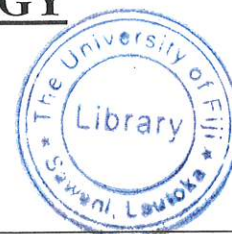




SCHOOL OF SCIENCE AND TECHNOLOGY
Semester 1, 2025

FINAL EXAMINATION PAPER



PHY315: ENVIRONMENTAL SOIL PHYSICS

Important Instructions to Students:

1. Read the questions, instructions carefully and answer the questions. There are 7 pages in this paper.
2. You are allowed an **extra 10 minutes reading time** (during this time, you are not allowed to write with pen) and **180 minutes (3 Hours) to complete this paper**.
3. Silent, non-programmable calculators are allowed, but not supplied.
4. Write all your answers in the answer booklet provided. If you need extra sheets, please ask from the supervisor. Write your name, course code and student identification number in the answer booklet and in the attendance sheet.
5. This paper contains five (5) questions. All questions are compulsory.
6. Write all your answers legibly. The marker has the right to award zero for answers that are not legible.
7. This is a **Closed Book Examination**. The University views plagiarism, cheating and dishonest practice as serious offences and if found, offenders are penalized.

Examination Paper Content (Format):

<u>Question</u>	<u>Content</u>	<u>Marks</u>	<u>Suggested Time</u>
1	Short Answer Questions	20	36 minutes
2		20	36 minutes
3		20	36 minutes
4		20	36 minutes
5		20	36 minutes
		100	180 Minutes

There are five (5) questions in this paper, all are compulsory.

Question: 1 **[start on a new page]** **[20 Marks]**

1. A moist soil sample has a wet mass of 1.0 kg and occupies a volume of 0.64 liters. After oven drying, the dry mass of the soil is found to be 0.8 kg. Assuming a particle density (ρ_s) of 2650 kg/m³, calculate the following physical properties of the soil:

- i. Bulk density (ρ_b)
 - ii. Porosity (f)
 - iii. Gravimetric (mass) water content (ω)
 - iv. Volumetric water content (θ)
 - v. Degree of saturation (s)
 - vi. Air-filled porosity (f_a)
- (9 marks: 1.5 marks each)

2. A 20 cm thick soil layer overlies an impermeable bedrock. The soil has a known water retention curve, represented by the relationship $\theta(h)$, where θ is the volumetric water content and h is the pressure head (cm).

$$\theta(h) = 0.46 \left(\frac{-5}{h} \right)^{0.25}$$

If the initial pressure of the soil given by a tensiometer is -98,000 Pa, determine what depth of rainfall (in cm) would be required to raise the pressure head to -100 cm throughout the entire soil layer.

(3 marks)

3. Prove the following relation between volume wetness (θ), mass wetness (ω), bulk density (ρ_b), and water density (ρ_w):

(3 marks)

$$\theta = \omega \frac{\rho_b}{\rho_w}$$

4. A soil profile is 1.2 m deep and is divided into three distinct layers with varying bulk densities and mass wetness values as follows:

- Layer 1: Top 0.3 m, mass wetness = 25%, bulk density = 1400 kg/m³
- Layer 2: Middle 0.4-0.6 m, mass wetness = 20%, bulk density = 1600 kg/m³
- Layer 3: Bottom 0.4 m, mass wetness = 18%, bulk density = 1650 kg/m³

Calculate the equivalent depth of water contained in the entire soil profile. (5 marks)

Question: 2**[start on a new page****[20 Marks]**

1. Describe how the soil pH influences the charge of soil colloids and their ability to retain nutrients. (2 marks)

2. *Cation Exchange Capacity (CEC)* is crucial for nutrient retention in soil. A farmer wants to improve the fertility of sandy soil. Suggest two ways this can be done. (2 marks)

3. Discuss the formation and structure of the electrostatic double layer around clay particles in aqueous environments. In your answer, explain the forces leading to the double layer formation. (3 marks)

4. A clay particle with a diameter of $2\ \mu\text{m}$ settles in water at 25°C . The viscosity of water is $0.001\ \text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$, the density of the clay particle is $2.65\ \text{g}/\text{cm}^3$, and the density of water is $1.00\ \text{g}/\text{cm}^3$.

i. Using Stokes' Law, calculate the terminal settling velocity of the clay particle. (3 marks)

ii. If the particle falls through a height of $0.2\ \text{m}$, calculate the time it takes to settle. (1 mark)

5. A soil sample contains 30% coarse sand with a diameter of $0.5\ \text{mm}$, 30 % fine sand with a diameter of $0.05\ \text{mm}$, and 40 % silt with a diameter of $0.01\ \text{mm}$. Assuming uniform particle density of $2650\ \text{kg}/\text{m}^3$, calculate the specific surface area (per unit mass) of the soil sample. (4 marks)

6. Calculate the mass of water adsorbed by $150\ \text{g}$ of montmorillonite, if the specific surface area of the clay is $845\ \text{m}^2/\text{g}$. Assume monomolecular adsorption. (5 marks)

Use the diameter of a water molecule as $3 \times 10^{-10}\ \text{m}$ and the mass per molecule as $3 \times 10^{-23}\ \text{g}$.

Question: 3**[start on a new page]****[20 Marks]**

1. A soil system is made of uniform spherical aggregates occurring in cubic packing. Assume that each aggregate has a bulk density ρ_b of $1.8 \times 10^3 \text{ kg/m}^3$ and that particle density ρ_s is $2.65 \times 10^3 \text{ kg/m}^3$. Assume that each sphere is packaged into a volume equal to the volume of a unit cube.

- i. Calculate the macroporosity of the aggregates (between-aggregates). (2 marks)
- ii. Determine the microporosity within the aggregates. (2 marks)
- iii. What is the total porosity of the aggregates? (2 marks)

2. Both dry sieving and wet sieving are commonly used methods for separating soil aggregates. Explain the principle behind each method and discuss the situations for which each of these sieving methods would be more appropriate?

(3 marks)

3. A soil sample contains aggregates arranged in a composite packing structure, where 60% of the aggregates follow a cubic packing arrangement with a porosity of 47.6%. The remaining 40% of the aggregates follow a rhombohedral packing arrangement with a porosity of 25.9%.

- i. Calculate the composite porosity of the soil using the given proportions. (2 marks)
- ii. Explain how this composite arrangement of aggregates affects soil air and water retention. (2 marks)
- iii. If the total volume of the soil sample is 0.75 m^3 , determine the volume of void spaces in the sample. (2 marks)

4. Calculate the mean weight diameters (MWD) of the assemblages of aggregates given in table. The percentages refer to the mass fractions of dry soil in each diameter range.

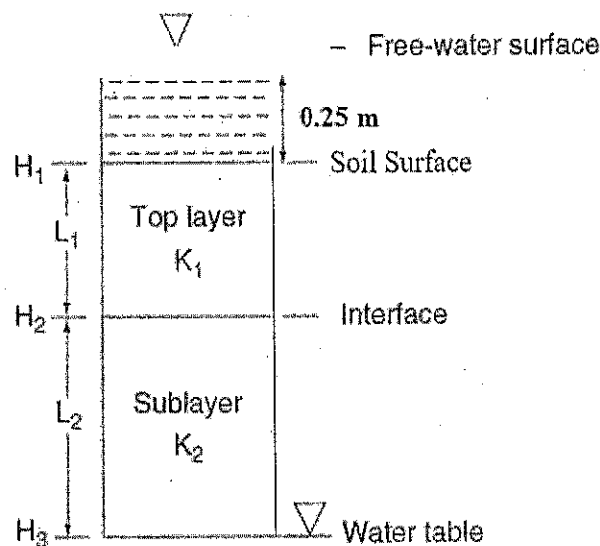
Aggregate Diameter Range (mm)	Dry Sieving Virgin Soil (%)	Dry Sieving Cultivated Soil (%)
0.0–1.0	20	50
1–5	30	30
5–20	40	17
20–50	10	3

Discuss how differences in MWD values obtained above can be interpreted in terms of soil structure, stability, and susceptibility to erosion or compaction. (5 marks)

Question: 4**[start on a new page]****[20 Marks]**

1. A 100 cm long column is packed with two different soils as shown below. The pressure head at the base of the column is 0 cm and 25 cm at the top of the column. The upper layer has a hydraulic conductivity of 2.55×10^{-7} m/s and the bottom layer has a hydraulic conductivity of 4.62×10^{-8} m/s.

- Calculate the flux through the column using Darcy's law. (3 marks)
- What is the total hydraulic head at the interface? (2 marks)
- What is the pressure head at the interface? (1 mark)



2. An artificial soil water delivery system mimics natural subsurface seepage by releasing water through capillary tubes embedded at different depths in a soil column. Each outlet consists of a coiled capillary tube that is 1 meter long. The system is pressurized at 100 kPa and includes two tubes with internal diameters of 0.2 mm and 1.0 mm.

Assuming laminar flow through the tubes and treating the water as an incompressible, calculate the **discharge rate (Q)** from each tube using the Poiseuille's equation.

Discuss the implications of this result in the context of preferential flow and water distribution in soils with varying pore size distribution. (6 marks)

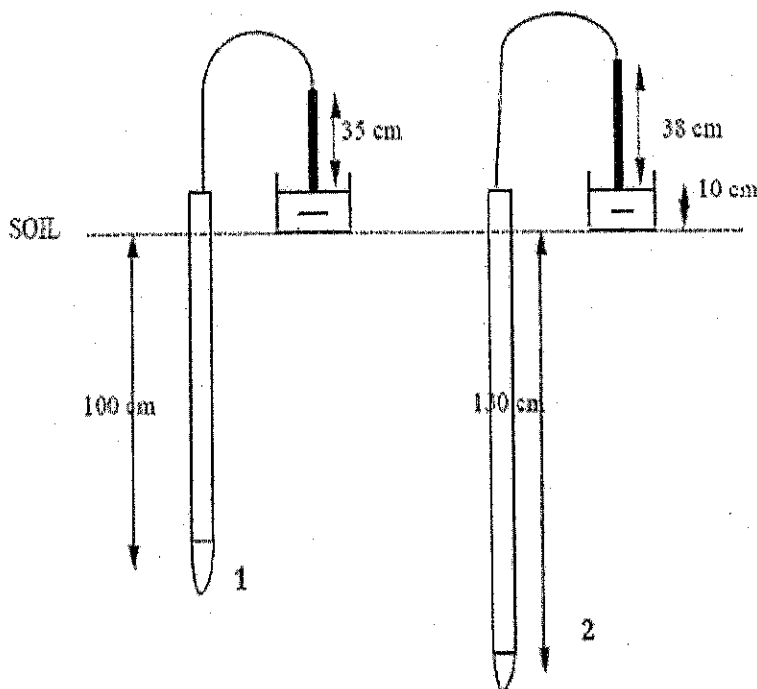
3. The diagram below shows two mercury tensiometers installed at different depths in a soil profile. The pressure head (h) at a depth can be computed using the following formula.

$$h = y - 13.5x$$

Where y is the height of water from the bottom of the tensiometer to the level of mercury rise and x is the height of mercury rise.

- Calculate the pressure head in the soil tested with tensiometer 1 and 2.
- Calculate the hydraulic head of the sample tested in both tensiometers.
- From the value for h , determine whether the soil is saturated or unsaturated.
- From the values of hydraulic head, determine the direction of flow (upwards or downwards).

(8 marks: 2 marks each)



Question: 5**[start on a new page]****[20 Marks]**

1. Explain how the aeration of well-drained and poorly drained soils differ. What toxic substances are produced in soils with low oxygen levels, and how do these substances form under such conditions? (3 marks)

2. What processes influence the convective transport of soil air? Explain how each factor contributes to the movement of soil gases. (3 marks)

3. Consider a soil profile where the air-phase CO₂ concentration increases linearly from 0.03% at the surface to 0.06% at a depth of 0.5 meters. The diffusion coefficient for CO₂ in soil is 10⁻⁹ m²/s. Apply Fick's first law to compute the steady-state one-dimensional diffusive flux of CO₂ out of the soil. (5 marks)

4 The soil surface temperature equals the mean daily temperature at 6 am for a particular soil profile. Assume that the diurnal temperature wave is symmetrical and mean temperature is equal throughout the profile. Daily maximum and minimum soil surface temperatures are 36°C and 8°C and thermal diffusivity (D_h) is 0.003 m²/hr

i. Find the characteristic damping depth d . (2 marks)

$$d = \sqrt{2D_H / \omega}$$

ii. Calculate the temperature at midnight for a depth of 10 cm and 20 cm (3 marks)

iii. Calculate the thermal heat flux between 10 cm and 20 cm at midnight. Consider a thermal conductivity of 1.6 J m⁻¹ s⁻¹ °C⁻¹ for the soil. (4 marks)

The End

