Petrophysics

POROSITY

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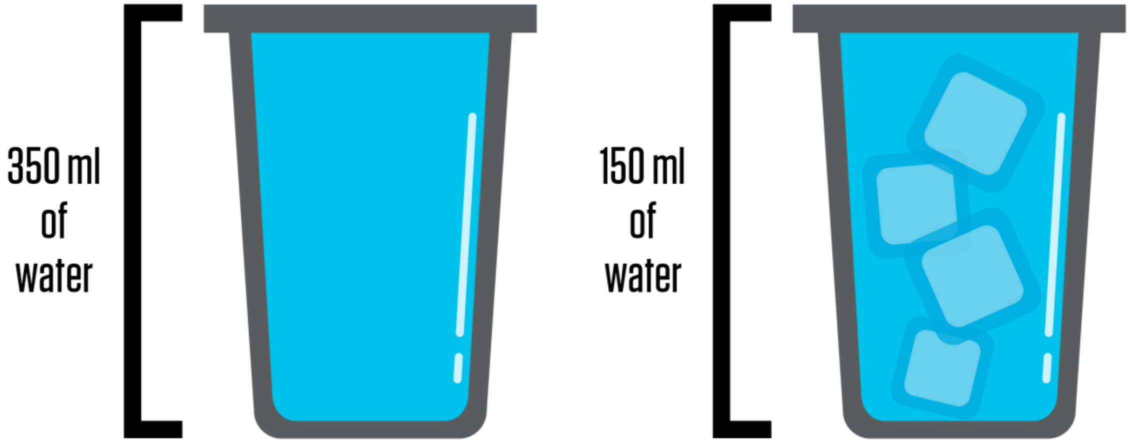
Introduction (What is Porosity?)

Consider 2 identical glasses, and 4 ice cubes. If each ice cube has a volume of 50 ml. The total volume (V_t) = 350 ml

Then, the ice (matrix) volume (V_m) = 4 x 50 = 200 ml



If we put the ice cubes in one glass, then the pore (void) volume (V_p) in the glass = 150 ml (if it is assumed that the ice does not melt).

$$Porosity\,(\phi) = \frac{Pore\ volume\ (V_p)}{Total\ volume\ (V_t)} = \frac{150ml}{350} = 0.43$$

where,
V_t: total volume (Bulk volume (V_b))

- Porosity is the ratio of the pore (void) volume to the bulk volumes (total volume)

Introduction (What is Porosity?)

$$\phi = \frac{V_p}{V_t}$$ and $$\phi = \frac{V_p}{V_t} = \frac{V_t - V_m}{V_t}$$ where $$V_t = V_m + V_p$$

or V_b

- Porosity is dimensionless because it is $\frac{V_p}{V_t}$
- V_t, V_m and V_p are in ml or cm^3
- If we know any two of the three volumes, we can calculate porosity
- Porosity is the ratio of the two volumes (a fraction)

Example 2.1

A core sample has a total volume of 24.5 cm^3 and a matrix volume of 18.9 cm^3.

(a) What is the pore volume of this sample?
(b) What is the porosity of this sample?

Solution

(a) **Equation 2.4** can be used to find the pore volume:

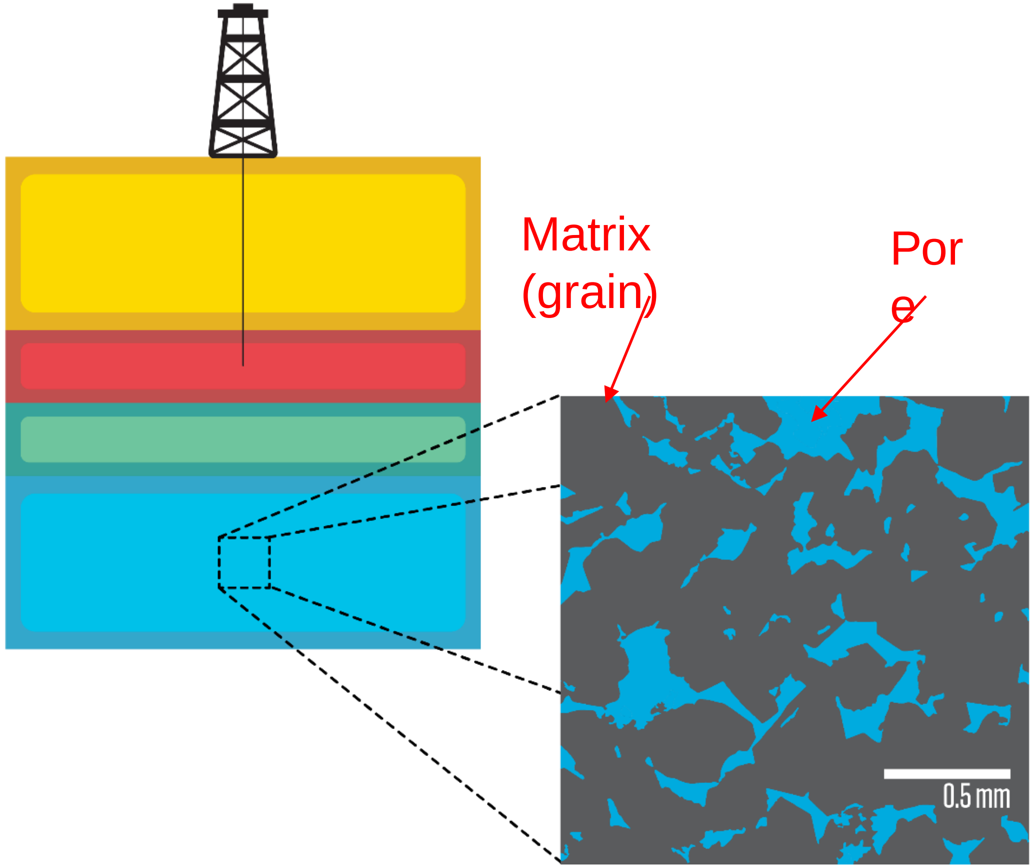
$$V_t = V_p + V_m$$
$$24.5 = V_p + 18.9$$
$$V_p = 5.6 \text{ cm}^3$$

(b) **Equation 2.1** can be used to find the porosity:

$$\phi = \frac{V_p}{V_t} = \frac{5.6}{24.5} = \mathbf{0.229} \text{ or } \mathbf{22.9\%}$$

Porosity in Reservoirs

- Porosity helps in quantifying the amount of hydrocarbon in the reservoir.
- Porosity can be multiplied by 100 to make it a percentage, but in calculation it should always be a fraction.
- Reservoir rocks are porous and contain fluids in their pores.
- Porosity measurement from a core is a part of RCAL (Routine Core Analysis).
- “Core” normally refers to a cylindrical rock sample with a length and a width of a few centimeters.



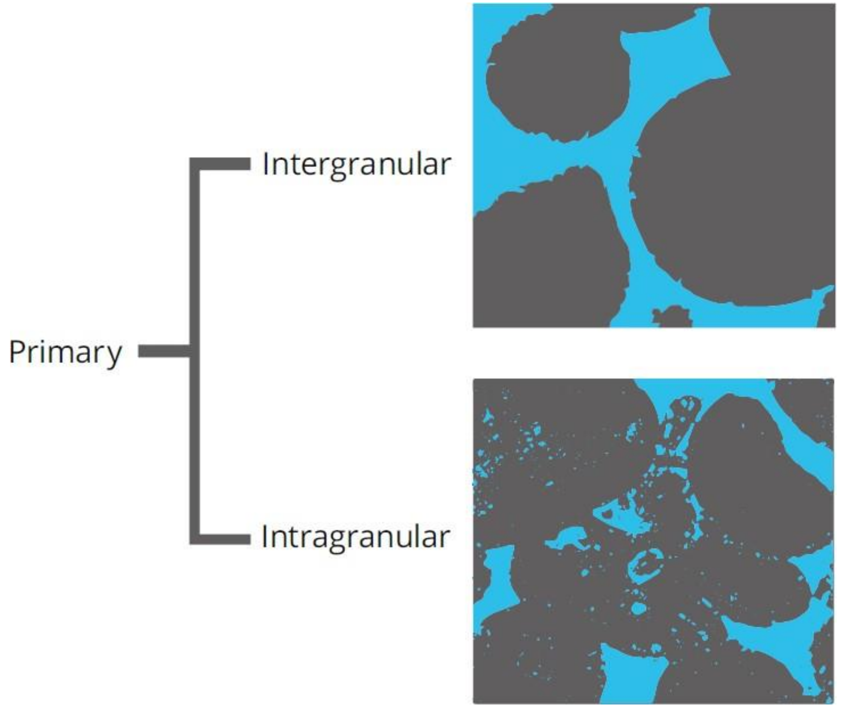
Porosity in Reservoirs

- Porosity of reservoir rocks normally ranges from 5% to 40%.
- Typical porosity values for reservoir rocks are:

Rock Type	Porosity Range
Loosely consolidated sands	35 – 40%
Sandstones	20 – 35%
Well cemented sandstones	15 – 20%
Limestones	5 – 20%

Geological Classification of Porosity

- Porosity is classified into two subdivisions:
  - Primary porosity: the original porosity that develops during the deposition of the material.
    - Intergranular porosity (between grains) – the significant one
    - Intragranular porosity (within the grains)
  - Secondary porosity: induced porosity developed after decomposition by geological processes. This results in vugs and fractures.



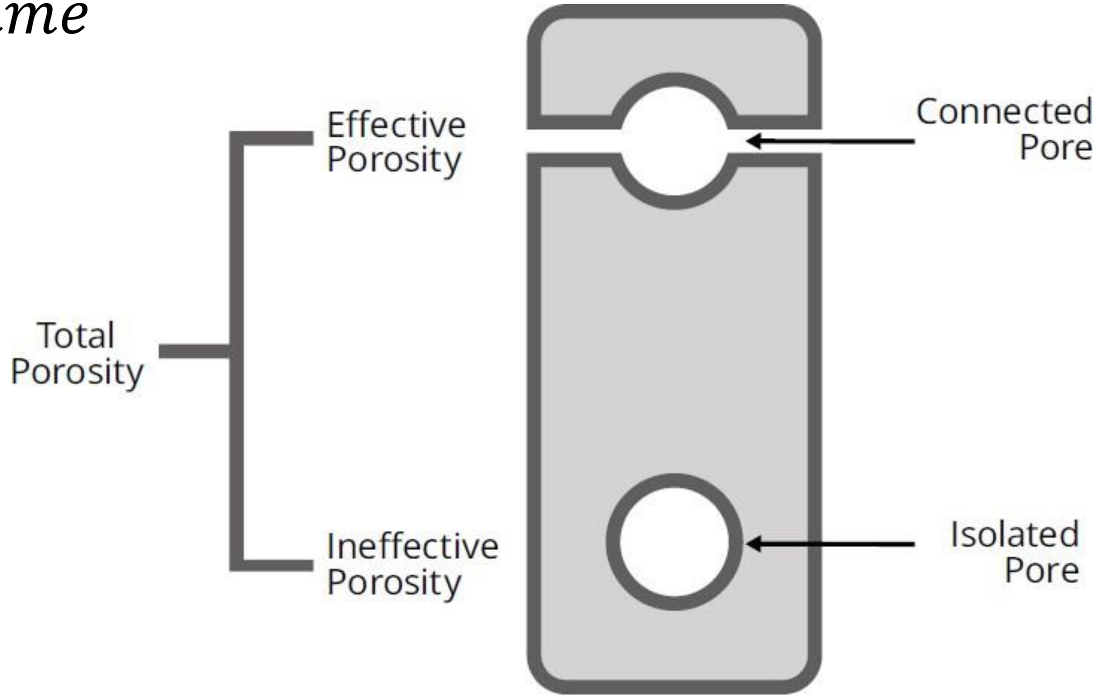
Engineering Classification of Porosity

- Porosity is classified into two subdivisions:
  - Total porosity (ϕ_t):
$$\phi_t = \frac{total\, Pore\ volume}{bulk\ volume}$$
  - Effective porosity (ϕ_e):
$$\phi_e = \frac{volume\ of\ interconnected\, pore}{bulk\ volume}$$

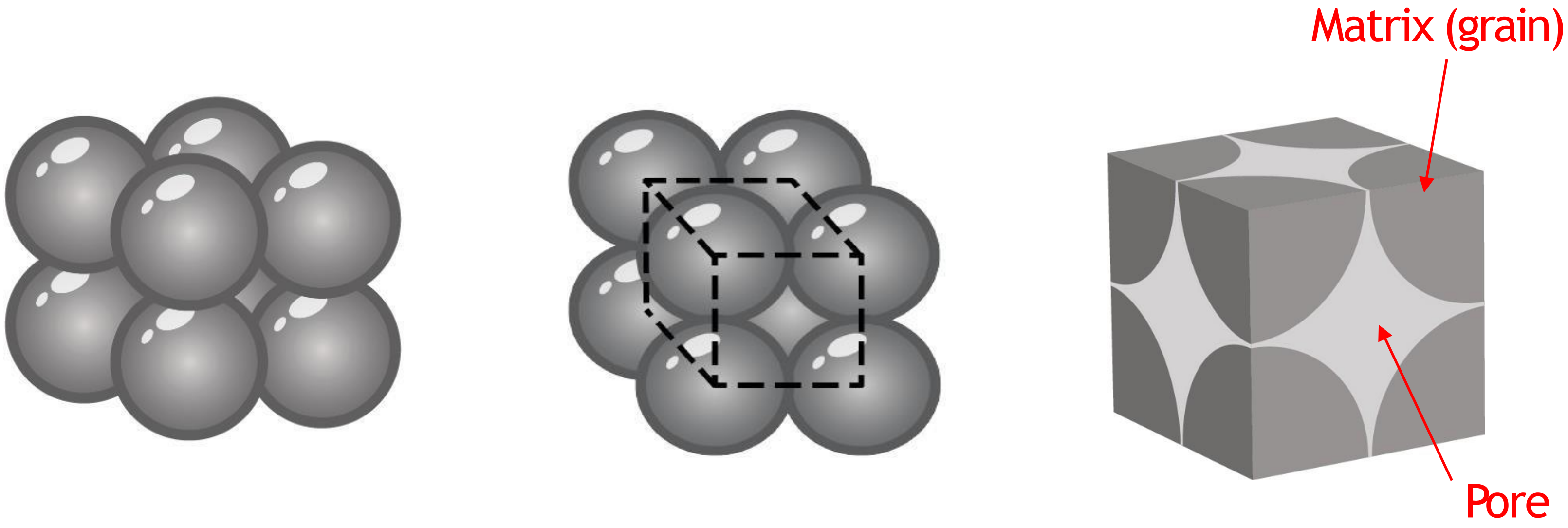
In sandstones: $\phi_t \approx \phi_e$

In carbonates: $\phi_t > \phi_e$

Petroleum engineers are interested in ϕ_e



Calculation of Porosity



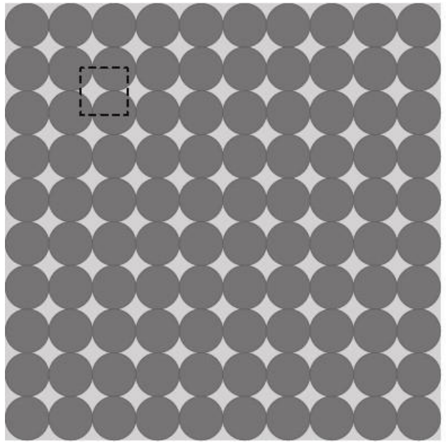
The bulk volume of the cube is: $V_b = (2r)^3 = 8r^3$

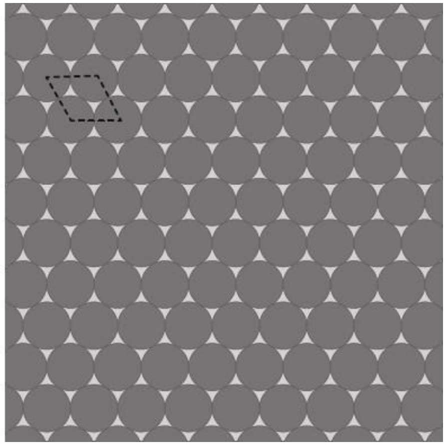
The matrix volume in the cube is: $V = 8\left(\frac{1}{8}\ sphere\right)$ = 1 sphere = $\frac{4}{3}\pi r^3$

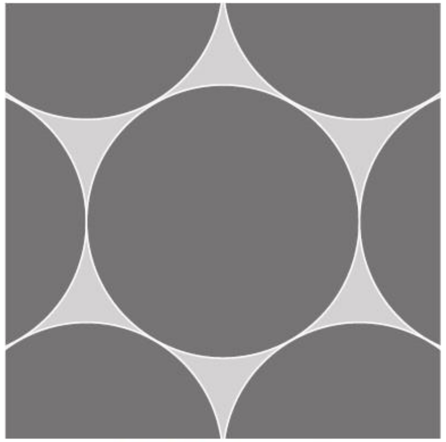
The porosity of the cube is: $\phi = \frac{V_t - V_m}{V_t} = \frac{8r^3 - \frac{4}{3}\pi r^3}{8r^3} = 1 - \frac{\pi}{6} = 0.476$ (maximum value)

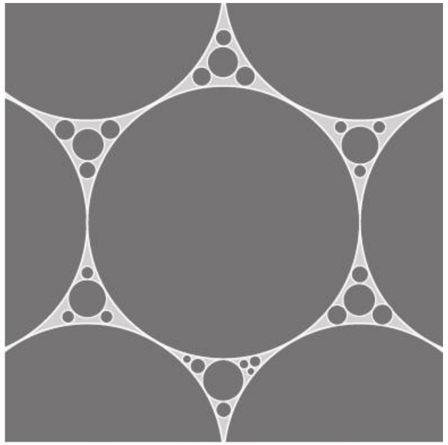
Factors Affecting Porosity

- **Primary Factors**
  - Particle Packing
    - Cubic packing
    - Rhombohedral packing
  - Sorting
    - Well sorted (particles have the same size)
    - Poorly sorted (particles have different sizes)
- **Secondary Factors**
  - Cementing materials
  - Overburden pressure (compaction)
  - Vugs, dissolution and fractures


Cubic packing


Rhombohedral packing


Well Sorted


Poorly Sorted

Example 2.2

A cylindrical core sample has a length of 5 cm and a diameter of 2 cm. The dry weight of the sample is 56.5 g, and the weight of the sample saturated with water is 60.3 g. Given that the density of water is 1 g/cm^3, find the porosity of the sample.

Solution

We find the total volume of the core sample:

$$V_t = \pi r^2 L = \pi \left(\frac{2}{2}\right)^2 5 = 15.71 \text{ cm}^3$$

We find the weight of water in the sample:

$$W_w = W_s - W_d = 60.3 - 56.5 = 3.8 \text{ g}$$

We find the pore volume of the sample:

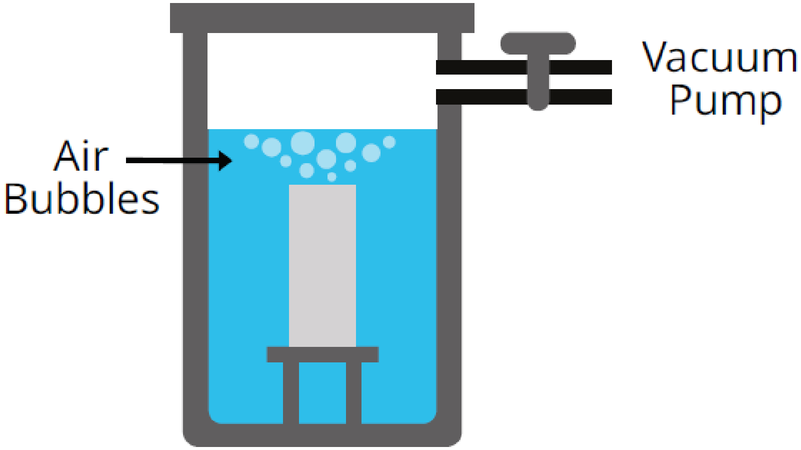
$$V_p = \frac{W_w}{\rho_w} = \frac{3.8}{1} = 3.8 \text{ cm}^3$$

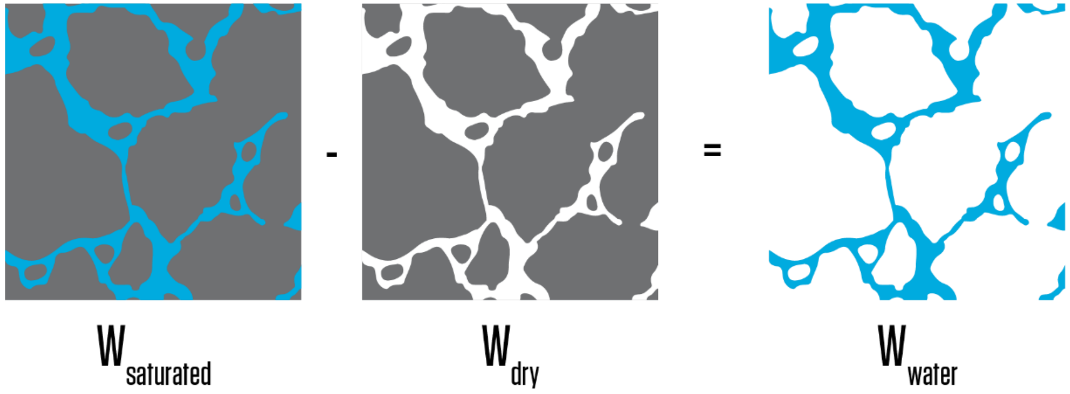
Equation 2.1 can be used to find the porosity:

$$\phi = \frac{V_p}{V_t} = \frac{3.8}{15.71} = \mathbf{0.242} \text{ or } \mathbf{24.2\%}$$

Laboratory Measurements

- **Fluid displacement**





If we know any two of the three volumes (V_p, V_b, V_m), we can calculate the porosity

$$V_b = \pi r^2 L \text{ (for cylindrical cores)}$$

$$V_p = \frac{W_{sat} - W_{dry}}{\rho}$$

$$\phi = \frac{Pore\ volume\ (V_p)}{bulk\ volume\ (V_b)}$$

From core analysis we can get the effective porosity

Example 2.3

The dry weight of a sample is 330 g, and its weight when saturated with water is 360 g. The apparent weight of this sample in water is recorded as 225 g. Given that the density of water is 1 g/cm^3, find the porosity of the sample. Assuming the sample is coated with a material of negligible weight.

Solution

Equation 2.8 can be used to find the pore volume of the sample:

$$V_p = \frac{W_s - W_d}{\rho_w} = \frac{360 - 330}{1} = 30 \text{ cm}^3$$

Equation 2.9 can be used to find the weight of the displaced fluid:

$$W_{df} = W_r - W_a = 330 - 225 = 105 \text{ g}$$

Equation 2.10 can be used to find the bulk volume:

$$V_b = \frac{W_{df}}{\rho_w} = \frac{105}{1} = 105 \text{ cm}^3$$

Equation 2.1 can be used to find the porosity:

$$\phi = \frac{V_p}{V_b} = \frac{30}{105} = \mathbf{0.286} \text{ or } \mathbf{28.6\%}$$

Laboratory Measurements

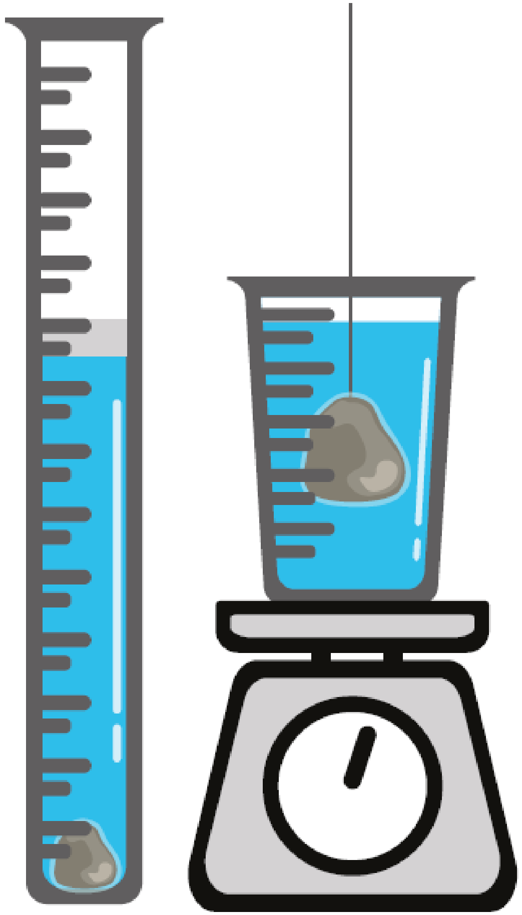
- **Fluid displacement**

From this method, we can also find the bulk volume (V_b) of irregular shapes. To do that:

1. Measure the dry weight of the rock sample
2. Coat the rock sample with insulating material (e.g. paraffin)
3. Use the equation: $paraff = \frac{W_{coated} - W_{dr}}{\rho_{paraffin}}$
4. Measure the volume level and subtract the paraffin volume
   a) Directly through the use of a graduated cylinder
   b) Through the use of Archimdes' principles:

$$W_{displaced} = W_{real} - W_{apparent}$$

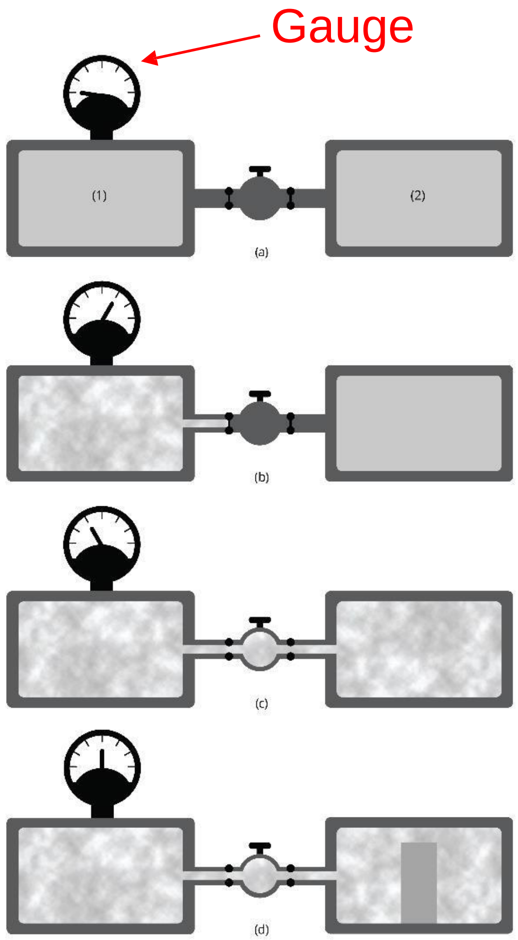
$$V_b = \frac{W_{displaced}}{\rho} - V_{paraffin}$$



(a) (b)

Laboratory Measurements

- **Gas Expansion Method**



- Use helium porosimeter that relies on Boyle's law:

$$P_1V_1 = P_2V_2$$

- We usually use helium because it has low MW (molecular weight), so it enters small pores.

$$P_1V_1 = P_2(V_1 + V_2)$$

$$P_1V_1 = P_2(V_1 + V_2 - V_m)$$

$$\phi = \frac{V_p}{V_b} = \frac{V_b - V_m}{V_b}$$

Example 2.4

A helium porosimeter is used to find the porosity of a certain core sample. Both the chambers in the porosimeter have a volume of 100 cm^3, and the sample has a bulk volume of 16.2 cm^3. Initially, helium is contained in chamber 1, the sample is placed in chamber 2 and the valve separating the two chambers is closed. The initial pressure in chamber 1 is recorded to be 30 kPa, and the pressure after the valve is opened is recorded to be 16 kPa. Find the porosity of the core sample.

Solution

Equation 2.13 can be used to find the matrix volume:

$$P_1V_1 = P_2(V_1 + V_2 - V_m)$$

Rearranging this equation:

$$V_m = V_1 + V_2 - \frac{P_1V_1}{P_2}$$

$$V_m = 100 + 100 - \frac{30 \times 100}{16} = 12.5 \text{ cm}^3$$

We find the pore volume:

$$V_p = V_b - V_m = 16.2 - 12.5 = 3.7 \text{ cm}^3$$

The porosity can be found using **Equation 2.1:**

$$\phi = \frac{V_p}{V_t} = \frac{3.7}{16.2} = \mathbf{0.228} \text{ or } \mathbf{22.8\%}$$

Problems

1) A 10^5 cubic feet reservoir has a porosity of 18%. Calculate the pore volume of the reservoir.

Problems

2) You have a core sample of bulk volume of 135 cc with 45 cc of pore space.

a) Calculate the porosity of the sample

b) What is the matrix volume of the core sample? (Use two different ways)

Problems

3) A rock of 1-in diameter and 3.5-in length weighs 105.05 g when dry, and 108.94 g when fully saturated with oil (ρ = 0.72 g/cc). Estimate the porosity of this rock sample. (1 in = 2.54 cm)

Problems

4) Suppose a rectangular reservoir is 1000 ft long, 200 ft wide and and 50 feet thick; and suppose the porosity of a rock sample obtained from the reservoir is 22%. What is the pore volume of the reservoir?