Montogue

Quiz SL101

SOIL PHYSICS AND CHEMISTRY

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▶▶ PROBLEMS

▶ Problem 1

A sample of the A horizon of a soil is analyzed for aggregate size distribution by dry sieving. The data obtained are summarized below. Determine the mean weight diameter for dry sieving and the geometric mean diameter for dry sieving.

Aggregate diameter range (mm)	Average diameter (mm)	Dry sieving (%)
0 – 0.2	0.1	13
0.2 – 1.0	0.6	9
1.0 – 2.0	1.5	14
2.0 – 4.0	3.0	22
4.0 – 10.0	7.0	26
10.0 – 20.0	15.0	16

A) $\bar{d}_m$ = 2.58 mm and $\bar{d}_g$ = 2.44 mm.

B) $\bar{d}_m$ = 2.58 mm and $\bar{d}_g$ = 5.03 mm.

C) $\bar{d}_m$ = 5.16 mm and $\bar{d}_g$ = 2.44 mm.

D) $\bar{d}_m$ = 5.16 mm and $\bar{d}_g$ = 5.03 mm.

▶ Problem 2

A cube of soil measures 0.1×0.1×0.1 m and has a total (wet) mass of 1.52 kg, of which 0.32 kg is water. Assume the density of water, ρ_w, is 1000 kg/m³, and the soil particle density, ρ_s, is 2700 kg/m³. True or false?

0.1 m
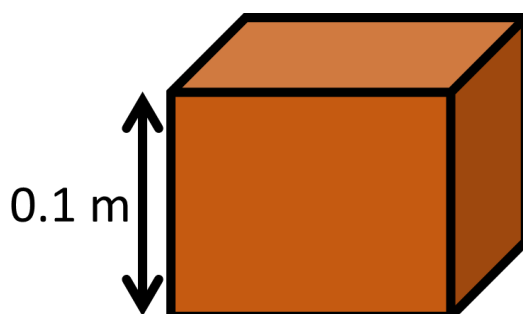
1.( ) The mass water content of the soil sample is greater than 0.25.

2.( ) The volume water content of the soil sample is greater than 0.35.

3.( ) The equivalent depth of water of the soil sample is greater than 40 mm.

4.( ) The bulk density of the soil is greater than 1150 kg/m³.

5.( ) The total porosity of the soil is greater than 0.6.

6.( ) The relative saturation of the soil is greater than 0.62.

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► **Problem 3**

Consider a soil-root system with the following properties.

→ Field capacity (FC) = 22% by weight
→ Permanent wilting point (PWP) = 8% by weight
→ Rootzone depth = 85 cm
→ Soil bulk density = 1.8 g/cm³
→ Irrigation application efficiency = 60%

Determine the depth of water required to irrigate the soil when the PWP is reached.

A) D = 10.9 cm
B) D = 20.4 cm
C) D = 35.7 cm
**D)** D = 50.2 cm

► **Problem 4**

The following figure shows a hypothetical soil profile. The positive z-axis is directed upwards. The gravitational potentials at points 1 and 3 are $Z_1 = -20$ cm and $Z_3 = -60$ cm, respectively, while the tensions at the same points are $T_1 = 80$ cm and $T_3 = 50$ cm. Bear in mind that tensions are always positive, and matric potentials are numerically equal to tensions with a negative sign. In what direction will water flow, and what is the absolute value of the hydraulic gradient between points 1 and 3?
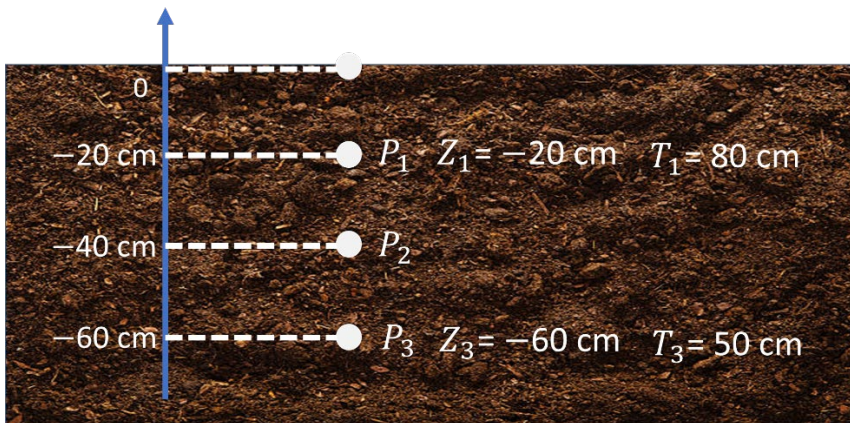
A) Water will flow from 1 to 3, and the hydraulic gradient is 0.25 cm cm⁻¹.
B) Water will flow from 1 to 3, and the hydraulic gradient is 0.5 cm cm⁻¹.
C) Water will flow from 3 to 1, and the hydraulic gradient is 0.25 cm cm⁻¹.
D) Water will flow from 3 to 1, and the hydraulic gradient is 0.5 cm cm⁻¹.

→ **Problem 5.1**

The following graph shows the pF curves as a function of volume water content for nine Dutch soils: (1) dune sand; (2) loamy sand; (3) calcareous fine sandy loam; (4) calcareous loam; (5) silt loam derived from loess; (6) young oligotrophous peat soil; (7) marine clay; (8) eutrophous peat soil, and (9) river basin clay. Determine the volume fraction of water available to plants for soil 6.

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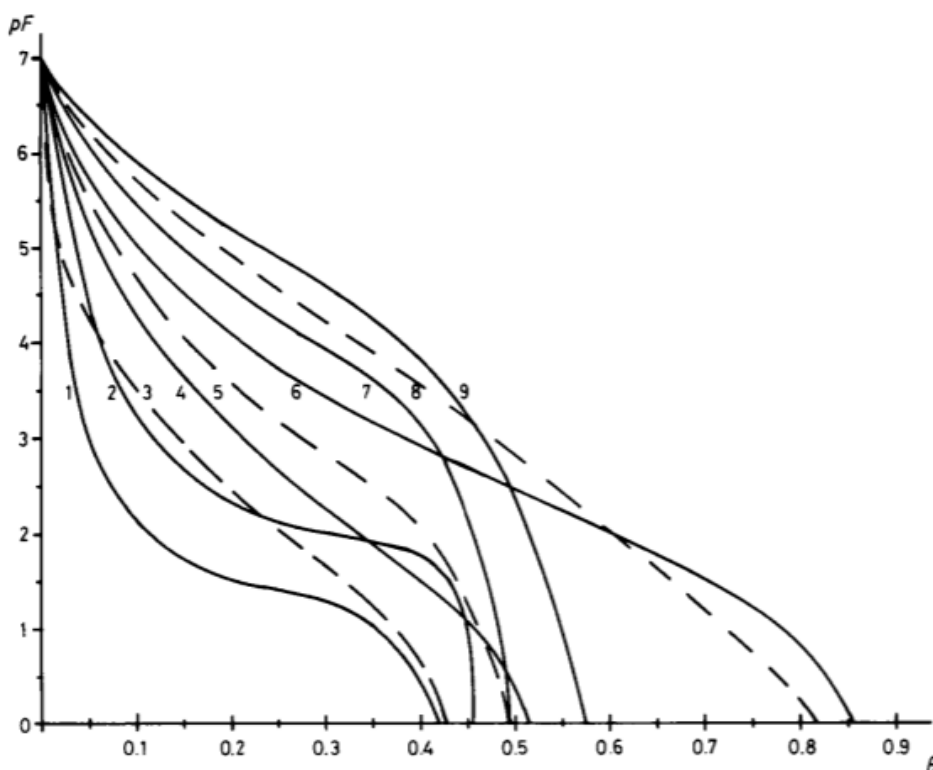
A) $\Delta\theta = 0.2$
B) $\Delta\theta = 0.4$
C) $\Delta\theta = 0.6$
D) $\Delta\theta = 0.8$

→ Problem 5.2

A rain shower of 9 mm falls on a soil of type 4 in the foregoing chart. Calculate the penetration depth of the rainwater if the soil is wetted up to field capacity ($pF = 2.0$).

A) $D = 10.3$ mm
B) $D = 20.5$ mm
C) $D = 30.6$ mm
D) $D = 40.9$ mm

→ Problem 5.3

Reconsider the situation introduced in Problem 5.2. How many cubic meters of water are required per hectare to wet 0.3 m of soil to field capacity?

A) $V = 325$ m³
B) $V = 660$ m³
C) $V = 818$ m³
D) $V = 904$ m³

▶ Problem 6

Regarding aspects of soil physics and chemistry, true or false?

1.( ) Like hydraulic conductivity, a soil's permeability is measured in units of length per time; the SI unit of permeability is meters per second.

2.( ) The capillary rise in soil is a function of size and pore space. In general, as the particle size decreases from sand to silt to clay, the capillary rise decreases concomitantly. The time required to reach maximum capillary rise is lowest for clays.

3.( ) From calibration of a neutron probe we know that when a soil's volumetric wetness is 15%, we get a reading of 25,000 cpm (counts per minute), and at a wetness of 40% we get 43,000 cpm. Assuming the volumetric wetness varies linearly with cpm between these two data points, the wetness value that corresponds to a count rate of 33,000 cpm. is found to be greater than 25%.

4.( ) The particle density of a soil was measured using a pycnometer with a volume of 175 cm³ and an empty mass of 40 g. 220 g of dry soil was placed in the pycnometer. The mass of the pycnometer, soil, and deaerated water, when the pycnometer was filled to capacity, was 350 g. The experiment was conducted at 20°C, for which the density of water is about 1 g/cm³. We surmise that the particle density of this soil is greater than 2.65 g/cm³.

5.( ) A hydrometer test was performed in a soil physics laboratory using water with a viscosity of 0.001 Pa·s. The soil specific gravity and the water density were established as 2.71 and 1000 kg/m³, respectively. Under these conditions, we surmise that the settling velocity for a soil particle with 0.2-mm equivalent diameter is greater than 0.03 m/s.

6.( ) Consider a granular soil composed of 25% coarse sand (average diameter 0.1 cm), 45% fine sand (average diameter 0.01 cm), and 30% silt (average diameter 0.005 cm). The specific gravity of all soil particles is 2.71. Accordingly, the specific surface area of this soil is greater than 25 m²/kg.

7.( ) A clay particle can be represented as a plate-shaped, rectangular particle with δ as thickness and a and b as length and width, respectively. The specific surface area of plate-shaped clay particles with $\delta = 1$ nm, $a = b = 18$ nm, and particle density $\rho_s = 2700$ kg/m³, expressed in ha kg⁻¹, is greater than 75 ha/kg.

8.( ) Reconsider the clay particles introduced in the previous statement. The number of such particles that would make a total mass of 1 kg is greater than 10^{22}.

9.( ) At the permanent wilting point (PWF), the residual water is held so firmly at the surfaces of clay minerals that it cannot be extracted by plant roots. The water potential at this state is often taken as −15,000 cm, and corresponds to a pF value greater than 4.5.

10.( ) With increasing clay content, the field capacity (FC) and the permanent wilting point (PWP) do not change to the same extent. The difference between FC and the PWP represents the quantity of plant-available water, and tends to be maximum for sandy clays and loamy sands.

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11.( ) The following figure illustrates the availability of essential plant nutrient elements at different mineral soil pH levels. The mineral soil pH range for best plant growth is between 5.5 and 6.5. The figure shows that at particularly acidic conditions the availability of the essential nutrients P and Mg decline, while the concentrations of Mn and Cu rise to potentially toxic levels.
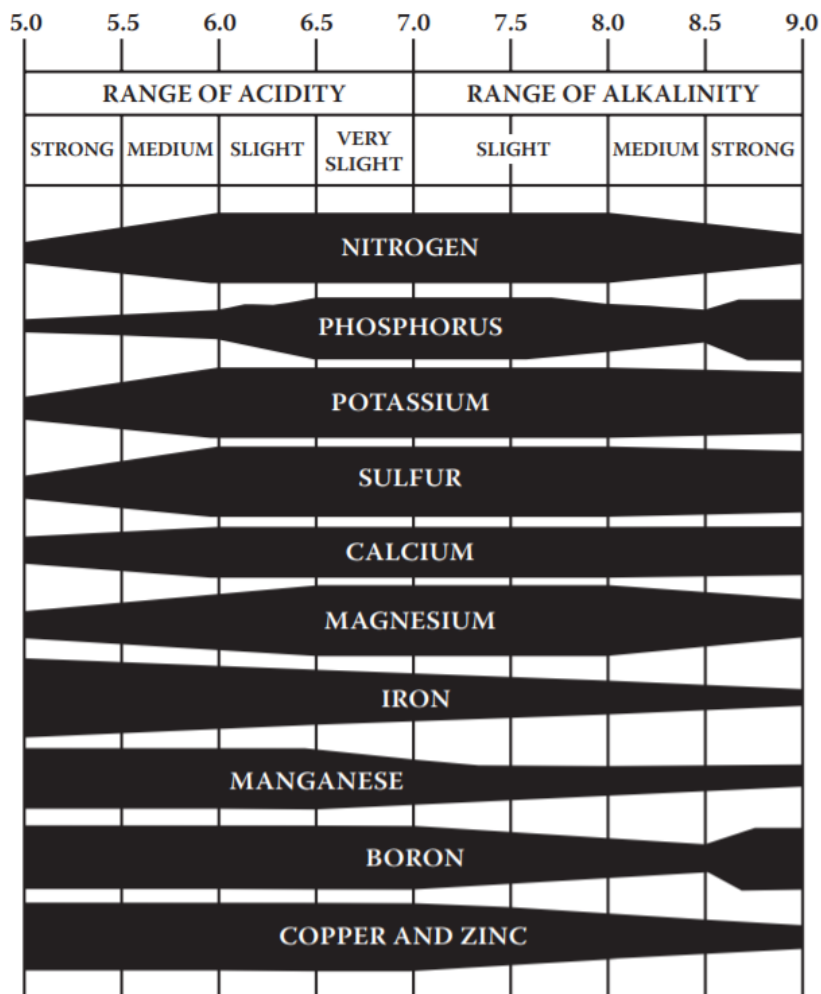
12.( ) The cation exchange capacity (CEC) of clays, as expressed in milliequivalents per 100 g of soil, tends to be higher for clays composed of kaolinite and illite colloids, and lower for clays constituted of vermiculite and smectite colloids.

13.( ) Cation exchange reactions in soils are rapid. The exchange step itself is virtually instantaneous, and the rate-limiting step is generally the ion diffusion to or from the colloid surface.

14.( ) A sample of a soil's A horizon produced the following concentrations of exchangeable cations in mEq/100 g. The base saturation of this soil, observing that the exchangeable bases used in the calculation are Na, K, Ca and Mg, is greater than 32%.

Exchangeable cation	Ca	Mg	K	Na	H	Al
mEq/100 g	0.80	0.45	0.25	0.07	1.4	1.5

15.( ) In the 1940s, Schoffield proposed a ratio law governing the distribution of soil cations. He stated that "when cations in a solution are in equilibrium with a larger number of exchangeable ions, a change in the concentration of the solution will not disturb the equilibrium if the concentrations of all the monovalent ions are changed in one ratio, those of all the divalent ions in the square of that ratio, and those of the trivalent ions in the cube of that ratio." This result, albeit striking, is not applicable to all soils; one fundamental condition for applicability of the ratio law is the effective exclusion of anions from the cation adsorption sites in the inner parts of the electrical double layer. This occurs only if there is a high potential drop between the charged surfaces and the solution, which requires that the external electrolyte concentration be low and that the soils have a high surface negative charge.

16.( ) The diffuse double-layer formula derived by Eriksson in the 1950s is said to be the most realistic approach to describe ion exchange equilibria between some ion pairs, such as Na and Ca. It is also mathematically simpler than other common approaches, such as the Gapon and Kerr equations.

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17.( ) Humic and fulvic acids account for a substantial portion of soil humus. The following table lists the mean content, measured in grams per kilogram, of nonmetal elements in soil humic substances worldwide. From these data, we surmise that there is more C and N in the composition of fulvic acid, whereas humic acid has a greater content of O.

Subst.	C	H	N	S	O	H/C Ratio	O/C Ratio
Humic acid	554 ± 38	48 ± 10	36 ± 13	8 ± 6	360 ± 37	1.04 ± 0.25	0.50 ± 0.09
Fulvic acid	453 ± 54	50 ± 10	26 ± 13	13 ± 11	462 ± 52	1.35 ± 0.34	0.78 ± 0.16

18.( ) Over the years, several alternatives to limestone have been proposed as soil liming agents. Two examples are burned lime (CaO) and hydrate lime [Ca(OH)$_2$], which offer superior reactivity and produce longer-lasting effects than equivalent amounts of CaCO$_3$ administered to the same acidic soil.

19.( ) One of the quality factors of a liming material is its equivalency to that of pure calcium carbonate (CaCO$_3$), referred to as the calcium carbonate equivalent (CCE). CaCO$_3$ has a CCE of 100%, but other aglime materials, including CaO and Ca(OH)$_2$, may have CCE values greater than 100.

20.( ) The matric potential is generally negative and equals zero for a fully saturated soil.

21.( ) The shape of the soil-water retention curve exhibits hysteresis. One reason for this is that, for a given pore, the contact angle between the water meniscus and the pore walls is lower when the meniscus is advancing (wetting) than when it is retreating (drying). This means that the radius of curvature is lower for the advancing (wetting) meniscus and that the absolute value of the pressure developed is correspondingly greater for the same water content.

▶ Problem 7

The ammonium acetate method was used to establish the cation exchange capacity of an alkaline soil. A 3-g soil sample is treated with a pH 8.2, 1 M C$_2$H$_3$O$_2$Na (sodium acetate) solution followed by the removal of entrained Na$^+$. The Na$^+$-saturated soil is then treated by sequential washings with a pH 7, 1 M C$_2$H$_3$O$_2$NH$_4$ solution. The supernatant solutions from the C$_2$H$_3$O$_2$NH$_4$ washings are collected and combined into a 80-mL volumetric flask, which is brought to volume with distilled-deionized water. This solution is analyzed by atomic emission spectrometry and the total Na concentration is determined to be 180 mg/L. Determine the potential CEC for this soil.

A) CEC = 9.78 cmol$_c$/kg
B) CEC = 14.5 cmol$_c$/kg
C) CEC = 20.9 cmol$_c$/kg
D) CEC = 25.2 cmol$_c$/kg

→ Problem 8.1

The average values for selected properties of a soil in a field plot are listed in the table below.

Horizon	Depth (cm)	Exchangeable sodium percentage (%)	Organic matter (%)	CEC (cmol$_c$ kg^{-1})	Bulk density (g cm^{-3})
Ap	0 – 21	4.6	1.8	20.2	1.49
Bt	21 - 74	9.0	0.6	24.1	1.35
CB	74 - 105	6.2	0	9.7	1.35
C1	105 - 200	1.8	0	8.8	1.29

A mass of 100 g of oven-dried soil extracted from the Bt horizon of this soil is mixed with 600 cm^3 of a strong KCl solution. The soil-KCl solution mixture is shaken for 24 hours to replace all the cations on the exchange sites with K$^+$. Determine the amount of potassium attached to the exchange sites of the soil particles at the end of the process.

A) m = 7.88 g K$^+$ per kg soil
B) m = 11.2 g K$^+$ per kg soil
C) m = 15.4 g K$^+$ per kg soil
D) m = 21.4 g K$^+$ per kg soil

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All the sodium in the upper 50 cm of the soil must be replaced with calcium. Determine the minimum amount of lime (CaCO₃) that must be applied to the soil per hectare for this purpose.

A) m = 5700 kg CaCO₃/ha
B) m = 7000 kg CaCO₃/ha
C) m = 8100 kg CaCO₃/ha
D) m = 9040 kg CaCO₃/ha

▶ Problem 9

Soil salinity is a growing problem in many areas of the world, and use of brackish irrigation waters is one of the main practices that compound this problem. One way to characterize soil concentrations in water and soil solutions is to measure electrical conductivity. For water solutions in the electrical conductivity range from 0.1 to 5 dS m⁻¹, the concentration of cations or anions is related to EC by the simple expression

$$\text{Sum of cations or anions [mmol (+) or (−)L}^{-1}] \approx \text{EC}\left[\text{dSm}^{-1}\right] \times 10$$

Further, the total dissolved solids (TDS) can be estimated as

$$\text{TDS}\left[\text{mg L}^{-1}\right] \approx \text{EC}\left[\text{dSm}^{-1}\right] \times 640$$

Lastly, the osmotic potential can be estimated as

$$\text{OP[bars]} \approx \text{EC}\left[\text{dSm}^{-1}\right] \times (-0.36)$$

The osmotic potential is the negative of the osmotic pressure of the water. The osmotic pressure or osmotic potential most directly measures the effects of salinity on plant growth.

Consider an irrigation water with the following cationic composition. True or false?

Cation	Concentration [mmol(+) L⁻¹]
Na⁺	8.0
Ca²⁺	10.0
Mg²⁺	6.0

1.( ) The electrical conductivity of the irrigation water is greater than 2.5 dS cm⁻¹.
2.( ) The TDS of the water is greater than 1500 mg L⁻¹.
3.( ) The absolute value of the osmotic potential is greater than 0.85 bar.

▶ Problem 10

Consider a 100-cm long soil column with a cross-sectional area of 50 cm² packed with a medium of permeability equal to 5×10^{-13} m² and pressure heads at the top and bottom of 0 and 180 cm, respectively. Take the arbitrary datum elevation to be located at the base of the column and let the vertical coordinate z be positive upward. The density and dynamic viscosity of water in this system can be taken as 1000 kg/m³ and 0.0015 Pa·s, respectively. True or false?
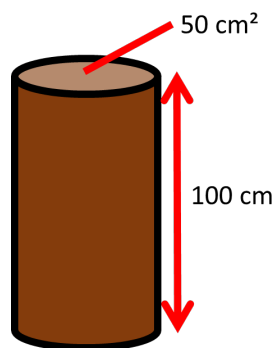
1.( ) The Darcy flux is greater than 2.4×10^{-6} m/s.
2.( ) The volumetric flow rate of water is greater than 1.5×10^{-8} m³/s.
3.( ) If the soil medium has a porosity η = 0.3 cm³ cm⁻³, the time required for a particle of water to flow through the column is greater than 36 hours.

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► Problem 11

A 100 cm long column is packed with a uniform soil medium of 5×10^{-5} cm/s hydraulic conductivity. After packing, the uppermost 1 cm is replaced with a medium with hydraulic conductivity equal to 1×10^{-7} cm/s. The pressure head is 25 cm at the base of the column and 160 cm at the top of the column. The volumetric water content equals the porosity, which is 0.42 cm³ cm⁻³. Set the datum elevation at the base of the column. True or false?

1.( ) The equivalent vertical hydraulic conductivity is greater than 9×10^{-6} cm/s.

2.( ) The absolute value of the volumetric flow rate through the soil is greater than 1.8×10^{-5} m³/s.

3.( ) The average residence time of water in the column during steady-state flow is greater than 600 hours.

► Problem 12

In a hotizontal infiltratrion run for a permeable sandy soil, the initial water content by volume was θ_{vi} = 0.12 and the saturated water content by volume was θ_{vs} = 0.48. A sharp wetting front had progressed 8 cm from the source in 15 min. Using these data, estimate the sorptivity of the soil in question.

A) S = 0.123 cm/min$^{1/2}$

B) S = 0.313 cm/min$^{1/2}$

C) S = 0.744 cm/min$^{1/2}$

D) S = 0.983 cm/min$^{1/2}$

► Problem 13

Assume that the cumulative depth of water (I), in centimeters, infiltrating downward into a long soil column is given by

$$I = 4t^{0.5} + 0.2t$$

where t is the time of infiltration in hours. True or false?

1.( ) The depth of water that will infiltrate vertically into the soil column at t = 30 min is greater than 2.8 cm.

2.( ) The time required for 4 cm of water to infiltrate horizontally into a soil stratum described by the equation above is greater than 1.2 hours.

3.( ) The time required for 20 cm of water to infiltrate vertically *upward* into the soil is greater than 80 hours.

4.( ) The infiltration rate for horizontal infiltration at 45 minutes is greater than 2.5 cm/h.

5.( ) The infiltration rate for downward vertical infiltration at 1 hour is greater than 2.0 cm/h.

► Problem 14

The following data were obtained with tension plate and pressure plate extraction devices from two soils of unknown texture. Plot the two soil-moisture characteristic curves on a semilog scale (logarithm of matric suction versus wetness), then consider the following statements. The specific gravity of the soil particles is 2.65. True or false?

Suction head		Volumetric wetness (%)	
(bar)	(cm)	Soil A	Soil B
0	0	45	58
0.01	10	45	58
0.025	25	44.8	58
0.05	50	39.1	56.9
0.1	100	24.2	50.4
0.2	200	20.1	40.2
0.3	300	11.4	25.1
1	1000	6.9	20.7
10	10000	5.8	19.9
25	25000	5.7	19.8
100	100000	5.6	19.7

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1. ( ) The bulk density of soil A, assuming it does not swell or shrink, is greater than 1.35 g/cm³.

2.( ) The bulk density of soil B, assuming it does not swell or shrink, is greater than 1.35 g/cm³.

3,( ) The volume wetness of soil A at 0.25 bar suction pressure is greater than 10%.

4.( ) The volume wetness of soil B at 15 bar suction pressure is greater than 15%.

5.( ) The mass wetness of soil A at 15 bar suction pressure is greater than 7.5%. Assume the density of water to be 1 g/cm³.

6.( ) The mass wetness of soil B at 0.25 bar suction pressure is greater than 20%. Assume the density of water to be 1 g/cm³.

7.( ) The water, in depth units, that soil A can release per one meter depth in transitioning from 0.25 bar to 15 bar of suction is greater than 130 mm.

8.( ) The water, in depth units, that soil B can release per one meter depth in transitioning from 0.25 bar to 15 bar of suction is greater than 130 mm.

▶▶ SOLUTIONS

P.1 ➡ *Solution*

The mean weight diameter is given by the sum

$$\bar{d}_m = 0.1 \times 0.13 + 0.6 \times 0.09 + 1.5 \times 0.14 + 3.0 \times 0.22$$

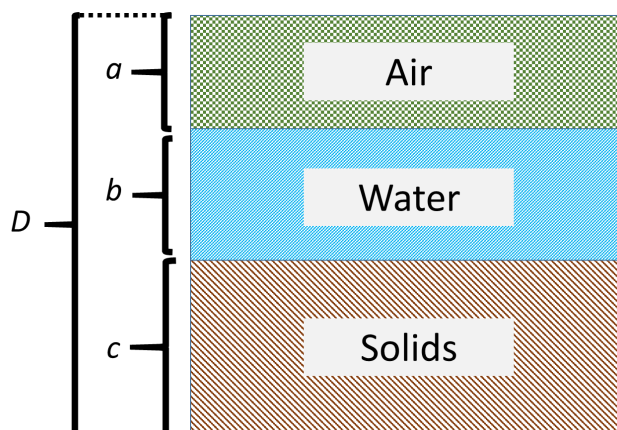$$+7.0 \times 0.26 + 15.0 \times 0.16 = \boxed{5.16\,\text{mm}}$$

The geometric mean diameter, in turn, is given by the exponential

$$\bar{d}_g = \exp\left[\begin{array}{l} 0.13\ln(0.1) + 0.09\ln(0.6) + 0.14\ln(1.5) \\ +0.22\ln(3.0) + 0.26\ln(7.0) + 0.16\ln(15.0) \end{array}\right] = \boxed{2.44\text{ mm}}$$

♦ The correct answer is **C**.

P.2 ➡ *Solution*

1. True. The following illustration, which shows the equivalent depths of each component of the soil structure, should prove useful.

The mass water content is the ratio of mass of water to the mass of soil,

$$\theta_m = \frac{m_w}{m_s} = \frac{0.32}{1.52 - 0.32} = \boxed{0.267}$$

2. False. The volume water content is the ratio of volume of water to the bulk volume of the soil sample,

$$\theta_v = \frac{V_w}{V_b} = \frac{m_w}{\rho_w V_b} = \frac{0.32}{1000 \times 0.1^3} = \boxed{0.32}$$

3. False. The equivalent depth of water is given by the product of volume water content and the total equivalent depth of soil,

$$D_e = \theta_v D = 0.32 \times 0.1 = 0.032 \text{ m} = \boxed{32\,\text{mm}}$$

4. True. The bulk density is the ratio of the mass of solids to the bulk volume of the sample,

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$$\rho_b = \frac{m_s}{V_s} = \frac{1.52 - 0.32}{0.1^3} = \boxed{1200 \text{ kg/m}^3}$$

5. False. Let a denote the a denote the equivalent depth of air, b the equivalent depth of water, and c the equivalent depth of solids. In addition, suppose A denotes the cross-sectional area of the sample. The total porosity is the ratio of the total pore volume = $(a + b) \times A$ to the bulk volume of soil = $D \times A$, so that

$$\eta = \frac{(a+b)A}{DA} = \frac{a+b}{D} = \frac{D-c}{D} = 1 - \frac{c}{D}$$

However, $c = D(\rho_b / \rho_p)$, where bulk density ρ_b = 1200 kg/m³ as determined above and ρ_p = 2700 kg/m³ is the soil particle density. Substituting c in the equation above brings to

$$\eta = 1 - \frac{\rho_b}{\rho_p} = 1 - \frac{1200}{2700} = \boxed{0.556}$$

6. False. The relative saturation is the ratio of the water volume content to the corresponding saturated value,

$$S = \frac{\theta_v}{\theta_v \left[\text{saturated}\right]} = \frac{bA}{(a+b)A} = \frac{b}{a+b}$$

However, $b = D_e = \theta_v D$, so that

$$S = \frac{\theta_v D}{a+b} = \frac{\theta_v}{\dfrac{a+b}{D}} = \frac{\theta_v}{\eta} = \frac{0.32}{0.556} = \boxed{0.576}$$

P.3 ➡ Solution

Irrigation is deployed when the soil reaches the PWP. The available moisture by weight is AM_W = 22 – 8 = 14%, and the corresponding quantity by volume is AM_V = 14 × 1.8 = 25.2%. The depth of water needed at root zone at PWP is 0.252 × 85 = 21.4 cm. Accounting for the irrigation application efficiency, the depth of water required is found as 21.4/0.6 = 35.7 cm.

◆ The correct answer is **C**.

P.4 ➡ Solution

The total potentials at points 1 and 3 are, respectively,

$$\phi_1 = \Psi_1 + Z_1 = -80 + (-20) = -100 \text{ cm}$$

$$\phi_3 = \Psi_3 + Z_3 = -50 + (-60) = -110 \text{ cm}$$

Water drains from the greater to the lower potential; accordingly, we conclude that water will flow from 1 to 3. It remains to compute the hydraulic gradient,

$$\frac{\Delta \phi}{\Delta z} = \frac{-100 - (-110)}{-20 - (-60)} = \boxed{0.25 \text{ cm cm}^{-1}}$$

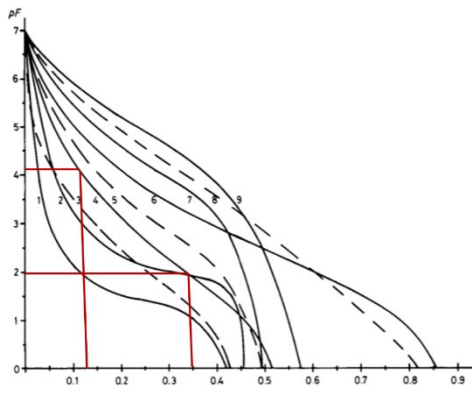◆ The correct answer is **A**.

P.5 ➡ Solution

Part 1: The volume fraction available at a pF of 2 is close to 0.62, while the volume fraction available at a pF of 4.2 is about 0.22. Thus, the volume fraction available is 0.62 – 0.22 = 0.40.

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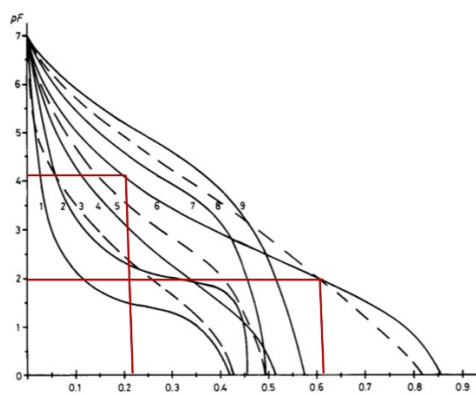
♦ The correct answer is **B**.

Part 2: For soil 4, θ = 0.13 at pF = 4.2 and θ = 0.35 at pF = 2.0. Thus, to wet this soil from wilting point to field capacity requires filling a volume fraction of about 0.35 – 0.13 = 0.22 with water. The penetration depth of the rainshower is then 9 mm/0.22 = 40.9 mm.

♦ The correct answer is **D**.

Part 3: 0.3 m topsoil is wetted to field capacity by a rainshower of 0.22 × 300 = 66 mm. Per hectare this corresponds to a volume of 10,000 × 0.066 = 660 m³.

♦ The correct answer is **B**.

P.6 ➡ Solution

1. False. Soil permeability is measured in squared length, and the SI unit of permeability is squared meters.

2. False. On the contrary, capillary rise tends to increase as particle size is reduced. What's more, the time required to achieve a capillary rise level is greatest for fine-grained ground. Although the exact amount of capillary rise is ultimately dependent on the pore sizes and pore connectivity, some general values can be suggested, as shown in continuation.

Soil type	Typical capillary rise (cm)
Sand	20 – 50 cm
Loam	50 – 80 cm
Clay	> 80 cm

3. True. Let the data be related by an expression of the form $Y = aX + b$, where Y is the number of cpm, X is the volumetric wetness, and a and b are constants. Substituting the two data points we have brings to

$$\begin{cases} 25,000 = a \times 15 + b \\ 43,000 = a \times 40 + b \end{cases}$$

This system of equations can be solved to yield a = 720 and b = 14,200, so that $Y = 720X + 14,200$. Substituting Y = 33,000 cpm and solving for X, we can determine the wetness value that corresponds to this count rate,

$$Y = 720X + 14,200 \rightarrow 33,000 = 720X + 14,200$$

$$\therefore \boxed{X = 26.1\%}$$

4. False. The mass of water in the pycnometer is 350 – 220 – 40 = 90 g, and the corresponding volume is of course 90/1.0 = 90 cm³. The volume of soil (solids) in the pycnometer is 175 – 90 = 85 cm³. Lastly, the particle density of the soil is determined as

$$\text{Particle density} = \frac{\text{Dry mass of solids}}{\text{Volume of solids}} = \frac{220}{85} = \boxed{2.59 \ \text{g/cm}^3}$$

5. True. This is a straightforward application of Stokes' law,

$$V = \frac{\left(\rho_p - \rho_w\right)gd^2}{18\mu} = \frac{\left(2710 - 1000\right) \times 9.81 \times \left(0.2 \times 10^{-3}\right)^2}{18 \times 0.001} = \boxed{0.0373 \ \text{m/s}}$$

6. False. The approximate specific surface can be estimated with the summation equation

$$s = \frac{6}{\rho_s} \sum \left(\frac{c_i}{d_i}\right)$$

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where ρ_s = 2.71 g/cm³ is the density of soil particles and c_i is the mass fraction of particles of average diameter d_i. Substituting our data brings to

$$ s = \frac{6}{2.71} \times \left(\frac{0.25}{0.1} + \frac{0.45}{0.01} + \frac{0.3}{0.005} \right) = 238 \text{ cm}^2/\text{g} = \boxed{23.8 \text{ m}^2/\text{kg}} $$

7. True. The volume of the particle is $ab\delta$, the mass is $\rho_s ab\delta$, and the total surface area is $2(ab + \delta a + \delta b)$. The specific surface area of the particle is then

$$ s = \frac{2(ab + \delta a + \delta b)}{\rho_s \delta ab} = \frac{2}{\rho_s} \left(\frac{1}{\delta} + \frac{1}{b} + \frac{1}{a} \right) $$

Substituting ρ_s = 2750 kg/m³, δ = 1 nm, and $a = b$ = 18 nm yields

$$ s = \frac{2}{2750} \times \left(\frac{1}{1 \times 10^{-9}} + \frac{1}{18 \times 10^{-9}} + \frac{1}{18 \times 10^{-9}} \right) = 808,000 \text{ m}^2/\text{kg} $$

Since 1 ha = 10,000 m², the specific surface area becomes 808,000/10,000 = 80.8 ha/kg. It is interesting to note that, if $\delta \ll a$ and $\delta \ll b$, which is true for thin plates, the equation above reduces to

$$ s \approx \frac{2}{\rho_s \delta} $$

so that, in the present case, s = 2/[2700 × (1×10⁻⁹)] = 727,000 m², which is a crude approximation to the result obtained with the complete formula.

8. False. The volume of one clay particle is $\delta \times a \times b$ = 10⁻⁹ × (18×10⁻⁹) × (18×10⁻⁹) = 3.24×10⁻²⁵ m³, and the corresponding mass is 3.24×10⁻²⁵ × 2700 = 8.75×10⁻²² kg. The number of particles in 1 kg of soil follows as

$$ N = \frac{1 \text{ particle}}{8.75 \times 10^{-22} \text{ kg}} \times 1 \text{kg} = \boxed{1.14 \times 10^{21} \text{ particles}} $$

9. False. Schofield's pF function expresses the tension of water retained in the soil. It is expressed as the base-10 logarithm of tension, which is measured as a head of water in centimeters. Accordingly, the pF value for the permanent wilting point is $pF = log_{10}$ 15,000 = 4.2.

10. False. In general, the FC tends to be close to the maximum in silt loam soils, while the PWP steadily increases with clay content. It follows that the quantity of plant-available water, as expressed by the difference between FC and PWP, tends to a maximum in silty and clayey loams.

11. True. By inspection, the concentrations of phosphorus and magnesium indeed reduce substantially at low pH, while those of manganese and copper rise appreciably. Although many mineral soil plant species do have a predilection for mildly acidic conditions, pH values below 5.5 or so can be detrimental to growth of many species.

12. False. In general, vermiculite clays have the highest CEC, while kaolinite clays display the lowest values. Some typical figures are listed below. Vertisols tend to have some of the greatest CEC values owing to their high smectitic clay content, while highly weathered soils, as found in the Ultisol and Oxisol orders, are characterized by relatively low CEC values, due to the absence of constant charge surfaces and the presence of constant potential mineral surfaces that have relatively low CEC values.

Soil colloids	CEC (mEq/100 g)
Vermiculite	100 – 150
Smectite	70 – 95
Illite	10 – 40
Kaolinite	3 – 15

13. True. Indeed, CE reactions are rapid and have a rate mainly determined by ion diffusion to or from the colloid surface. As noted by Bohn *et al.*, this is especially true under field conditions, where ions may have to move through tortuous pores or through relatively thick, stagnant water films on soil colloid surfaces to reach an exchange site.

14. True. The base saturation is, in mathematical terms,

$$ \%\text{Base saturation} = \frac{\Sigma \text{Exchangeable bases (in mEq/100 g)}}{\text{CEC}} \times 100\% $$

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The CEC = 0.80 + 0.45 + 0.25 + 0.07 + 1.4 + 1.5 = 4.47 mEq/100 g. The sum of the four exchangeable bases mentioned in the problem statement is 0.80 + 0.45 + 0.25 + 0.07 = 1.57 mEq/100 g. Lastly, the base saturation is calculated to be

$$\%\text{Base saturation} = \frac{1.57}{4.47} \times 100\% = \boxed{35.1\%}$$

15. True. This is an excerpt from the *Encyclopedia of Soil Science*'s article on activity ratios. Indeed, the Schoffield ratio law only holds for soil solutions with a low external electrolyte concentration and for soils with a high surface negative charge. For soils of low surface negative charge, and particularly for variable charge soils which contain measurable amounts of surface positive charge, small changes in solution composition alter the relative proportions of cations on the soil surfaces, and activity ratios do not remain constant.

16. False. The mathematics of the Eriksson equation are more intricate than those of most other ion exchange formulas. This high degree of complexity, along with the formula's limitation to few sets of ions besides Na and Ca, have led to its near abandonment in soil cation exchange applications. The Eriksson equation, as applied to sodium and calcium, is stated as

$$\frac{\left[Na^+\right]}{\left[Ca^{2+}\right]} = \frac{\left[(1/\beta)/\sinh^{-1}\left(\beta^{1/2}\right)\Gamma/\left(Na^+\right)/\left(Ca^{2+}\right)^{1/2} + 4VC\left(Ca^{2+}\right)^{1/2}\right]}{\Gamma - \left[\left(Na^+\right)/\left(Ca^{2+}\right)^{1/2}/\beta^{1/2}\right]\sinh^{-1}\left(\beta^{1/2}\right)\Gamma\left[\left(Na^+\right)/\left(Ca^{2+}\right)^{1/2}\right]}\rho$$

Here, Γ is charge density, $\beta = 0.08RT$, $VC = 1$, and $\rho = (Na^+)/(Ca^{2+})^{1/2}$.

17. False. All it takes is a quick inspection of the data: a kilogram of humic acid has a greater mean mass of carbon (554 g vs. 453 g) and nitrogen (36 g vs. 26 g), whereas a kg of fulvic acid contains a substantially larger amount of oxygen (462 g vs. 360 g). Thus the molar ratios of H-to-C and O-to-C both are larger in fulvic acid than they are in humic acid, implying that the latter is the more aromatic and less polar humic substance.

18. False. While it is true that CaO and Ca(OH)$_2$ do possess high reactivity, their effects are inherently ephemeral. These substances have use when a quick neutralizing action is desired, but there will be little lasting effect after initial reaction with the acid soil.

19. True. Indeed, depending on the elemental composition, a compound can have a CEC value greater than 100; the most common substances that often exceed this value are slaked lime and burnt lime. Some average values for aglime materials are listed below.

Aglime material	CCE (%)
Calcium carbonate	100
Calcium limestone	85 – 100
Dolomitic limestone	95 – 110
Calcium hydroxide (slaked lime)	120 – 133
Calcium oxide (burnt or quick lime)	150 – 175
Calcium silicate	86
Basic slag	50 – 70

20. True. Indeed, the matric potential is generally negative, ranging from about −1000 mm at typical field values and −150,000 mm at the wilting point. A matric potential of zero indicates a fully saturated soil. One way soil scientists found to do away with this unintuitive scale is by defining an alternative quantity, the *matric suction*, as the negative of the matric potential.

21. False. The relationships have been swapped. In actuality, for a given pore the contact angle between the water meniscus and the pore walls is greater when the meniscus is advancing (wetting) than when it is retreating (drying). As a result, the radius of curvature is greater for the advancing (wetting) meniscus and that the absolute value of the pressure developed is correspondingly less for the same water content.

P.7 ➡ Solution

The CEC of a soil as determined with the ammonium acetate method is given by

$$CEC\left[\text{cmol}_c\ \text{kg}^{-1}\right] = C_{\text{Na}} \times \frac{V_L}{m_s \times MW_{Na} \times 10}$$

where C_{Na} is the mg/L concentration of Na in the combined wash solutions having volume V_L in liters, m_{kg} is the mass of the soil sample in kg, and MW_{Na} = 23 mg/mmol is the molar mass of sodium. Substituting our data brings to

$$CEC = 180\frac{\text{mg}}{\text{L}} \times \frac{0.08\ \text{L}}{0.003\,\text{kg} \times 23\,\text{mg/mmol} \times 10\,\text{mmol/cmol}} = \boxed{20.9\ \text{cmol}_c/\text{kg}}$$

♦ The correct answer is **C**.

P.8 ➡ Solution

Part 1: The CEC of the Bt horizon is 24.1 cmol$_c$ kg^{-1}. The molecular weight of K$^+$ is 39 g/mol, and 1 cmol$_c$ of K$^+$ contains 0.39 g. When all cations on the exchange sites of the soil are replaced by K$^+$, the amount of potassium in a 100-g soil sample will be 0.1 × 20.2 = 2.02 cmol$_c$. This corresponds to a mass m_K such that

$$m_K = 2.02\ \text{cmol}_c\ \text{K} \times \frac{0.39\,\text{g}}{1\,\text{cmol}_c\ \text{K}} = 0.788\ \text{g}$$

That is, 100 g of soil will have a mass of 0.788 g of K; equivalently, the soil will have 7.88 grams of potassium per kilogram of soil.

♦ The correct answer is **A**.

Part 2: The mass of soil in the upper 21-cm thick layer, considering a land area of 1 ha = 10,000 m², is m_1 = 10,000 × 0.21 × 1490 = 3.13×10⁶ kg. The mass of soil in the layer encompassing 21 to 50 cm depth, in turn, is m_2 = 10,000 × 0.29 × 1350 = 3.92×10⁶ kg. The amount of Na$^+$ on exchange sites for the Ap horizon is 20.2 × 4.6/100 = 0.929 cmol$_c$/kg, and the amount of sodium in 1 ha of this soil is 0.929 × 3.13×10⁶ = 2.91×10⁶ cmol$_c$. Likewise, the amount of Na$^+$ on exchange sites for the Bt horizon is 24.1 × 9.0/100 = 2.17 cmol$_c$/kg, and the corresponding amount of sodium in 1 ha is 2.17 × 3.92×10⁶ = 8.51×10⁶ cmol$_c$. It follows that the total amount of Na$^+$ in the 50-cm stratum is

$$n\left(\text{Na}^+\right) = \frac{2.91 \times 10^6 + 8.51 \times 10^6}{100} = 114,000\ \text{mol}_c\ \text{Na}^+$$

The mass of one mol$_c$ of calcium is 40/2 = 20 g. It follows that the mass of Ca^{2+} needed to replace all Na$^+$ on exchange sites is 114,000 × 20/1000 = 2280 kg. Now, note that one kilomole of CaCO$_3$ has a mass of 100 kg, of which 40 kg is calcium. The mass of lime that corresponds to 2280 kg of Ca^{2+} is then

$$\frac{40\,\text{kg}\,\text{Ca}^{2+}}{100\,\text{kg}\,\text{CaCO}_3} = \frac{2280\,\text{kg}\,\text{Ca}^{2+}}{m} \rightarrow \boxed{m = 5700\,\text{kg}\,\text{CaCO}_3\ /\ \text{ha}}$$

Approximately 5.7 tons of lime should be administered to each hectare of soil.

♦ The correct answer is **A**.

P.9 ➡ Solution

1. False. The sum of cation concentrations in solution is 8.0 + 10 + 6.0 = 24 mmol(+)/L. Referring to the first formula we were given, we get

$$24 = \text{EC} \times 10 \rightarrow \boxed{\text{EC} = 2.4\ \text{dS}\,\text{m}^{-1}}$$

2. True. The total dissolved solids is given by

$$TDS = EC \times 640 \rightarrow TDS = 2.4 \times 640$$

$$\therefore \boxed{TDS = 1540\,\text{mg}\,\text{L}^{-1}}$$

3. True. The osmotic potential is estimated as

$$OP = 2.4 \times \left(-0.36\right) = \boxed{-0.864\,\text{bar}}$$

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P.10 ➡ Solution

1. True. To begin, we compute the hydraulic conductivity,

$$K = \frac{\rho g k}{\mu} = \frac{1000 \times 9.81 \times \left(5 \times 10^{-13}\right)}{0.0015} = 3.27 \times 10^{-6} \text{ m/s}$$

Taking $z = z_2$ at the top and $z = z_1$ at the bottom, we appeal to Darcy's law to obtain

$$q = -K \frac{\Delta H}{\Delta z} = -K \frac{\left(h_{z,2} + h_2\right) - \left(h_{z,1} + h_1\right)}{z_2 - z_1}$$

$$\therefore q = -\left(3.27 \times 10^{-6}\right) \times \frac{\left(100 + 0\right) - \left(0 + 180\right)}{100 - 0} = \boxed{2.62 \times 10^{-6} \text{ m/s}}$$

2. False. To determine the volumetric flow rate, we simply multiply the Darcy flux by the cross-sectional area of the sample,

$$Q = |q| A = \left(2.62 \times 10^{-6}\right) \times \left(50 \times 10^{-4}\right) = \boxed{1.31 \times 10^{-8} \text{ m}^3/\text{s}}$$

3. False. Given the porosity $\eta = 0.3$ and the foregoing data, the time required for a water particle to flow through the column is

$$t = \frac{L}{\left(|q|/\eta\right)} = \frac{1.0}{\left(2.62 \times 10^{-6}/0.3\right)} = 115,000 \text{ s} = \boxed{31.9 \text{ h}}$$

P.11 ➡ Solution

1. False. The equivalent vertical hydraulic conductivity is given by

$$K_{\text{eq}} = \frac{L_{\text{upper}} + L_{\text{lower}}}{\dfrac{L_{\text{upper}}}{K_{\text{upper}}} + \dfrac{L_{\text{lower}}}{K_{\text{lower}}}} = \frac{1 + 99}{\dfrac{1}{1.0 \times 10^{-7}} + \dfrac{99}{5 \times 10^{-5}}} = \boxed{8.35 \times 10^{-6} \text{ cm/s}}$$

2. True. The steady-state flow through the column follows from Darcy's law,

$$q = -K_{\text{eq}} \frac{\Delta H}{\Delta z} = -\left(8.35 \times 10^{-6}\right) \times \frac{\left(100 + 160\right) - \left(0 + 25\right)}{100 - 0} = \boxed{-1.96 \times 10^{-5} \text{ cm/s}}$$

Flow is from higher to lower hydraulic head, i.e. from top to bottom.

3. False. The average residence time of water is given by

$$t = \frac{L}{\left(|q|/\eta\right)} = \frac{100}{\left(1.96 \times 10^{-5}\right)/0.42} = 2.14 \times 10^6 \text{ s} = \boxed{594 \text{ h}}$$

P.12 ➡ Solution

Where there is a sharp wetting front, the sorptivity can be estimated by solving the Philip equation for S, giving

$$S = \frac{\left(\theta_{v,s} - \theta_{v,i}\right) I}{t^{1/2}} = \frac{\left(0.48 - 0.12\right) \times 8}{15^{1/2}} = \boxed{0.744 \text{ cm/min}^{1/2}}$$

◆ The correct answer is **C**.

P.13 ➡ Solution

1. True. All we have to do is substitute $t = 0.5$ h in the Philip equation, giving

$$I = 4 \times 0.5^{0.5} + 0.2 \times 0.5 = \boxed{2.93 \text{ cm}}$$

2. False. The equation we were given has the form of a Philip equation for infiltration,

$$I = St^{0.5} + At$$

where S is sorptivity and A is a characterizing constant. Adsorption is described as the movement of a liquid into a medium under the influence of capillarity without the effects of gravity. Thus, cumulative horizontal infiltration can be described by the first term of the Philip equation only. Substituting $I = 4$ cm and solving for t brings to

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$$I = St^{0.5} \rightarrow 4 = 4t^{0.5}$$

$$\therefore \boxed{t = 1\text{h}}$$

3. True. For vertical upward infiltration, we must recognize that the sign on the second term will be negative because infiltration is working against gravity. The equation to solve is then

$$I = 4t^{0.5} - 0.2t \rightarrow 20 = 4t^{0.5} - 0.2t$$

$$\therefore \boxed{t = 100 \text{ h}}$$

4. False. The infiltration rate is the time derivative of the cumulative infiltration. For t = 45 min = 0.75 h, we have

$$I = 4t^{0.5} \rightarrow \frac{dI}{dt} = 2t^{-0.5}$$

$$\therefore \left. \frac{dI}{dt} \right|_{t=0.75} = 2 \times 0.75^{-0.5} = \boxed{2.31\,\text{cm/h}}$$

5. True. The infiltration rate for downward vertical infiltration is given by
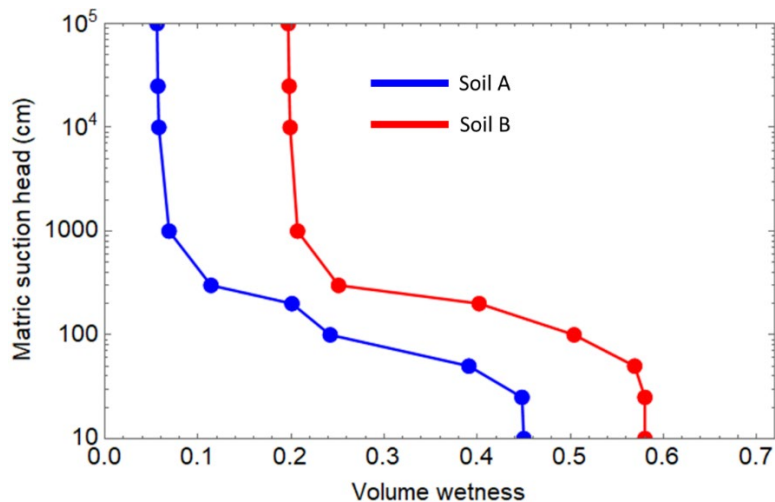
$$I = 4t^{0.5} + 0.2t \rightarrow \frac{dI}{dt} = 2t^{-0.5} + 0.2$$

so that

$$\left. \frac{dI}{dt} \right|_{t=1.0} = 2 \times 1.0^{-0.5} + 0.2 = \boxed{2.2 \text{ cm/h}}$$

P.14 ➡ *Solution*

1. True. The soil-moisture characteristic curves are plotted below.

The bulk density can be estimated from the volumetric wetness at saturation (zero suction) assuming it to be equal to the porosity η (i.e., no occluded air),

$$\eta = 1 - \frac{\rho_b}{\rho_s} \rightarrow \rho_b = \rho_s (1 - \eta)$$

For soil A, with η = 0.45, we have

$$\rho_b = \rho_s (1 - \eta) = 2.65 \times (1 - 0.45) = \boxed{1.46 \text{ g/cm}^3}$$

2. False. For soil B, with η = 0.58, we have

$$\rho_b = 2.65 \times (1 - 0.58) = \boxed{1.11 \text{ g/cm}^3}$$

3. True. Volume wetness for different suctions can be read directly from the soil moisture characteristic curves. For soil A at 0.25 bar (250 cm), the volume wetness is read as 15%.

4. True. For soil B at 15 bar (15,000 cm), the volume wetness is read as 20%.

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5. False. At 15 bar suction pressure, the volume wetness of soil A is about 5.5%. The corresponding mass wetness w is then

$$w = \theta \times \frac{\rho_w}{\rho_b} = 5.5 \times \frac{1.0}{1.46} = \boxed{3.77\%}$$

6. True. At 0.25 bar suction pressure, the volume wetness of soil B is about 30%. The corresponding mass wetness w is then

$$w = \theta \times \frac{\rho_w}{\rho_b} = 30 \times \frac{1.0}{1.11} = \boxed{27.0\%}$$

7. False. The volume wetness of soil A is 15% at 0.25 bar and 5.5% at 15 bar. The water released per 1 m depth in transitioning from 0.25 bar to 15 bar follows as

$$\Delta h = (0.15 - 0.055) \times 1000 = \boxed{95 \text{ mm}}$$

8. False. The volume wetness of soil B is 30% at 0.25 bar and 20% at 15 bar. The water released per 1 m depth in transitioning from 0.25 bar to 15 bar is then

$$\Delta h = (0.30 - 0.20) \times 1000 = \boxed{100 \text{ mm}}$$

▶▶ ANSWER SUMMARY

Problem 1		C
Problem 2		T/F
Problem 3		C
Problem 4		A
Problem 5	5.1	B
	5.2	D
	5.3	B
Problem 6		T/F
Problem 7		C
Problem 8	8.1	A
	8.2	A
Problem 9		T/F
Problem 10		T/F
Problem 11		T/F
Problem 12		C
Problem 13		T/F
Problem 14		T/F

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