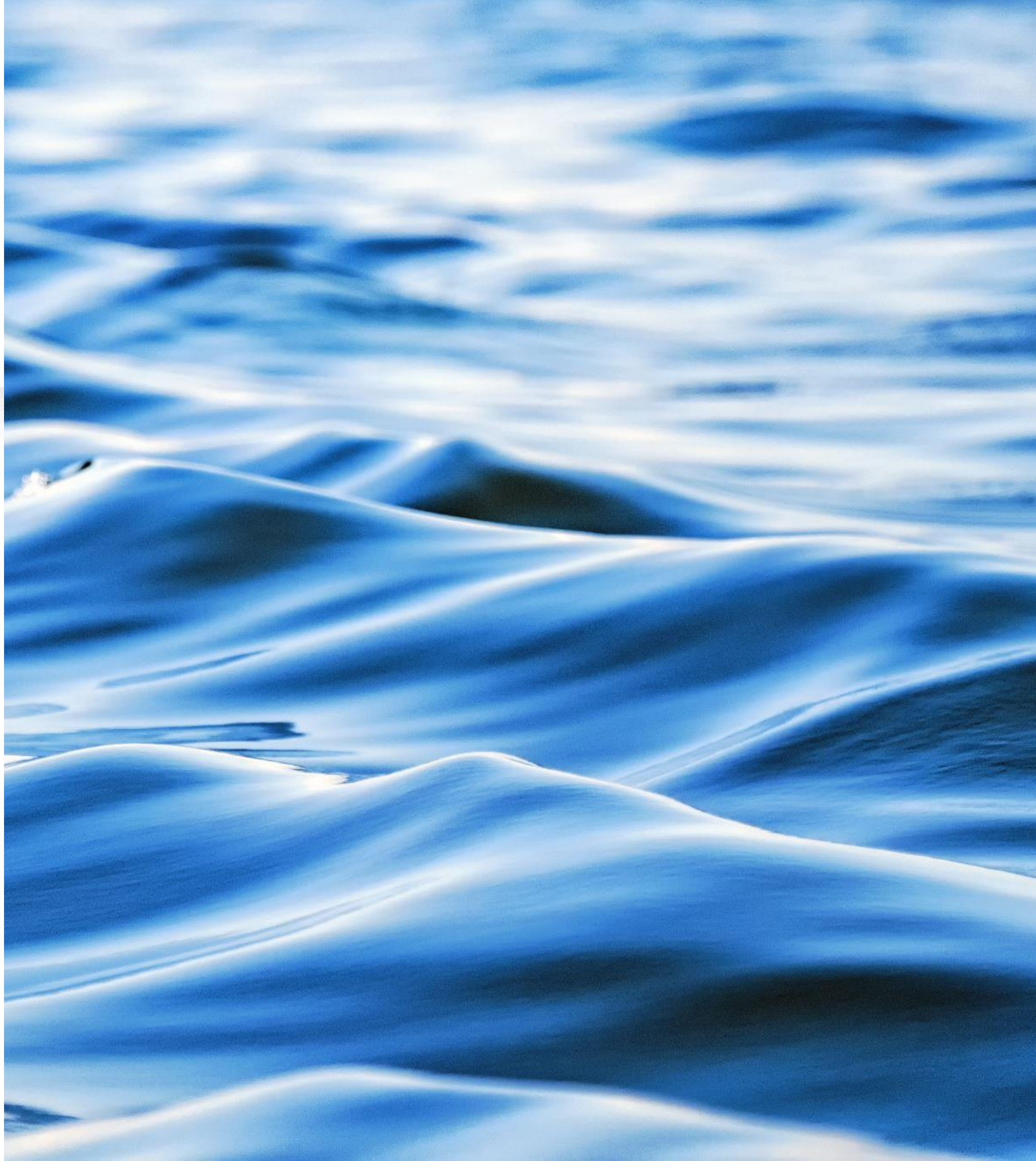
Water Resources Engineering Lecture 5

Physical Properties of Water

Dr. Zada Tawalbeh
Ajloun National University

Chapters Outlines

- Properties Involving Mass or Weight of Water
- Viscosity
- Elasticity
- Pressure and Pressure Variation
- Surface Tension
- Laminar and Turbulent Flow
- Continuity
- Hydrostatic Forces
- Buoyancy



Water Density

- Mass density, often called density, is the mass per unit volume, with units of kilograms (kg) per cubic meter (m^3) in SI units.
- The Greek symbol ρ (rho) is used to denote density.
- The mass density of water at 4 °C is 1000 kg/m^3 or 1.94 slugs/ft^3.
- For most applications in hydrologic and hydraulic processes, the density is assumed to be constant so that water is assumed incompressible.

Density

The density of a substance is defined as its **mass per unit volume.**

$$\rho = \frac{m}{V}$$

Where:

- ρ = density (kg/m^3)
- m = mass (kg)
- V = volume (m^3)

Material	Approx. Density (kg/m³)	Notes
Water	1000	Maximum density at 4°C
Oil	800	Floats on water
Air	1.2	Very low density
Wood	400–700	Floats most of the time
Steel	7850	Heavy, sinks
Aluminum	2700	Light metal

Examples 1

A metal block has:

- Mass = 5 kg
- Volume = 0.002 m^3

$$\rho = \frac{5}{0.002} = 2500\,\mathrm{kg/m^3}$$

Density = 2500 kg/m^3

Example 2

A container of oil has:

- Mass = 0.8 kg
- Volume = 0.001 m^3

$$\rho = \frac{0.8}{0.001} = 800\,\mathrm{kg/m^3}$$

Density of oil = 800 kg/m^3

(This is why oil floats on water.)

Example 3

- Mass of air sample = 0.004 kg
- Volume = 0.0032 m^3

$$\rho = \frac{0.004}{0.0032} = 1.25\,\mathrm{kg/m^3}$$

Density of air ≈ 1.25 kg/m^3

Specific weight

- Specific weight is the gravitational force (weight) per unit volume of water, denoted by the Greek symbol γ (gamma). The specific weight of water at 4C is 9810 N/m^3 or 62.4 lb/ft^3.

- The relationship between density and specific weight is:

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

Where:

- γ = specific weight (N/m^3)
- ρ = density (kg/m^3)
- g = 9.81 m/s^2
- Water at 4°C → $\gamma = 9810\,\mathrm{N/m^3}$

$$g = 9.81\ m/s^2$$
$$g = 32.2\ ft/s^2$$

Given:

- Volume = 2 m^3
- Specific weight of water = 9810 N/m^3

9.81 kN/m^3

$$W = \gamma V = 9810 \times 2 = 19620\,\mathrm{N}$$

Weight = 19,620 N

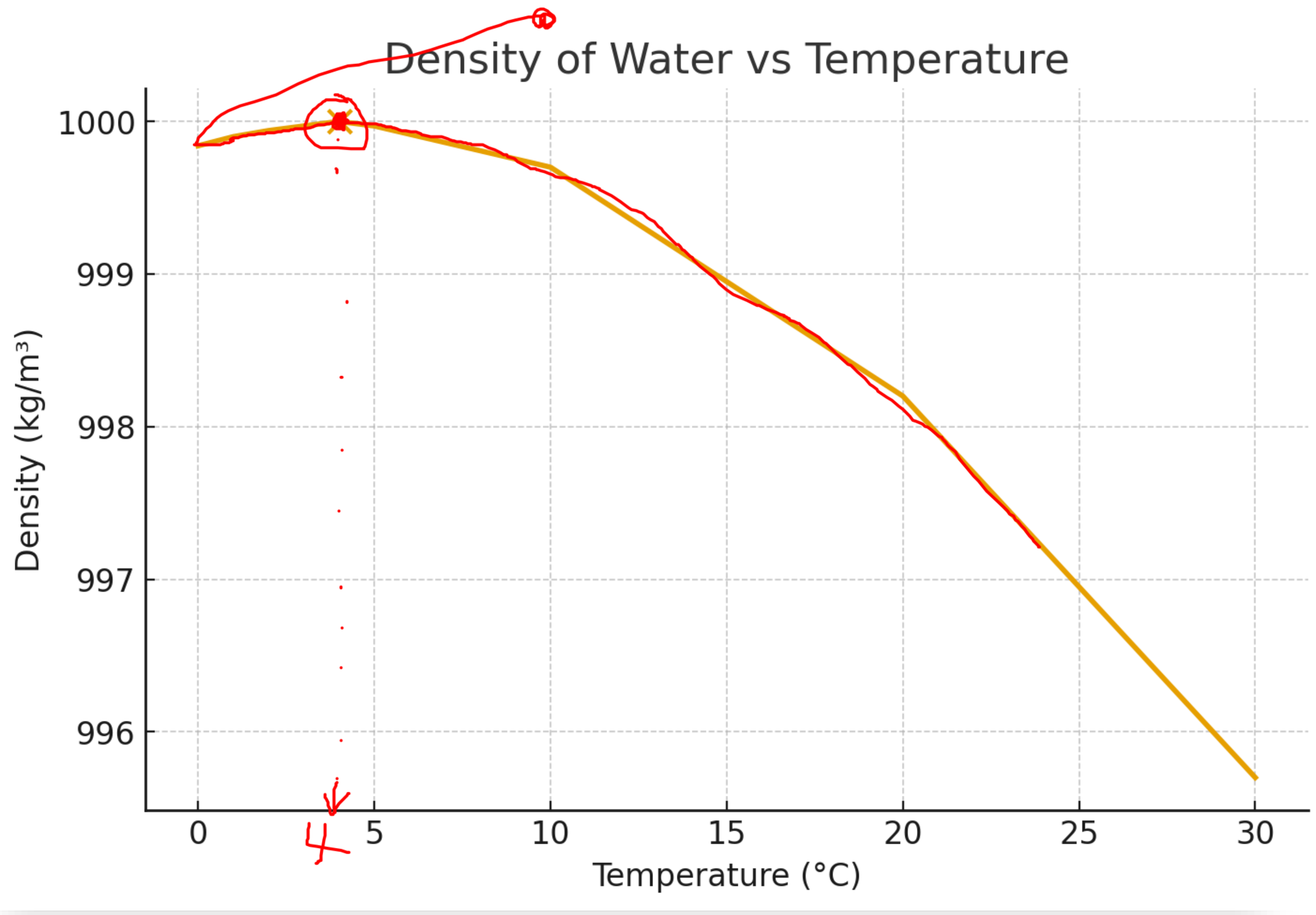
$\gamma = \frac{W}{V}$ N/m^3

Specific gravity

$$SG = \frac{\gamma_{\text{fluid}}}{\gamma_{\text{water at } 4^\circ C}}$$

$$SG = \frac{\rho_{\text{fluid}}}{\rho_{\text{water at } 4^\circ C}}$$

- Specific gravity (SG) of a fluid refers to the ratio of the specific weight of a given liquid to the specific weight of water.



Density of Water vs Temperature
1000
999
998
997
996
Density (kg/m³)
0
5
10
15
20
25
30
Temperature (°C)
4

Graph

1. From 0°C to 4°C – Density Increases

When water warms from **0°C to 4°C**, its density increases.
This is unusual because most substances expand when warmed.

But water contracts until it reaches **maximum density at 4°C**.

On the graph, this appears as the curve rising upward toward the highest point.

2. At 4°C – Maximum Density

The graph reaches its **peak** at **4°C**, shown by the marked point.
This means:

$$\rho_{max} = 1000\ kg/m^3\ at\ 4^\circ C$$

Water is densest at 4°C.
This is why cold water sinks to the bottom of lakes while ice floats.

Graph

3. From 4°C to Higher Temperatures – Density Decreases

As temperature increases above 4°C, water expands and its density decreases.
The graph slopes downward from 4°C to 30°C.

Hotter water takes up more space → lower density.

4. Overall Behavior

Water behaves **normally** above 4°C:
Higher temperature → lower density

Water behaves **abnormally** below 4°C:
Cooling below 4°C → lower density
(This is why ice is less dense than liquid water.)

The relationship between the temperature scales is:

$$^{\circ}C = \frac{5}{9}(^{\circ}F - 32)$$

or equivalently,

$$^{\circ}F = \frac{9}{5}(^{\circ}C) + 32.$$

Example 1

Given:

- $\gamma_{\text{oil}} = 8500\,\text{N}/\text{m}^3$

$$SG = \frac{8500}{9810} = 0.87$$

Oil SG = 0.87

(less than 1 → oil floats on water)

Example 2

Given:

- $\gamma_{\text{seawater}} = 10250\,\text{N}/\text{m}^3$

$$SG = \frac{10250}{9810} = 1.04$$

Seawater SG = 1.04

(denser than pure water)

Density-SG

Fluid	Density (kg/m³)	SG	Behavior
Water	1000	1.00	Reference
Oil	850	0.85	Floats
Alcohol	790	0.79	Floats
Concrete slurry	2200	2.20	Sinks
Seawater	1040	1.04	Slightly heavier
Air	1.2	0.0012	Very light

Physical Properties of Water

Table 3.1.1 Physical Properties of Water in English Units

Temp. (°F)	Specific weight, γ (lb/ft^3)	Density, ρ (slugs/ft^3)	Viscosity, $10^{-5}\mu$ (lb · sec/ft^2)	Kinematic viscosity, $10^{-5}\nu$ (ft^2/sec)	Surface tension, 100σ (lb/ft)	Vapor-pressure head, p_v/γ (ft)	Bulk modulus of elasticity, $10^3\ \beta$(lb/in^2)
32	62.42	1.940	3.746	1.931	0.518	0.20	293
40	62.43	1.940	3.229	1.664	0.514	0.28	294
50	62.41	1.940	2.735	1.410	0.509	0.41	305
60	62.37	1.938	2.359	1.217	0.504	0.59	311
70	62.30	1.936	2.050	1.059	0.500	0.84	320
80	62.22	1.934	1.799	0.930	0.492	1.17	322
90	62.11	1.931	1.595	0.826	0.486	1.61	323
100	62.00	1.927	1.424	0.739	0.480	2.19	327
110	61.86	1.923	1.284	0.667	0.473	2.95	331
120	61.71	1.918	1.168	0.609	0.465	3.91	333
130	61.55	1.913	1.069	0.558	0.460	5.13	334
140	61.38	1.908	0.981	0.514	0.454	6.67	330
150	61.20	1.902	0.905	0.476	0.447	8.58	328
160	61.00	1.896	0.838	0.442	0.441	10.95	326
170	60.80	1.890	0.780	0.413	0.433	13.83	322
180	60.58	1.883	0.726	0.385	0.426	17.33	313
190	60.36	1.876	0.678	0.362	0.419	21.55	313
200	60.12	1.868	0.637	0.341	0.412	26.59	308
212	59.83	1.860	0.593	0.319	0.404	33.90	300

Physical Properties of Water

Table 3.1.2 Physical Properties of Water in SI Units

Temp. (°C)	Specific weight, γ (N/m^3)	Density, ρ (kg/m^3)	Viscosity, $10^{-3}\mu$ ($N \cdot s/m^2$)	Kinematic viscosity, $10^{-6}\nu(m^2/s)$	Surface tension, 100σ (N/m)	Vapor-pressure head, p_v/γ (m)	Bulk modulus of elasticity, $10^7\beta$ (N/m^2)
0	9805	999.9	1.792	1.792	7.62	0.06	204
5	9806	1000.0	1.519	1.519	7.54	0.09	206
10	9803	999.7	1.308	1.308	7.48	0.12	211
15	9798	999.1	1.140	1.141	7.41	0.17	214
20	9789	998.2	1.005	1.007	7.36	0.25	220
25	9779	997.1	0.894	0.897	7.26	0.33	222
30	9767	995.7	0.801	0.804	7.18	0.44	223
35	9752	994.1	0.723	0.727	7.10	0.58	224
40	9737	992.2	0.656	0.661	7.01	0.76	227
45	9720	990.2	0.599	0.605	6.92	0.98	229
50	9697	988.1	0.549	0.556	6.82	1.26	230
55	9679	985.7	0.506	0.513	6.74	1.61	231
60	9658	983.2	0.469	0.477	6.68	2.03	228
65	9635	980.6	0.436	0.444	6.58	2.56	226
70	9600	977.8	0.406	0.415	6.50	3.20	225
75	9589	974.9	0.380	0.390	6.40	3.96	223
80	9557	971.8	0.357	0.367	6.30	4.86	221
85	9529	968.6	0.336	0.347	6.20	5.93	217
90	9499	965.3	0.317	0.328	6.12	7.18	216
95	9469	961.9	0.299	0.311	6.02	8.62	211
100	9438	958.4	0.284	0.296	5.94	10.33	207

Pressure

- Pressure at a given depth in a fluid can be expressed by the relationship:

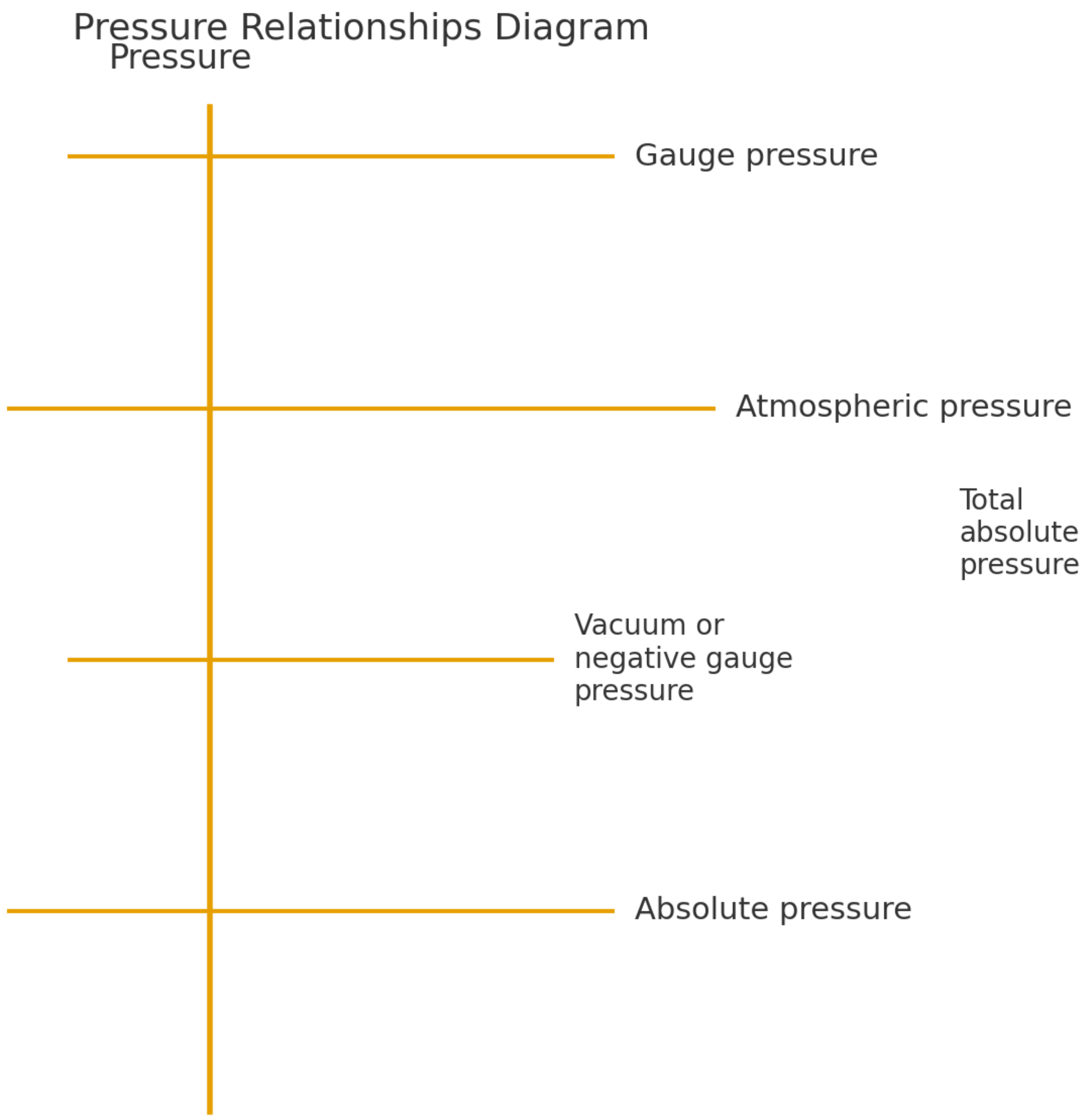
$$p = \gamma y$$

- where p is the pressure, γ is the specific weight of the fluid, and y is the depth below the fluid surface. Pressure describes the **force applied per unit area** and is commonly expressed in units such as **N/m² (Pascal)**, **lb/in² (psi)**, **lb/ft²**, **feet of water**, or **inches of mercury**.

Pressure

Gauge pressure is the pressure measured relative to atmospheric pressure. When a device reports gauge pressure, it sets atmospheric pressure as the zero reference point.

Absolute pressure, however, is measured relative to a perfect vacuum, meaning it includes both atmospheric pressure and the gauge pressure. **Vacuum pressure** represents any pressure that is **below atmospheric pressure**, often seen in suction systems or sealed containers.


Pressure Relationships Diagram
Pressure
Gauge pressure
Atmospheric pressure
Total absolute pressure
Vacuum or negative gauge pressure
Absolute pressure

Example 1

Example 1: Pressure on the bottom of a tank

A tank contains water to a depth of **5 m**.

Find the pressure at the bottom.

$$p = \gamma y$$

For water:

$$\gamma = 9810\,\mathrm{N/m^3}$$

$$p = 9810 \times 5 = 49{,}050\,\mathrm{Pa}$$

Answer: $49\,\mathrm{kPa}$

Conversion

Common conversion factors

- $1\,\text{atm} = 101{,}325\,\text{Pa}$
- $1\,\text{psi} = 6894.76\,\text{Pa}$
- $1\,\text{bar} = 100{,}000\,\text{Pa}$
- $1\,\text{in Hg} = 3386.39\,\text{Pa}$
- $1\,\text{ft of water} = 2989\,\text{Pa}$

101.3 kPa

1 bar = 100 kPa

$P = \gamma h \rightarrow h = \frac{P}{\gamma}$

Example

Example: Convert 100 kPa to meters of water

$$p = \gamma h \Rightarrow h = \frac{p}{\gamma} = \frac{100\ \text{KPa}}{9.81\ \text{KN}}$$

$$h = \frac{100\,000}{9810} = 10.19\ \text{m}$$

10.2 m of water

Convert 1 atm to feet of water

$$1\,\text{atm} = 101{,}325\,\text{Pa}$$

$$h = \frac{101{,}325}{9{,}810} = 10.33\,\text{m}$$

m = 3.281 ft

10.33 → ft

$$10.33 \times 3.281 = 33.9\,\text{ft}$$