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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONES: 224281/2/3/4/5/6
CABLE: CENTRATOM - TELEX 460392-I

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COLLEGE ON SOIL PHYSICS

15 April - 3 May 1985

COLLOQUIUM ON ENERGY FLUX AT THE SOIL ATMOSPHERE INTERFACE

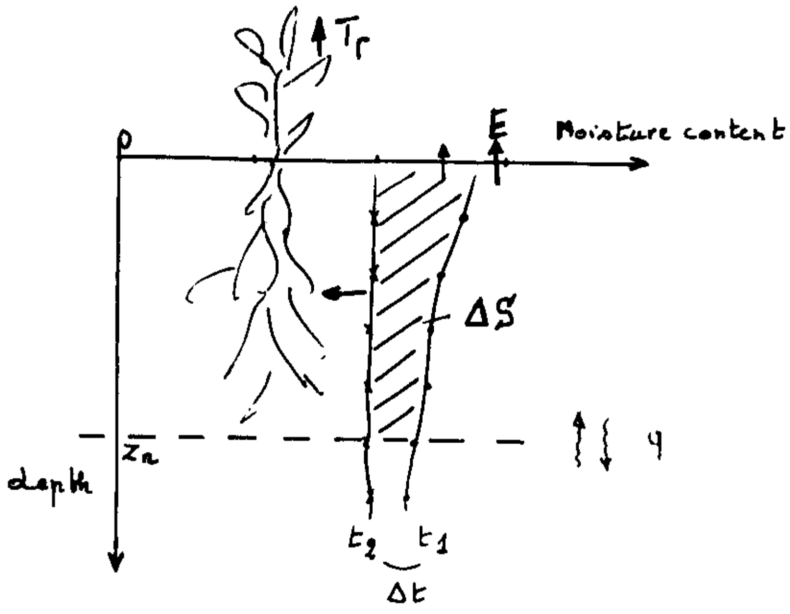
6 - 10 May 1985

SOIL WATER POTENTIAL

R. HARTMANN
Department of Soil Physics
Faculty of Agricultural Sciences
State University of Ghent
Coupure Links 653
B-9000 Ghent
Belgium

SOIL WATER POTENTIAL

Dr. ir. R. Hartmann



① [changes] in soil water content
↓ by neutron probe

② direction of water flow is governed by <u>the energy status</u> of the water at the different soil depths

↓

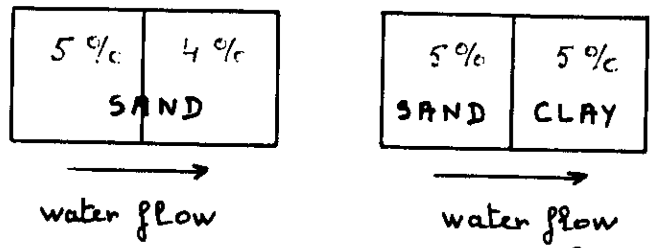
How <u>to determine</u> the energy status of the soil water?

↓

<u>Definition of the energy status</u>

Water in the soil is specified not only by its content

<u>Example</u>



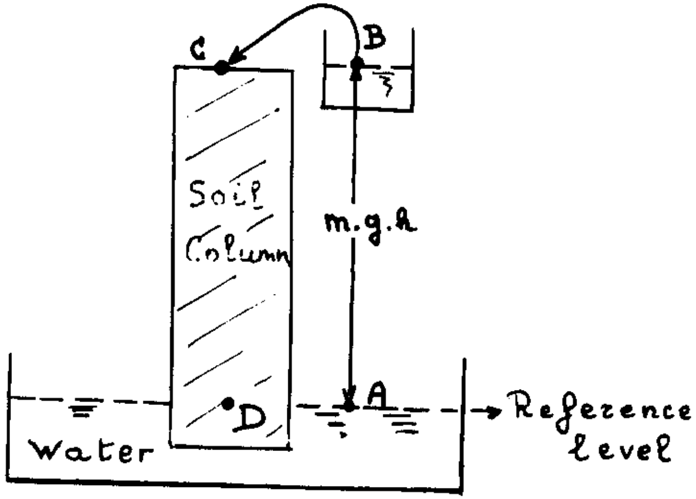
WHY?

but also by its "ENERGY STATUS"

If the energy is different within a soil <u>water movement</u> will occur <u>until equilibrium</u>!

<u>ENERGY in fluids</u>

- <u>Kinetic energy</u>: $1/2\, m v^2$
  negligible in soil water movement
- <u>Potential energy</u>:
  complicated property



Soil-water potential

expresses the specific potential energy (= per unit mass) of soil water relative to that of water in a standard reference state !

↓

Hypothetical reservoir of :

- pure free water
- at atmospheric pressure
- at the same temperature
- at a given and constant elevation

If work is required to transport water from a standard reference state to the soil-plant-atm. system the potential is positive, otherwise it is

Soil water is subjected to different force fields which cause its potential to differ from that of pure free water

$$\Psi_t = \Psi_m + \Psi_g + \Psi_o + \Psi_p$$

Ψ_t : total potential

Ψ_m : matric potential

Ψ_g : gravitational potential

Ψ_o : osmotic potential

Ψ_p : pressure potential

Quantitave expression of ψ

(potential) energy = force x distance

force → mass x acceleration

mass → kg ; acceleration → $m.s^{-2}$

kg . $m.s^{-2}$ → N (newton)

N . m = N.m (Joule)

- Energy per unit mass of water

  $Joule/kg \quad (J.kg^{-1})$

- Energy per unit volume of water

  $J.m^{-3} = N.m.m^{-3} = N\,m^{-2}$ (Pascal = Pa)

  10^5 Pa = 1 bar = 0,98 atm (Pressure)

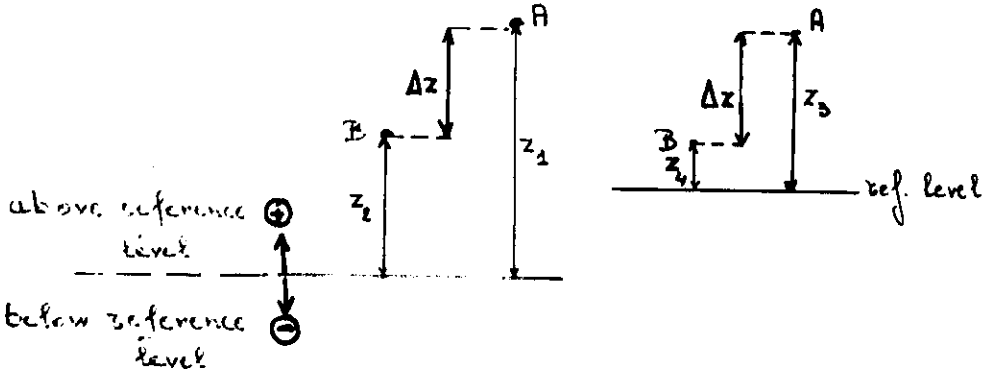
- Energy per unit weight of water

  $J.N^{-1} = N.m.N^{-1} = m$ (Head)

(I) Gravitational potential "ψ_g"

is determined by the elevation of the point under consideration relative to some arbitrary reference level.

It is independent of soil properties



P.E of mass M of water due to gravity equals

$$M g z = V \rho_w g z$$

= per unit mass

$g z$ ($erg.g^{-1}$) ($J.kg^{-1}$)

= per unit volume

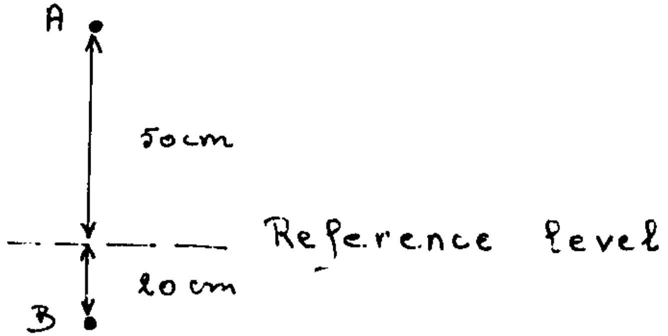
$\rho_w g z$ ($dyne.cm^{-2}$) (Pa ; atm ; bar)

= per unit weight

z (cm) (m)

Example

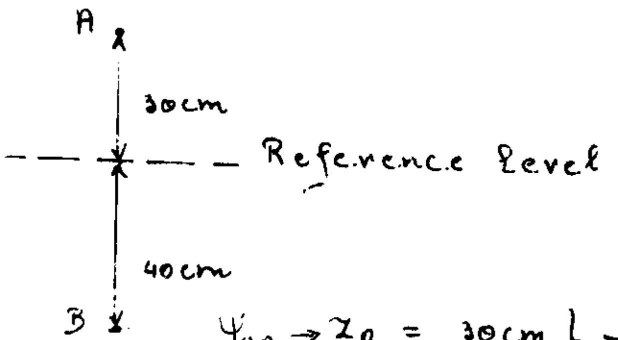
ⓐ



$\psi_{gA} \rightarrow z_A = 50\ cm$
$\psi_{gB} \rightarrow z_B = -20\ cm$
$\} \rightarrow \Delta z = 50\ cm - (-20\ cm)$

$\underline{70cm}$

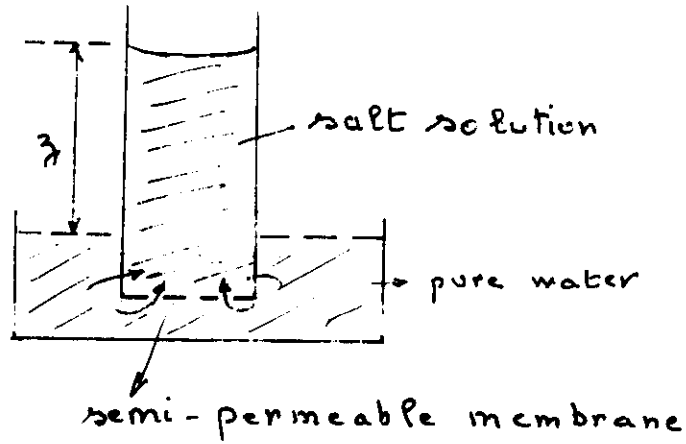
ⓑ



$\psi_{gA} \rightarrow z_A = 30cm$
$\psi_{gB} \rightarrow z_B = -40cm$
$\} \rightarrow \Delta z = 30cm - (-40cm) =$

$\underline{70cm}$

(II) Osmotic potential "ψ_o"



*

$$O.P.\ or\ \pi_{(atm)} = -\frac{n}{V} R T$$

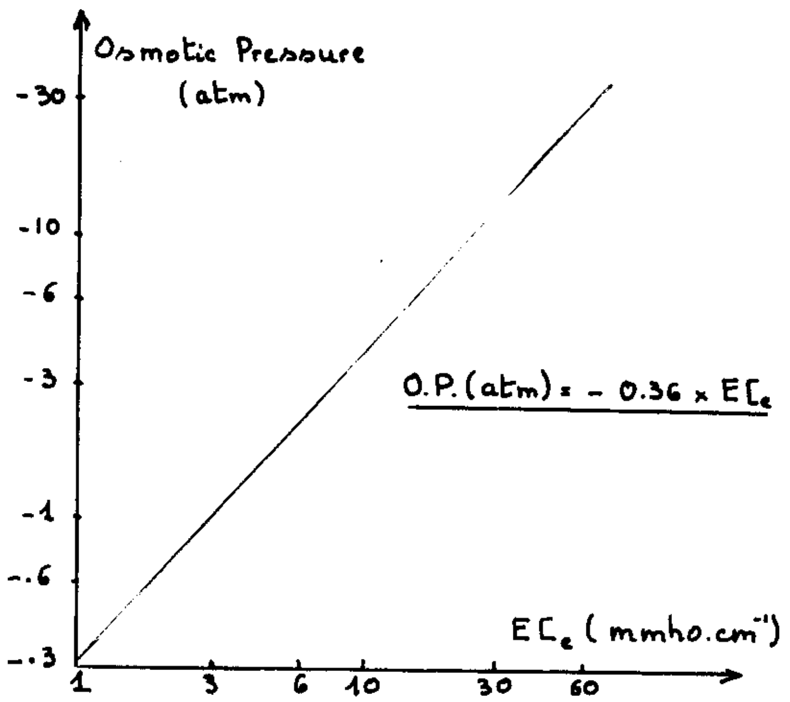
π : osmotic pressure (atm)

R : universal gas constant ($0.082\ l.mol^{-1}atm\ K^{-1}$)

$\frac{n}{V}$: molarity of salt solution ($mol\ l^{-1}$)

T : absolute temperature ($273 + t°C$)

RELATION ELECTRICAL CONDUCTIVITY – OSMOTIC PRESSURE



(U.S. Salinity Lab.)

(III) Matric potential "ψ_m"

related to the presence of the soil matrix.

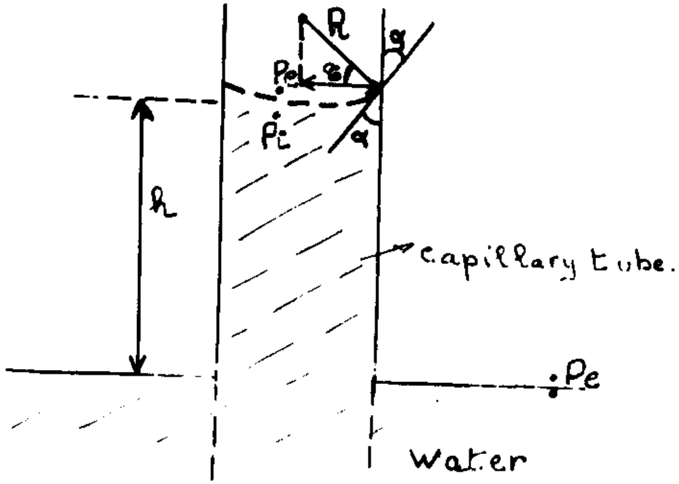
1. adsorptive forces by soil particles
2. capillary forces
3. adsorptive forces due to exchangeable and adsorbed counterions.

(1) Adsorptive Forces

short distance forces responsible for only a very small quantity of water and from practical point of view not important in water transport -(movement) process

"air-dry soil"

② Capillary Forces



Law of Laplace

$$P_e - P_i = \Delta P = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

R_1 and R_2 are the principal radii of the curvature

assuming $R_1 = R_2$

$$\Delta P = \frac{2\gamma}{R} \qquad \text{since } R = \frac{r}{\cos\alpha}$$

$$\alpha = 0 \rightarrow \cos\alpha = 1$$

$$R = r$$

$$\boxed{\Delta P = \frac{2\gamma}{r}}$$

$$P = \text{pressure} = \frac{\text{weight (or force)}}{\text{unit surface}}$$

$$= \frac{\text{mass} \cdot g}{\pi r^2} = \frac{V \cdot \rho \cdot g}{\pi r^2}$$

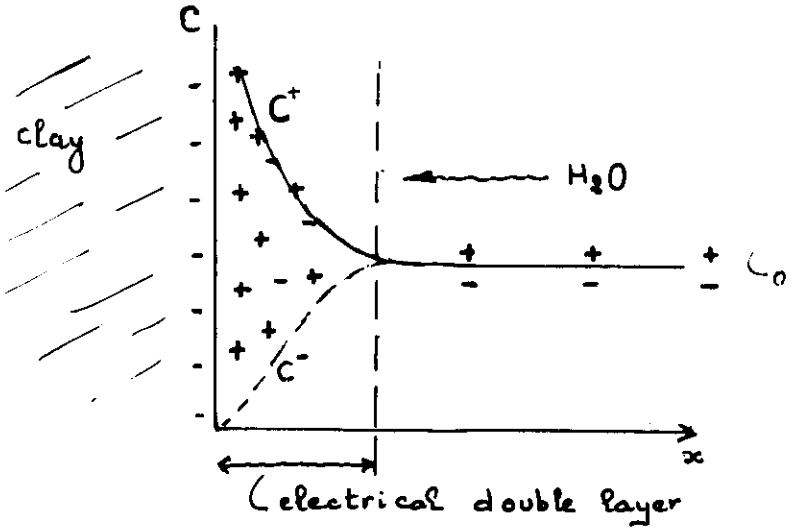
$$= \frac{\pi r^2 h \, \rho \, g}{\pi r^2}$$

$$\boxed{\Delta P = h \rho g} \quad (\text{dyne cm}^{-2}) \quad (N m^{-2} ; Pa ; bar)$$

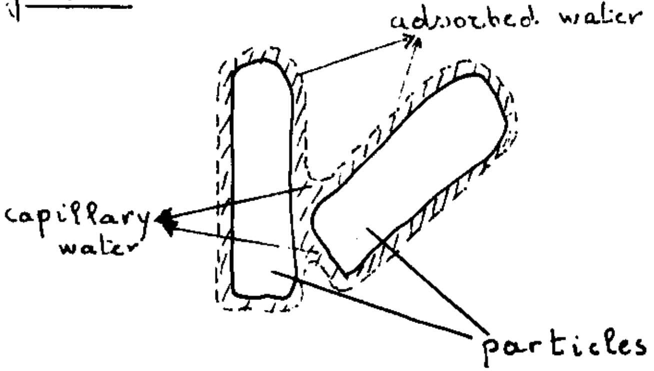
$$\frac{2\gamma}{r}$$

$$\boxed{h = \frac{2\gamma}{\rho g r}} \quad (cm) \quad (m)$$

③ Adsorptive Forces due to exchangeable / adsorbed } counterions (+)

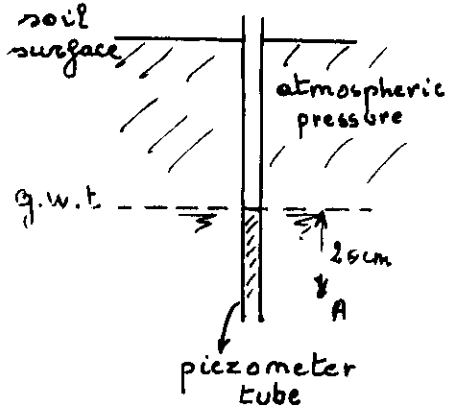


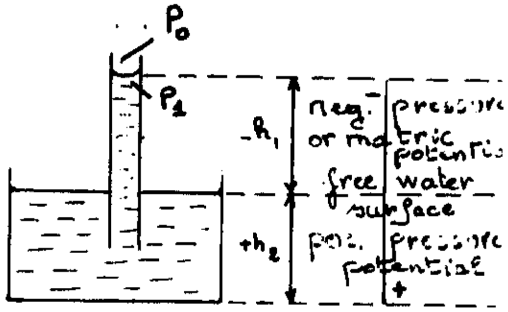
In general



Ⓘⓥ Pressure potential "ψ_p"

① Field (ψ_p^u : submergence potential)





the pressure potential in A (per unit weight) equals "20cm"

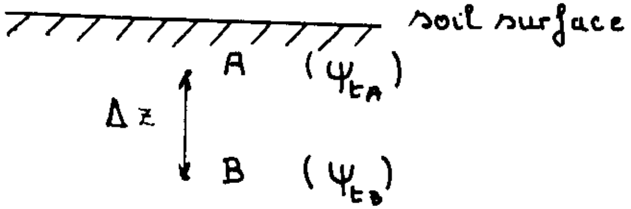
- pressure potential under g.w.t >0
- pressure potential at g.w.t =0
- pressure potential above g.w.t <0
  ↳ or matric potential

② Laboratory (ψ_p^n : pneumatic potential)

when overall air pressure > reference pressure
= atm. pressure

example: soil water characteristic curve or pF-curve.

FIELD SITUATION



if $\Psi_{tA} \neq \Psi_{tB}$ WATER FLOW

$$\Psi_{mA} + \Psi_{gA} + \Psi_{oA} + \Psi_{pA} \neq \Psi_{mB} + \Psi_{gB} + \Psi_{oB} + \Psi_{pB}$$

$\Psi_{oA} = \Psi_{oB}$

because in soil no semi-permeable membrane! so Ψ_o practically uneffective on the water movement in the soil.

So $\Psi_t \rightarrow (\Psi_H) = \Psi_m + \Psi_g + \Psi_p$

Ψ_H → Hydraulic Potential!

if $\Psi_{HA} = \Psi_{HB}$ ⟶ NO WATER FLOW

if $\Psi_{HA} \neq \Psi_{HB}$ ⟶ WATER FLOW

Note: 1 atm ≈ 1033 cm H_2O

Since Ψ_m and Ψ_p in a soil profile can be unified in a single continuous potential one obtains $\Psi_H = \Psi_m + \Psi_g$

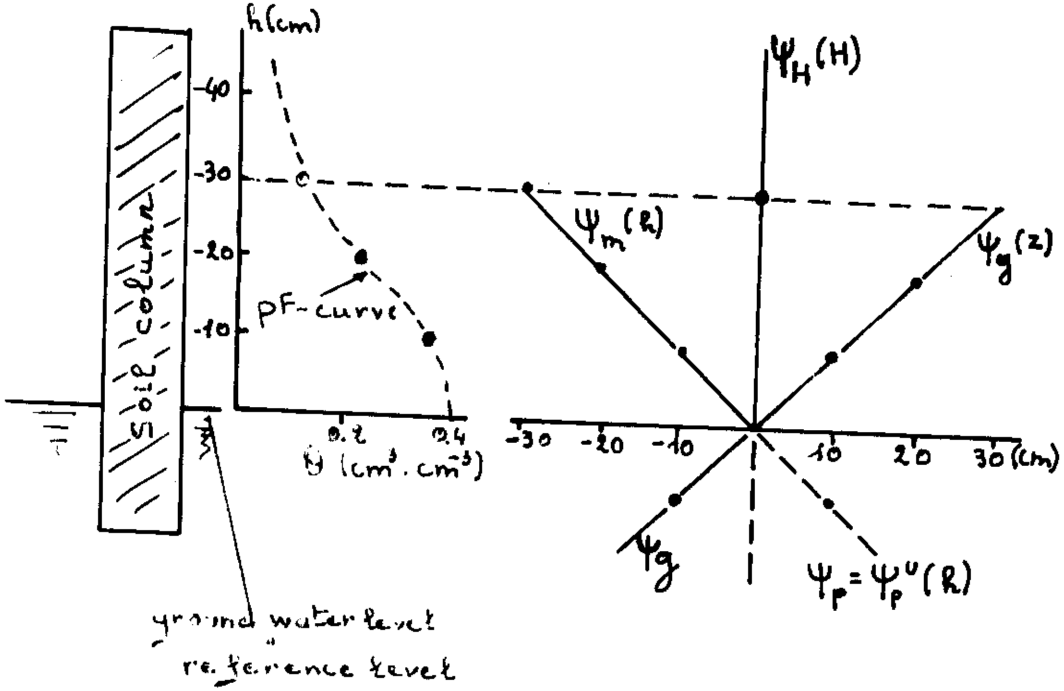
$$H = h + z$$

- H → hydraulic head
- h → soil water pressure head
  - ⊖ unsaturated soil
  - ⊕ under water table
- z → gravitational head

- Equilibrium condition $H_A = H_B$
- Non-equilibrium condition $H_A \neq H_B$

and $\left(\frac{\Delta H}{\Delta z}\right)$ is the driving force for water movement

Equilibrium condition



height (cm)	Ψ_g (z, cm)	Ψ_m (h, cm)	Ψ_p (h, cm)	Ψ_H (H, cm)
30	30	-30	0	0
20	20	-20	0	0
10	10	-10	0	0
– 0 ref. level	0	0	0	0
-10	-10	0	10	0
-20	-20	0	20	0