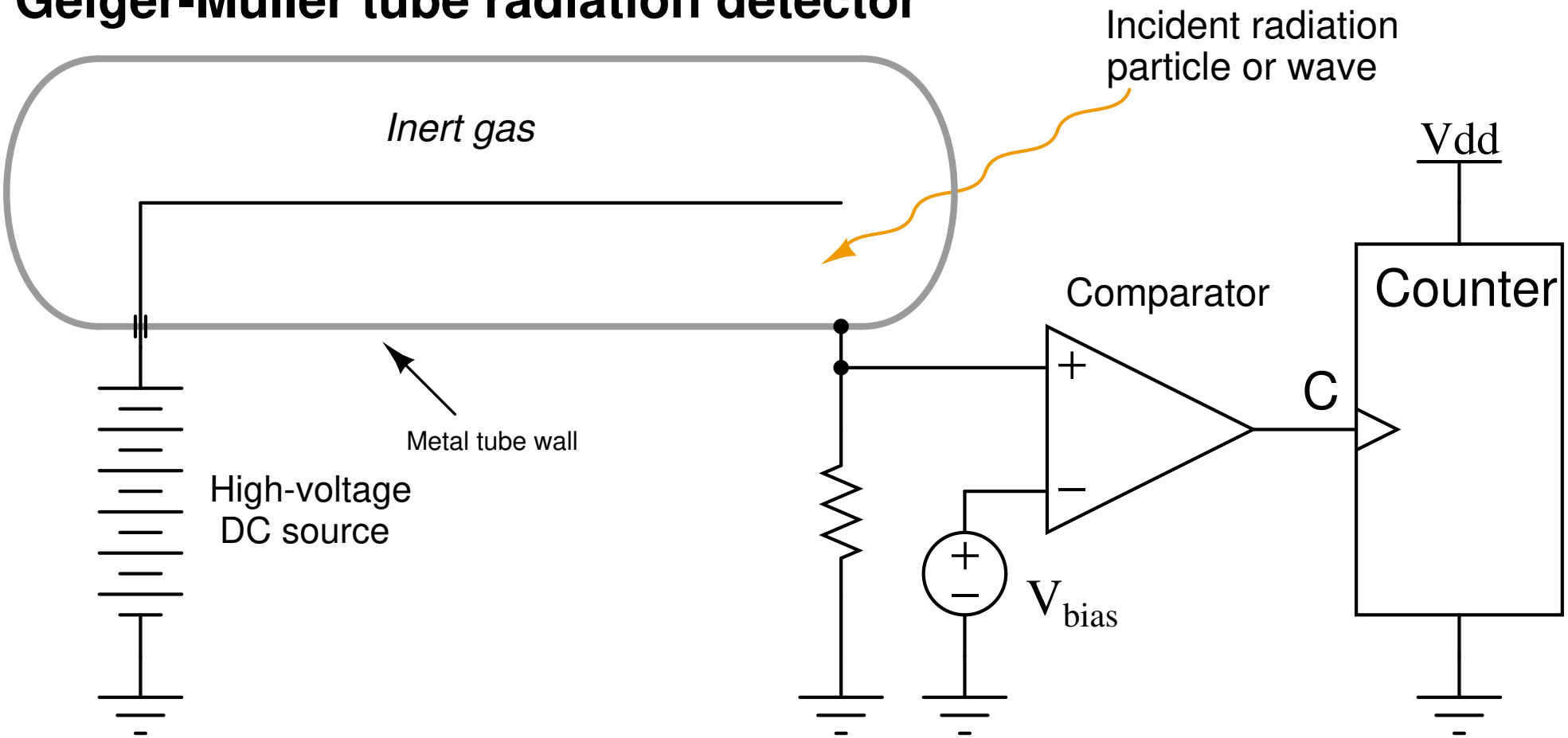

Probe
Terminals
Metal vessel
Vapor
Liquid
(dielectric)

n


Through-vessel application
Process vessel
Source
Detector
Backscatter application
Detector
Process vessel
Backscattered radiation
Source


Process vessel
Source
lead
Radiation
source
Detector
Shutter

Geiger-Muller tube radiation detector

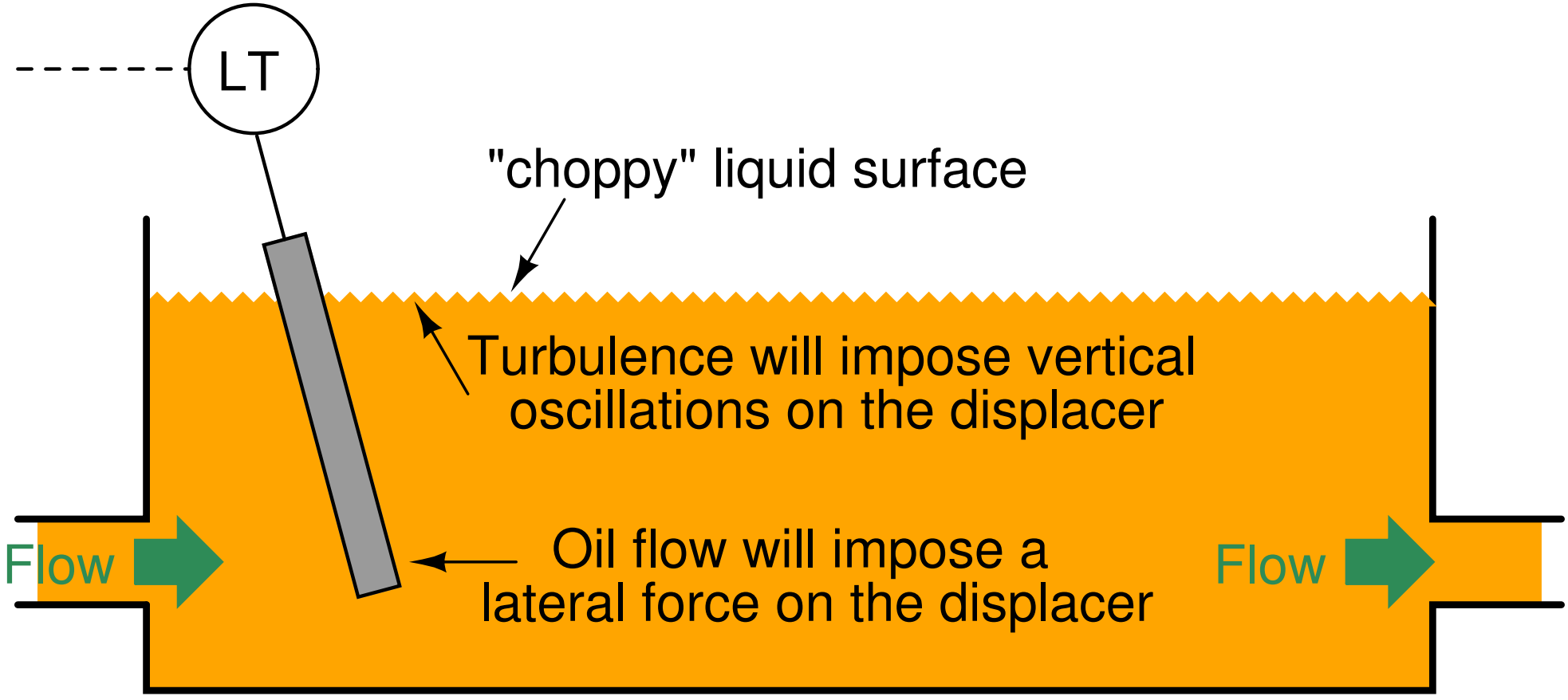


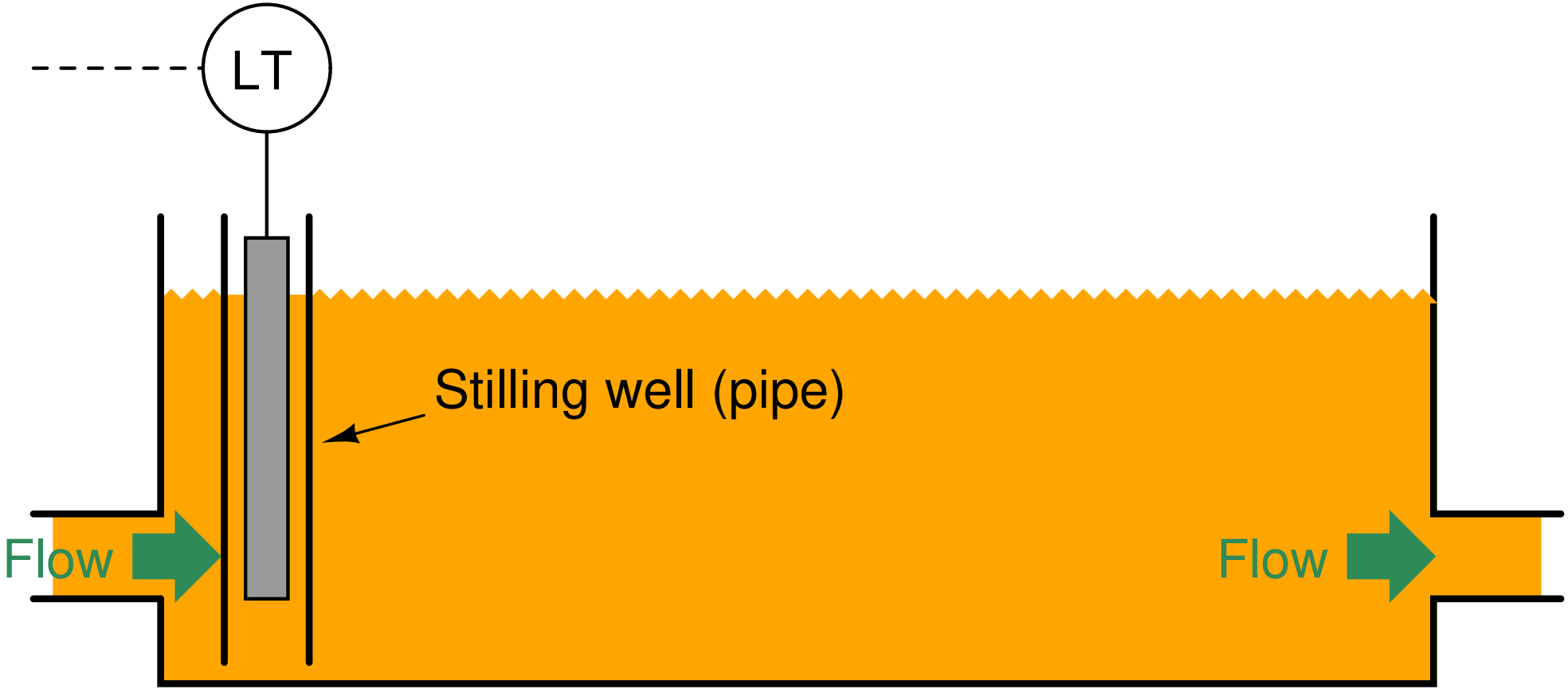

x100
HV
bat.
off
fast
response
off
audio

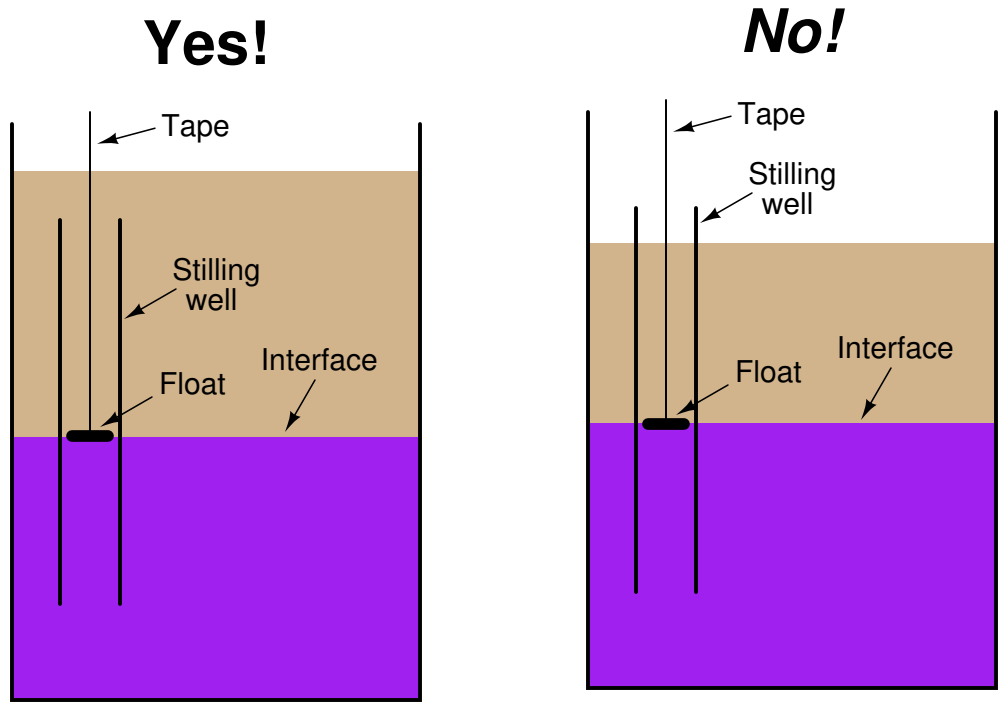
235

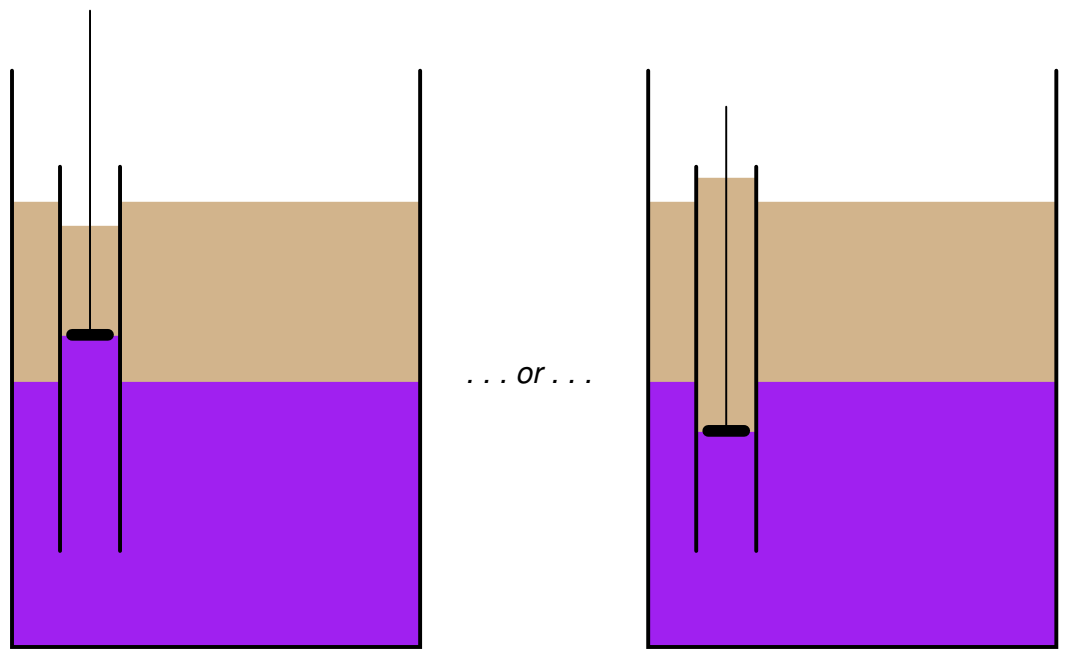
10

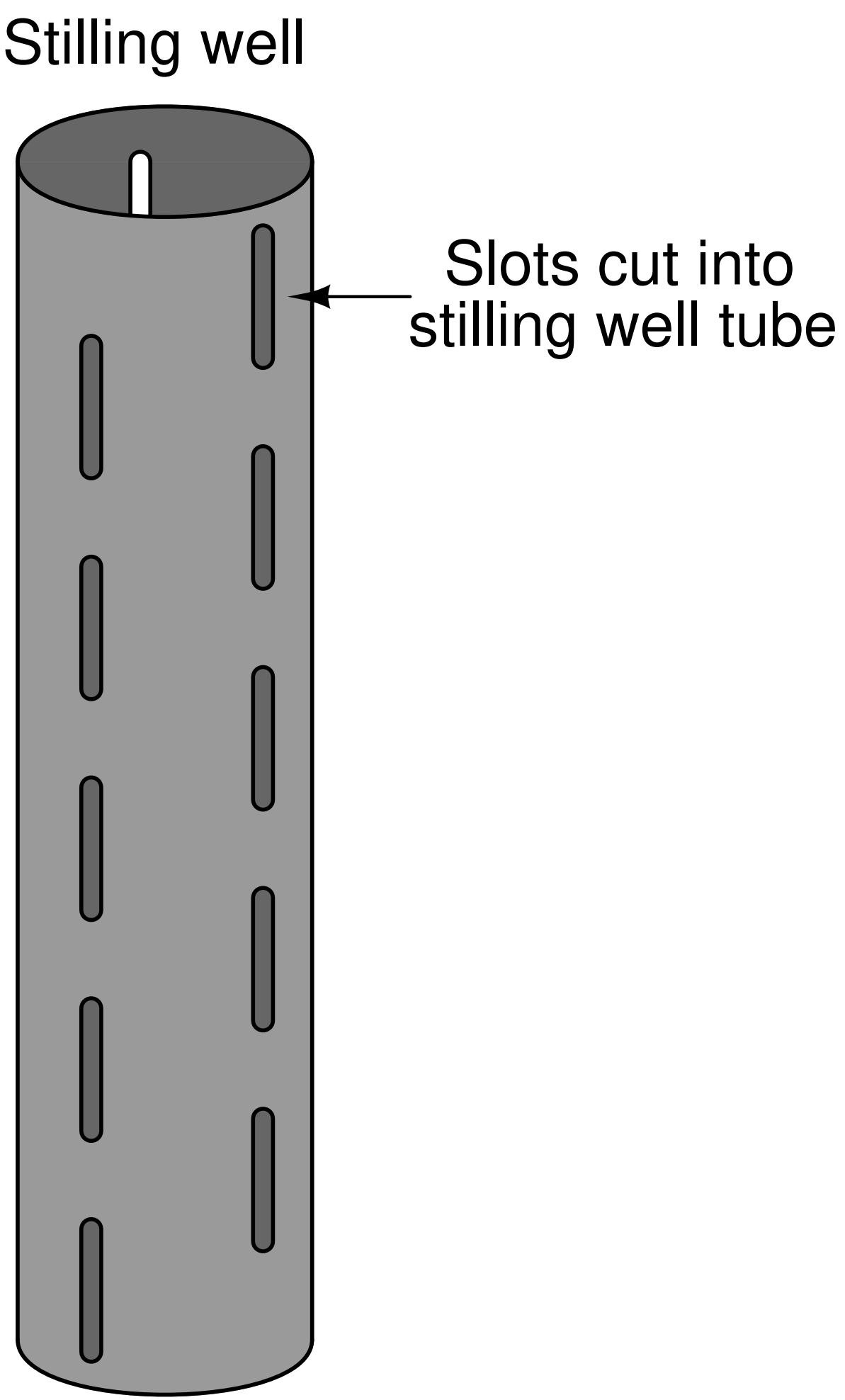
7


LT
"choppy" liquid surface
Turbulence will impose vertical
oscillations on the displacer
Flow
Oil flow will impose a
lateral force on the displacer
Flow


LT
Stilling well (pipe)
Flow
Flow


Yes!
Tape
Stilling well
Float
Interface
No!
Tape
Stilling well
Float
Interface


. . . or . . .


Stilling well
Slots cut into
stilling well tube

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

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

$$x = vt$$

$$C = \frac{\epsilon A}{d}$$