GEL 4250 - Hydrogeology (Groundwater)

LAB 2: POROSITY & HYDRAULIC CONDUCTIVITY

- Porosity Segment -

Name:____ Section: ______________

Grade:
/25

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For full credit, be precise in your answer, show ALL your work and TYPE the results!

Bulk Porosity of Sample	How computed:

Always indicate where you got your numbers! Do NOT forget units!

Particle Density (Pycnometer Method): T = _____°C

Fill in the blanks

$$SG(\tfrac{g}{cm^3}) = \frac{W_m\_\_\_\_g}{(W_{bw}\_\_\_\_g + W_m\_\_\_\_g - W\_\_\_\_g)} \times SG_{Liquid}\_\_\_\_\tfrac{g}{cm^3} = \_\_\_\_\_\frac{g}{cm^3}$$

What is your precision in %?

Derive answer from three independent measurements! How computed?

Always indicate where you got your numbers! Do NOT forget units!

Bulk Density of Material / Soil	How computed:

Always indicate where you got your numbers! Do NOT forget units!

Measured Effective Porosity of Sample	How computed:
Calculated Effective Porosity* of Sample:	Marotz and Henning:

* You may need to do PERMEABILITY LAB before you can estimate Effective Porosity using MAROTZ and HENNING

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Instructions:
During this LAB you will establish at least 3 hydraulically important parameters. You will need the following materials for all of the LAB exercises:

- ☐ Balance
- ☐ A bag of collected soil (It is best to use a lose sand or sand soil WITH LITTLE OR NO ORGANICS.)
- ☐ Rulers (metric of course)
- ☐ Calculators
- ☐ Pycnometers
- ☐ Several Graduated cylinders (the high narrow kind is preferred)

Read Fetter (2001) section 3.2 (p.69 - 78)

Porosity

Groundwater occurs in the void spaces of earth materials: soils, unconsolidated sediments, and rock. Even rock that was formed as a solid mass will fracture as it is brought towards the surface. These fractures provide space for the storage and movement of groundwater.

Porosity is defined as the percentage of a volume of rock (the all purpose term hydrologists use for 'earth materials') that is empty space. This porosity or total porosity (n) is expressed as:

$$n = \frac{100V_{voids}}{V_{total}}$$ Where n is total porosity in percent; V is equal to Volume

Effective porosity: void spaces that are too small to admit water molecules are of little interest to hydrologists. The amount of voidspace available for fluid flow is the effective porosity. Even large voidspaces that are interconnected by small pore throats are unavailable for fluid flow.

During LAB exercise - Part 1 we will measure and calculate **Bulk porosity**, which can be computed from measurements of density:

$$n = 100\left[1 - \left(\rho_{bulk} / \rho_{pd}\right)\right]$$ where ρ_{bulk} is the density of the bulk material (soil + porespace) ρ_{pd} is the density of the particles that make up the soil.

(For most rock and soil, the particle density is about 2.7 g/cm^3, roughly the density of quartz and clay minerals.)

I. MEASURING / CALCULATING BULK POROSITY (EXACT):

Step 1 - Establishing ρ_{pd} (Density of Soil Particles):

PYCNOMETER METHOD - A pycnometer for particle density testing consists of a glass vessel of known weight and volume. A special glass stopper assures that the volume in the bottle is constant when refilled and filled again. Excess liquid will just drain off. While other liquids may be used, distilled water is preferred since readily available. Be sure to measure the temperature of the water used to compute the temperature volume correction factor. Weigh the dry material (soil) sample (W_m) and then weigh the water filled pycnometer bottle (W_{bw}). Make sure there are no air bubbles inside. Place the material sample in the bottle, excess water will spill, and replace the stopper. Again, avoid air bubbles. Wipe the outside of the vessel dry and weigh the pycnometer vessel with the mineral specimen and water (W). Now you can calculate the weight of the water displaced by specimen (W_d) with the equation:

The weight of the displaced water is directly related to the volume of the mineral specimen. Since 1g of distilled water is exactly equal to 1ml or 1cm^3 of volume at 4°C. This volume changes slightly at elevated temperatures and can be corrected by dividing your results by a correction factor (SG_{Liquid}) given in table below:

Water temperature volume correction factors for **distilled water**

H_2O Temp °C	Correction factor	H_2O Temp °C	Correction factor	H_2O Temp °C	Correction factor
15	0.999099	19	0.998405	23	0.997538
16	0.998943	20	0.998203	24	0.997296
17	0.998774	21	0.997992	25	0.997044
18	0.998595	22	0.997770	26	0.996783

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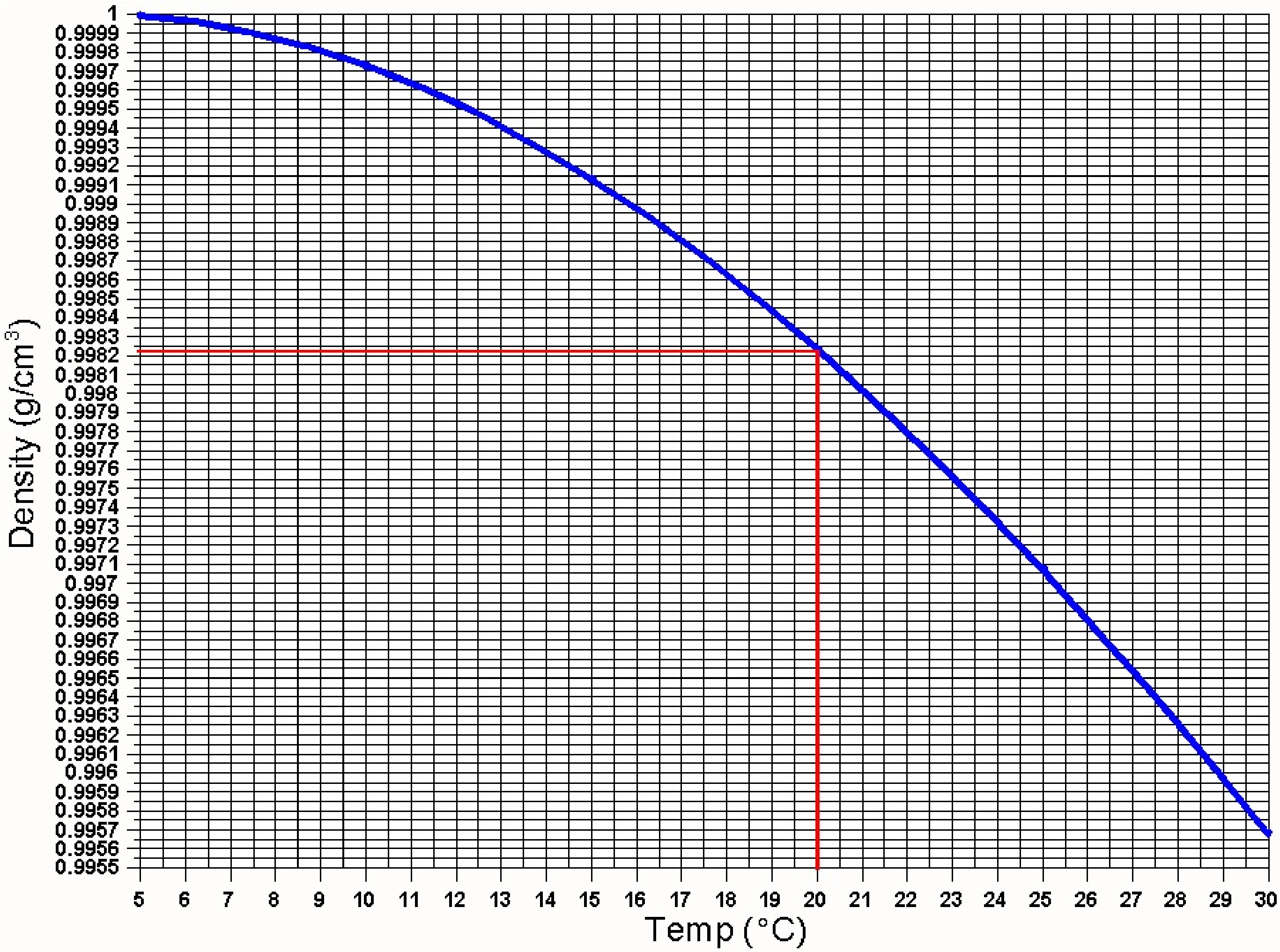

<u>DI Water</u> Density Correction Graph. *Example: For a water temperature of 20°C the volume correction factor would be 0.99825.*

Remember, the specific gravity (S.G.) is defined as Mass per unit Volume or: $\rho = \frac{m(grams)}{V(cm^3)}$

<u>Procedure:</u>

$$SG(\tfrac{g}{cm^3}) = \frac{W_m(g)}{(W_{bw}(g) + W_m(g) - W(g))} \times SG_{Liquid}$$

1. Use the procedural description from above. If your lab is not equipped with standard pycnometers, you can use a make-shift pycnometer consisting of an Erlenmeyer flask with rubber stopper with hole.
2. Use a good helping of unconsolidated soil sample material. Greater amount increases accuracy.
3. Be careful to remove all air bubbles from flask and specimen before replacing the stopper. Gentle tapping might be helpful.
4. When using the make-shift pycnometer, be sure to place rubber stopper carefully down to the <u>same depth</u> into the flask every time you replace it. DO THIS SLOWLY! Excess water should spill out the hole!
5. After obtaining the weight for the displaced water, do not forget to adjust the displaced volume according to the tables provided, either or tap water or distilled water.
6. Show ALL your calculations!

<u>Measurements:</u>

Material	Measurements & Calculations t = ______°C	ρ_{pd}
	$SG(\frac{g}{cm^3}) = \frac{W_m \_\_\_\_ g}{(W_{bw}\_\_\_\_ g + W_m \_\_\_\_ g - W \_\_\_\_ g)} \times SG_{Liquid} \_\_\_\_ \frac{g}{cm^3} = \_\_\_\_\_ \frac{g}{cm^3}$	$\rho = \frac{m(grams)}{V(cm^3)}$

Answer in graded section above. This answer box is for your own records and is NOT graded.

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Water Volume Correction Factor for average **tap water** (TDS 100mg/l)

Temperature °C	Temperature °F	Divide sample density by
15.0	59.0	÷ 0.9992
16.0	60.8	÷ 0.9990
17.0	62.6	÷ 0.9989
18.0	64.4	÷ 0.9987
19.0	66.2	÷ 0.9985
20.0	68.0	÷ 0.9983
21.0	69.8	÷ 0.9981
22.0	71.6	÷ 0.9979
23.0	73.4	÷ 0.9976
24.0	75.2	÷ 0.9974
25.0	77.0	÷ 0.9972
26.0	78.8	÷ 0.9969
27.0	80.6	÷ 0.9966
28.0	82.4	÷ 0.9963

Step 2 - Establishing ρ_{bulk} (Bulk Density of the Soil):

1. Take a 25 ml or 50 ml graduated cylinder.
2. Weigh the cylinder (unit: grams). Record answer.
3. Fill cylinder with your soil to a certain volume mark (example 25 mL) weigh again. Record answer.
4. Calculated as indicated below:

Material	Measurements & Calculations	ρ_{bulk}
	Mass Graduated Cylinder Empty W_{cyl} = _______ g Sample filled to Volume V = __________ mL Mass Graduated Cylinder with Sample W_{cs} = _______ g m = W_{cs} ___________ - W_{cyl} _____________= _______ g	$\rho = \frac{m(grams)}{V(cm^3)}$

Answer in graded section above. This answer box is for your own records and is NOT graded.

II. CALCULATING BULK POROSITY:

Step 1 - Establishing BULK POROSITY:

1. Use your measurement of bulk density from above: ρ_{bulk} = __________ ***(g/cm^3)***
2. Use your measurement of particle density from above: ρ_{pd} = __________ ***(g/cm^3)***
3. Just plug your answers for Bulk Density and Particle Density into the Bulk Porosity Equation:

Material	Measurements & Calculations	**Bulk Porosity (%)**
	$n_{bulk} = 100\left[1-\left(\frac{\rho_{bulk}}{\rho_{pd}}\right)\right]$	

Answer in graded section above. This answer box is for your own records and is NOT graded.

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III. MEASURING / CALCULATING EFFECTIVE POROSITY n_e FROM PERMEAMETER DATA:

(NOTE: You must collect data from the PERMEABILITY LAB in order to complete the final segment below!)

Method 1 - Establishing EFFECTIVE POROSITY n_e from Permeameter Data:

1. Use a Permeameter to establish Hydraulic Conductivity (k_f).
2. Use the following MAROTZ & HENNING equations to calculate PERCENT EFFECTIVE POROSITY. (Note: For the MAROTZ equation to work, k_f must be in the unit m/s!!!)

$$n_e(\%) = 46.2 + 4.5\ln k_f(\tfrac{m}{s}) \quad n_e(\%) = (0.05 \times \log k_f(\tfrac{m}{s}) + 0.4) \times 100$$

Answer:

Answer in graded section above. This answer box is for your own records and is NOT graded.

***Note:** You will save clean-up and time by measuring effective porosity first (see below) and then continued with the hydraulic conductivity test (see next Lab) using the same sample.*

Method 2 - Estimating EFFECTIVE POROSITY n_e from Gravitational Water Data:

1. Measure exactly 100 g of soil sample: $m_{soil} = 100.00g$
2. Establish the Volume of 100.00g of soil using graduate cylinder. V_{soil} = __________ cm^3
3. Place screen and filter paper cut out on the bottom of permeameter tube. Fill the lower part of the tube with your 100.00g of soil. Make sure this is the same soil used in the hydraulic conductivity experiments.
4. Water saturate your soil sample by filling the tube with a small amount of water and letting enough water run through the soil that ALL air is replaced by water. You can accelerate the process by blowing into the permeameter tube to increase pressure on the water. You should see the wetting front move through the sample. Water should drip out of the permeameter exit hose.
5. Adjust water level after saturation to the exact height of the sample. The water line should coincide with the top of your sample.
6. As close as possible to the permeameter tube, clamp exit hose shut. Extract ALL remaining water out of the unclamped area of the exit hose.
7. Weigh a dry, empty beaker and record its mass in grams. Place beaker under exit hose and open clamp.
8. Collect all the water that will drain out of the saturated sample by gravity alone. This is your gravitational water which is analogous to effective porosity. *Note: It can take a very long time if you use a fine grained soil.* You can accelerate the process by applying air pressure to the top of the permeameter tube (Blow in it! Hard!)
9. When completely drained (no more drips even with increased air pressure) empty all the water still in the exit hose into the beaker by squeezing and tapping the hose.
10. Weigh the beaker. Calculate the amount of water drained be subtracting the empty weight of the beaker. Record weight of gravitational water. H_2O_{grav} = _______________ g = ___________________ cm^3
11. Calculate the estimated effective porosity:

$$\sim n_e = \frac{H_2O_{grav}(cm^3)}{V_{soil}(cm^3)} \times 100 = \_\_\_\_\_\_\_\_\_\_\%$$

Answer in graded section above. This answer box is for your own records and is NOT graded.

12a. To save time, do NOT clean up permeameter tube, but use same sample to continue with the permeability lab.

12b. When done, CLEAN up. Dump wet sample into waste basket. **MAKE SURE YOU RECOVER THE METAL SCREEN THAT GOES WITH THE TUBE PERMEAMETER!** Rinse all mud and sand out of the permeameter tube. If lots of particulates, put in waste basket. Otherwise dump into sink. CLEAN SINK!!! For final cleaning, rinse with DI water and let dry! Wipe work are clean!

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STUDY QUESTIONS:
Which soil will have the highest bulk porosity, which one the lowest? Why?
In which soil would you predict water to flow the fastest?
Which soil could store more water?

Additional helpful information concerning porosity:
Factors affecting porosity

Grain size: In and of itself, grain size has no effect on porosity. Well rounded sediments that are packed into the same arrangement generally have porosities from 26% to 48% depending on the packing. A room full of bowling balls and a room full of BBs would have the same porosities if the spheres were packed the same way.

Sorting: Well sorted sediments generally have higher porosities than poorly sorted sediments for the simple reason that if a sediment is a range of particle sizes then the smaller particles may fill in the voids between the larger particles.
Sorting is measured as a ratio of the larger to smaller particle sizes in the sediment. This measure is called a uniformity coefficient.

Grain shape: Irregularly shaped particles tend not to pack as neatly as rounded particles, resulting in higher proportions of voidspace.

Clay and organic content: Organic particles tend to be irregularly shaped and can increase voidspace. Clay particles tend to electrostatically repell one-another along the surface of the particles. This results in a relatively large proportion of voidspace.

Primary vs secondary porosity

Primary porosity is the porosity that exists between individual grains in the rock.

Secondary porosity is the porosity that results from fracturing, dissolution, and separation of the rock after its formation.

In our case bulk porosity approximates effective porosity, since we are working with unconsolidated sediments. In “real” life, this is not always the case. Effective porosity can be determined from hydraulic flow parameters.

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GEL 4250 - Hydrogeology (Groundwater)

LAB 2: POROSITY & HYDRAULIC CONDUCTIVITY

- Hydraulic Conductivity Segment -

Name:____ Section: _______________

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For full credit, be precise in your answer, show ALL your work and TYPE the results!

Hydraulic Conductivity of my Sample:	How computed:

Always indicate where you got your numbers! Do NOT forget units!

Simplified Hydraulic Conductivity **Equation** :	How derived:

Always indicate where you got your numbers! Do NOT forget units!

Effective Porosity of my Sample (Use Data from Porosity Lsb):	How computed:

Always indicate where you got your numbers! Do NOT forget units!

Class Results LAB 2 (Don't forget units)

Group Sample	Hydraulic Conductivity	Bulk Porosity	Effective Porosity

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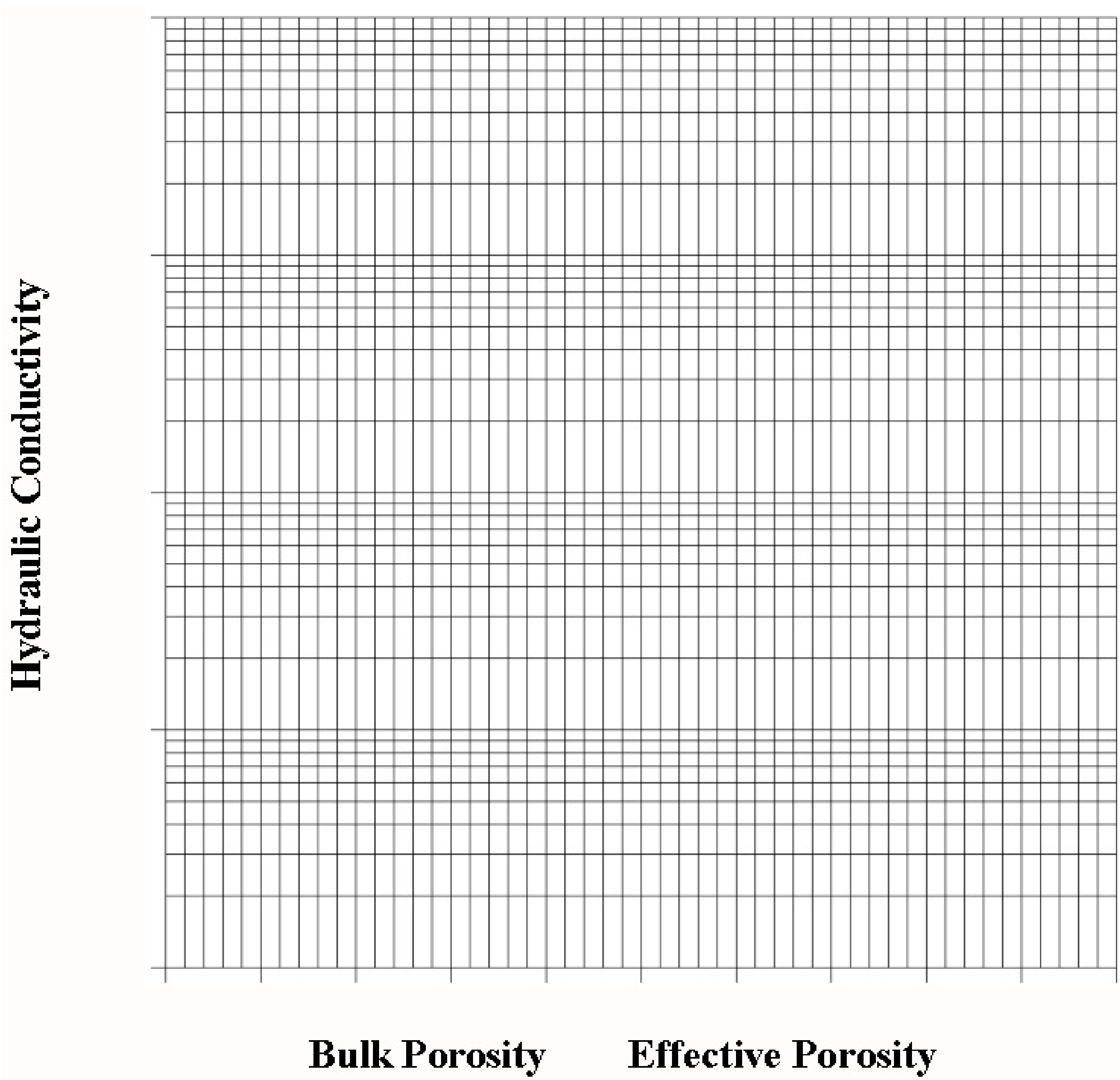
GEL 3150 - Groundwater (Hydrogeology)

LAB 2 - HYDRAULIC CONDUCTIVITY (PERMEABILITY)

Name:____ Section: ________________

Complete the graph below in preferably EXCEL and attach. Answer the questions in section II below.



1. How are the values related to each other?
2. Write a algebraic equation showing the effect of porosity on hydraulic conductivity, if applicable!

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Name:____ Section: _______________

1. How are the values related to each other?

2. Write a algebraic equation showing the effect of porosity on hydraulic conductivity, if applicable!

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Instructions:
During this LAB you will establish hydraulically important parameters. You will need the following materials for all of the LAB exercises:

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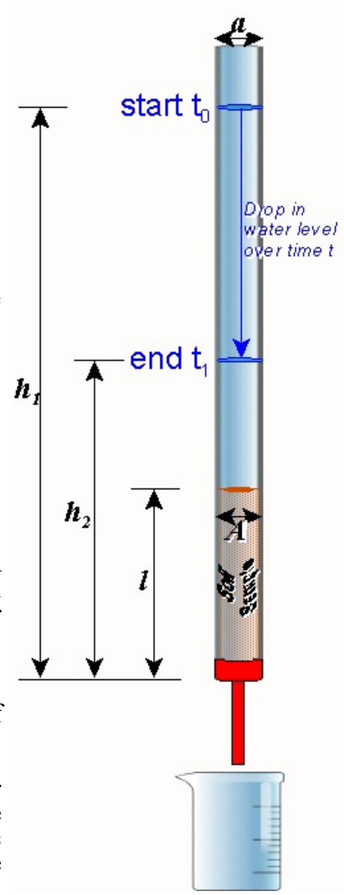
1. Triple Beam Balances or analytical scale
2. Soil Sample (It is best to use a lose sand or sand soil.)
3. Stop Watches
4. Ruler / Meter stick (metric of course)
5. Calculators
6. Pycnometers
7. A 100 ml beakers
8. Aquarium Filter Wool or Filter Paper
9. Markers that will mark on plastic
10. Falling Head Permeameter Tube & set-up

Read Fetter (2001) section 3.4 & 3.5 (p. 81-93)



MEASURING / CALCULATING HYDRAULIC CONDUCTIVITY (k_f):

Permeability which is analogous to **hydraulic conductivity** in hydrogeology is based on the concept of Darcy's law (the e=mc^2 of hydrology), which states:

$$Q = k_f \times A \times \frac{h}{l}$$

Where

Q is the amount of water passing through a medium per unit time (m^3/s)
k_f is the medium-specific Coefficient (m/s). This is the one we need for permeability.
A is the surface area of the medium perpendicular to the flow (m^2)
h/l is the hydraulic gradient... or the change in elevation per unit length of flow.

Darcy's law equation can be solve for k_f, the unit indicating permeability. There are two standard LAB experiments for establishing k_f. Basically a certain volume of water is "forced" through a soil or rock sample of known volume (diameter, height) and the length of time needed for the particular flow is clocked.

The standard experiment uses a constant gradient, or a constant head (height) of the water level. This experiment is a little bit more elaborate to set up. It is commonly used for sediments of higher permeabilities such as gravels and sands.

During this lab exercise we will use a simplified version commonly used for samples of lower permeabilities such as fine sands, clays and mudstones. The experiment uses a change in the hydraulic gradient (falling head) and the time it takes for this change to occur. From this hydraulic conductivity and hence permeability can be derived. The experimental set-up is a Tube Type Falling Head Permeameter as pictured.

***Note:** You will save clean-up and time by measuring effective porosity first (Previous Lab) and then continued with the hydraulic conductivity test using the same sample.*

Procedure for establishing hydraulic conductivity using the permeameter tube:

1. Calculate the cross-sectional area of the permeameter tube (*a*) in m^2.
2. Either use sample already in prepared tube from porosity experiment and continue with step 5., or...
3. Place screen and filter paper cut out on the bottom of permeameter tube.
4. Fill the lower part of the tube with 100.00g of soil. Make sure soil is the same as used in porosity determinations.
5. Water saturate your soil sample by filling the tube with water and letting enough water run through the soil. You should see the wetting front move through the sample. Water should drip out of the exit hose for a while.
6. Measure sample height (l) in meters and record. Also, calculate the cross-sectional area of the sample (A) in m^2.
7. As close as possible to the permeameter tube, clamp exit hose shut. Extract ALL remaining water out of the unclamped area of the exit hose.
8. Refill water to an arbitrary height of h_1 in the permeameter tube. Mark this height, measure in meters from bottom of sample and record.
9. Start timer as soon as you unclamp the exit hose (t_0). Let experiment run until water level has dropped a few centimeters in the permeameter tube to level h_2. For very fine grained samples this can take hours. Stop timer as soon as you reclamp the exit hose and record time t_1 in seconds. Measure and record h_2 from the bottom of the sample.
10. In order to calculate hydraulic conductivity (k_f) from a falling head permeameter data, the following equation was devised for calculating hydraulic conductivity in meters per second using measurements with changing gradients:

$$k_f = \frac{a \times l}{t \times A} \times \ln \frac{h_1}{h_2}$$

Where

t is the time it took to change from h_1 to h_2 in seconds
l is the length (height) of the sample in meters
h_1 is the height of water in m at beginning of experiment measured from bottom of sample
h_2 is the height of water in m at end of experiment measured from bottom of sample
A and a are both the cross-sectional areas [$(d/2)^2 \times \pi$]

Small a designates the cross-sectional area of the water above the sample in a smaller vessel or long, narrow burette used in

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professional laboratory equipment, resulting in different cross-sectional areas for sample and water column. Since we have the same diameter for the sample and the water above, our original falling head permeameter equation can be simplified. Derive a simplified version of the k_f equation above if A is equal to a. Use YOUR derived simplified equation for your hydraulic conductivity calculations!

My Simplified Hydraulic Conductivity Equation for a Tube Type Permeameter: *Answer in graded section above. This answer box is for your own records and is NOT graded.*

My Calculated Hydraulic Conductivity: *Answer in graded section above. This answer box is for your own records and is NOT graded.*

11. When done, CLEAN up. Dump wet sample into waste basket. **MAKE SURE YOU RECOVER THE METAL SCREEN THAT GOES WITH THE TUBE PERMEAMETER!** Rinse all mud and sand out of the permeameter tube. If lots of particulates, put in waste basket. Otherwise dump into sink. CLEAN SINK!!! For final cleaning, rinse with DI water and let dry! Wipe work are clean!

If the experiment was successful, you should roughly obtain the following (very small numbers...)

pea gravel	10^{-1} to 10^{-2} m/s	*18.3 to 1.8 ft/min*
coarse sand	approx. 10^{-3} m/s	*2.19 in/min*
medium sand	10^{-3} to 10^{-4} m/s	*2.19 to 0.22 in/min*
fine sand	10^{-4} to 10^{-5} m/s	*13.14 to 1.31 in/hr*
loamy sand	10^{-5} to 10^{-7} m/s	*1.31 to 0.013 in/hr*
sandy clay	10^{-6} to 10^{-9} m/s	*3.14 to 0.003 in/day*
clay	$< 10^{-9}$ m/s	*< 1 in/yr*

The value of hydraulic conductivity or k_f in meters/second relates to **permeability** of rock and soil.

Background Info For Permeability

Permeability is a measure of the ability of rock or soil to transmit fluid. In short, porosity is not enough. All the pores must also be connected to transmit fluid. The quality of those connections AND the pore space is **permeability**. For your information, when discussing permeability, the following mathematical relationship might be helpful:

$k \approx C * d^2$ Where k = intrinsic permeability. C and d are interesting, for they describe the soil attributes of permeability. C is a dimensionless constant depending on porosity, particle size, shape of grains, etc. d = mean grain diameter.

Permeability is usually measured in Darcys (Where have I heard this name before?). One Darcy exists when in a certain amount of time a certain amount of fluid (with a certain viscosity) under a certain pressure is squeezed through a certain areal cross section. The unit of measure of a Darcy is area, cm^2.
Hint: The USGS uses **intrinsic permeability** in micrometers squared (μm^2). Intrinsic permeability is a little different from a Darcy: 1 Darcy = $9.87 * 10^{-9}$ μm^2 Intrinsic Permeability.

II. HYDRAULIC CONDUCTIVITY (k_f) IN RELATION TO POROSITY:

You will need:

- ☐ Graph Paper
- ☐ Colored pencils
- ☐ Data from other groups

Please use EXCEL for the following:

1. Copy porosity (LAB 1), k_f (LAB2) and n_e (LAB2) data from the other groups.
2. Create a scatter plot to plot porosity versus hydraulic conductivity.
3. Interpret the graph!
   a. Are the values dependent on each other? Hint: If you see a pattern, such your data points falling on a straight line or curved path: YES. If your data points are randomly all over: NO.
   b. Can you predict the one value, if you know the other? If the data is related, try a straight line model. Remember y = mx + b.

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