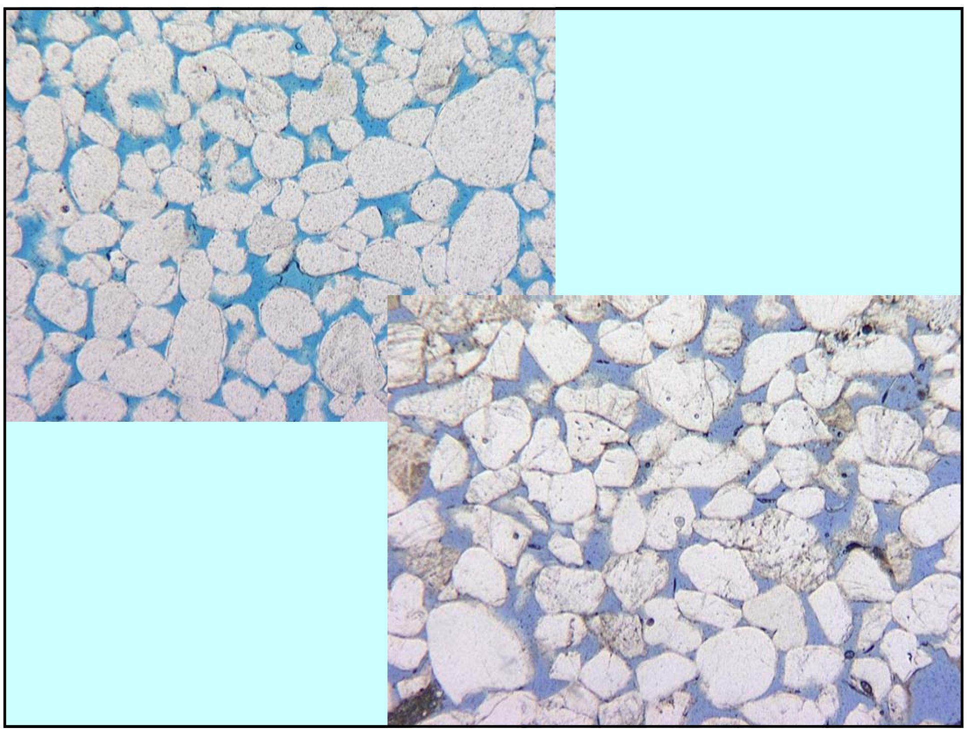
PORE SPACES -
WHERE GW IS STORED AND MOVES THROUGH MATERIALS

POROSITY (TOTAL) - % OF MATERIAL THAT IS VOIDS

Porosity = $\Phi = V_V / V_T$

V_V - VOL OF VOIDS
V_T - TOTAL VOLUME



SOIL ENGINEERS USE VOID RATIO, e

$$e = \frac{V_v}{V_S}$$

V_V - VOL OF VOIDS
V_S - VOL OF SOLIDS

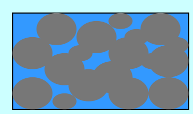
Relationship of void ratio and porosity

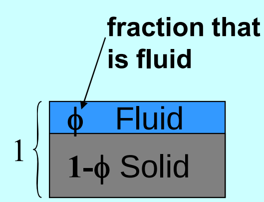
$$\phi = \frac{e}{1+e} \qquad e = \frac{\phi}{1-\phi}$$

METHODS OF MEASURING POROSITY (ϕ, n)

DEDUCE from

PD - PARTICLE DENSITY : M/L^3
FD - FLUID DENSITY: M/L^3
BD - BULK DENSITY : M/L^3
BD = (1- ϕ) PD + ϕ (FD)





OR (for fresh water in grams and cc's)

SW - SATURATED WEIGHT
V_T - TOTAL VOL
DW - DRY WEIGHT

$$\phi = \frac{SW - DW}{V_T}$$

DW - DRY WEIGHT
V_T - TOTAL VOLUME
PD - PARTICLE DENSITY

$$\frac{DW}{V_T} = PD(1-\phi)$$

$$\phi = 1 - \frac{DW}{PD * V_T}$$

Given:

Wet Bulk Density = 2.24 g/cm^3

Particle Density = 2.65 g/cm^3

Fluid Density (FD) = 1.0 g/cm^3

What is:

Porosity = ?

BD = (1- ϕ) PD + ϕ (FD)

$$\phi = \frac{SW - DW}{V_T}$$

$$\frac{DW}{V_T} = PD(1-\phi)$$

$$\phi = 1 - \frac{DW}{PD * V_T}$$

Knowing:

Wet Bulk Density = 2.24 g/cm^3

Particle Density = 2.65 g/cm^3

Fluid Density (FD) = 1.0 g/cm^3

Porosity = 0.25

And If:

Total Volume = 25cm^3

What is:

Saturated Weight = ?

Dry Weight = ?

BD = (1- ϕ) PD + ϕ (FD)

$$\phi = \frac{SW - DW}{V_T}$$

$$\frac{DW}{V_T} = PD(1-\phi)$$

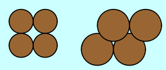
$$\phi = 1 - \frac{DW}{PD * V_T}$$

PRIMARY POROSITY

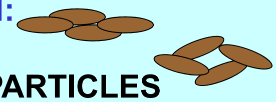
- FORMED CONTEMPORANEOUSLY WITH ROCK

SECONDARY POROSITY

- FORMED AFTER ROCK IS FORMED



POROSITY DEPENDS ON:



SHAPE AND ARRANGEMENT OF PARTICLES

DEGREE OF SORTING (MIX OF PARTICLE SIZES)

CEMENTATION OR COMPACTION

REMOVAL OF MATERIAL BY SOLUTION

FRACTURING AND JOINTING

SHAPE AND ARRANGEMENT OF PARTICLES

magnitude of ϕ depends on packing as well as shape

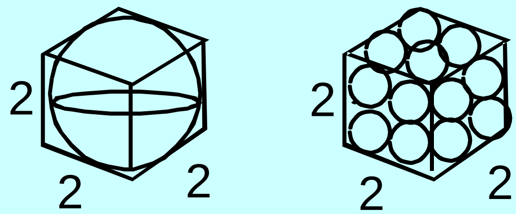
packing - the spacing and mutual arrangement of particles within the mass

- will influence not only porosity but also density, bearing capacity, strength, amount of settling, permeability

- difficult to study with real particles because shapes are so varied, so consider spheres

Assume that you have two boxes that each have a volume of 8 cubic meters.
Each box is filled with spheres in a cubic packing arrangement.
Box number one is filled with spheres having a radius of 1 meter
while the spheres in box number two have a radius of 0.5 meters.

Which box do you suppose has the highest pore volume?



This is a bad drawing but I hope you get the idea

Calculate the porosity: the volume of a sphere is $V=4/3\pi r^3$

POROSITY CAN BE DECREASED FURTHER BY FILLING VOIDS WITH SMALLER PARTICLES

SORTING (poor = lots of sizes, well = few sizes)
GRADING (poor = few sizes, well = lots of sizes)
i.e. well graded has a gradation of sizes

I.E. POORLY SORTED OR WELL GRADED YIELDS LOW ϕ
WELL SORTED OR POORLY GRADED YIELDS HIGH ϕ

CEMENTATION OR COMPACTION

DECREASES ϕ

REMOVAL OF MATERIAL BY SOLUTION

INCREASES ϕ

FRACTURING AND JOINTING

Generally INCREASES ϕ

EFFECTIVE POROSITY Contributes to Fluid Flow
% OF MEDIUM THAT IS INTERCONNECTED PORE SPACE

$$\phi_e = \frac{V_{IV}}{V_T}$$

V_{IV} - VOL OF INTERCONNECTED VOIDS

MEASUREMENT OF EFFECTIVE POROSITY:

GRAVITY DRAINAGE @ 100% RELATIVE HUMID

TRACER TEST - MONITOR RATE OF MOVEMENT OF A TAG ON THE WATER

Darcy velocity is a DISCHARGE per unit AREA

$$V_{Darcy} = \frac{Q}{A}$$

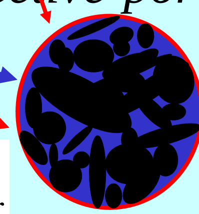
Average Linear Velocity

velocity through the pores

this governs rate of pollutant movement

$$V_{AverageLinear} = \frac{Q}{A\phi_e} = \frac{V_D}{\phi_e} = \frac{V_D}{effective\ porosity}$$

Entire face of the porous medium



Just pore space

OTHER NAMES
Seepage Velocity
Interstitial Velocity

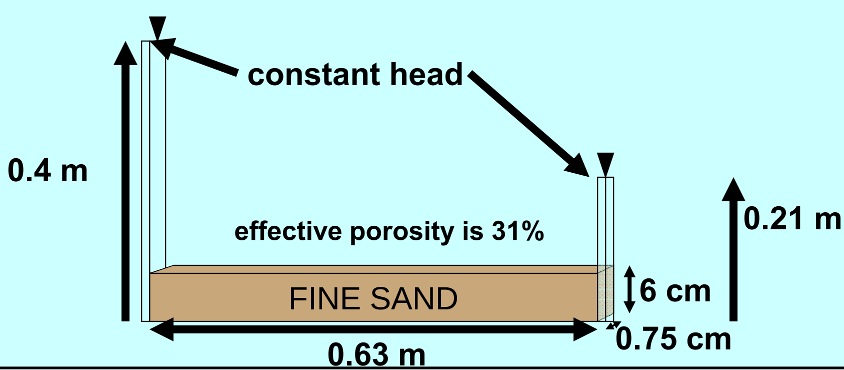
Often repesented as $\bar{v}$, pronounced, v bar

Recall Darcy discharge calculation from the first class?

$$Q = K \frac{\text{Head Difference}}{\text{Distance between Heads}} \text{Area}$$

$$Q = 0.01 \frac{cm}{sec} \frac{0.19\ m}{0.63\ m} 6cm\ 0.75cm \frac{1\ liter}{1000cm^3} \frac{86400sec}{day} = 1.17 \frac{liter}{day} = \frac{1\ liter}{day}$$

What is the travel time for a drop of water from left to right if effective porosity is 31%?



WE CAN'T RECOVER ALL THE WATER FROM THE PORES,
SO CONSIDER HOW MUCH WATER THEY WILL YIELD

SPECIFIC YIELD - % OF TOTAL VOLUME THAT CAN BE DRAINED BY GRAVITY

SPECIFIC RETENTION - % OF TOTAL VOLUME HELD AGAINST GRAVITY

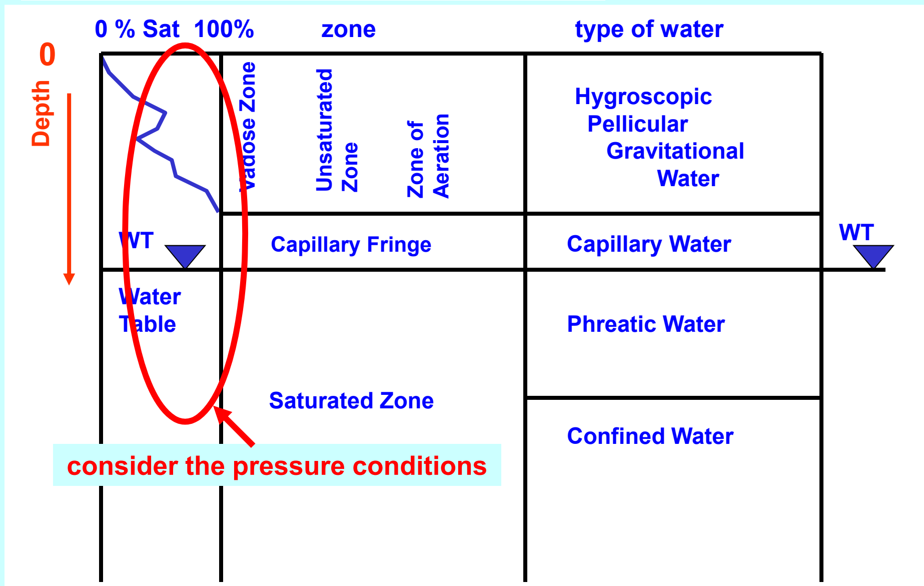
SRdemo

BY DEFINITION - ϕ = SY + SR

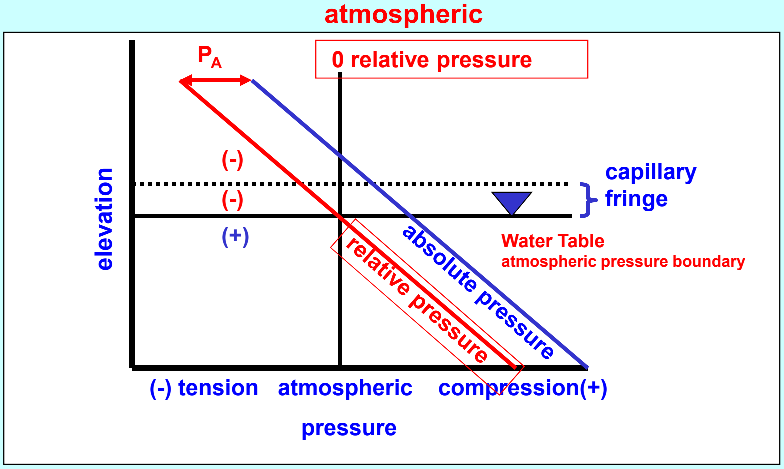
Consider the character of Occurrence of Water in various Zones

Zones of Different Water Occurrence

Degree of Saturation = $\frac{\text{volume water filled pores}}{\text{volume of all pores}}$



ABOVE Water Table PRESSURES ARE < ATMOSPHERIC (-)
BELOW Water Table PRESSURES ARE > ATMOSPHERIC (+)
WATER TABLE is the surface at which the pore water pressure is atmospheric



In a hydrostatic (still) system pressure increases with depth below the water table due to the weight of the overlying water

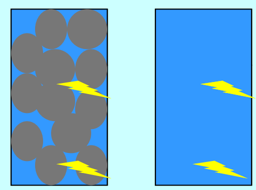
Pascal's Law: $\Delta P = \rho g \Delta h = \gamma \Delta h$

Pascal's Law:

$$\Delta P = \rho g \Delta h = \gamma \Delta h$$

ΔP difference in hydrostatic pressure (pascals) at two points in a fluid column
ρ fluid density (kg m^{-3})
g acceleration due to Earth's gravity at sea level (ms^{-2})
Δh height of fluid above a datum (m), or difference in elevation of two points in a fluid column
γ specific weight (ρg)

Fluid does not support shear stress so pressure is transmitted equally throughout the fluid.



ABSOLUTE PRESSURE
LOCAL ATMOSPHERIC P + GAGE P

GAGE PRESSURE
P RELATIVE TO PREVAILING ATMOSPHERIC P

ATMOSPHERIC PRESSURE
DEFINED AS ZERO for many Hydrology calculations

Standard Atmospheric Pressure =
1.013×10^5 Pascals or 14.7 lb/in^2

1 pascal (Pa) ≡ 1 $N \cdot m^{-2}$ ≡ 1 $J \cdot m^{-3}$ ≡ 1 $kg \cdot m^{-1} \cdot s^{-2}$

Pressure Units

http://en.wikipedia.org/wiki/Pascal

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (mmHg)	Pound per square inch (psi)
1 Pa	≡ 1 $N \cdot m^{-2}$	10^{-5}	10.197×10^{-6}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100 000	≡ 10^6 $dyn \cdot cm^{-2}$	1.0197	0.98692	750.06	14.504
1 at	98 066.5	0.980665	≡ 1 $kgf \cdot cm^{-2}$	0.96784	735.56	14.223
1 atm	101 325	1.01325	1.0332	≡ 101 325 Pa	760	14.696
1 Torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	≡ 1 mmHg	19.337×10^{-3}
1 psi	6,894.76	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	≡ 1 $lbf \cdot in^{-2}$

Calculate the pressure on your head if you stood
At the bottom of a well with its:

surface at sea level
bottom at 600 ft
water level 50 ft below the surface

sketch a diagram
determine appropriate equation
label distances
gather constants / properties
calculate

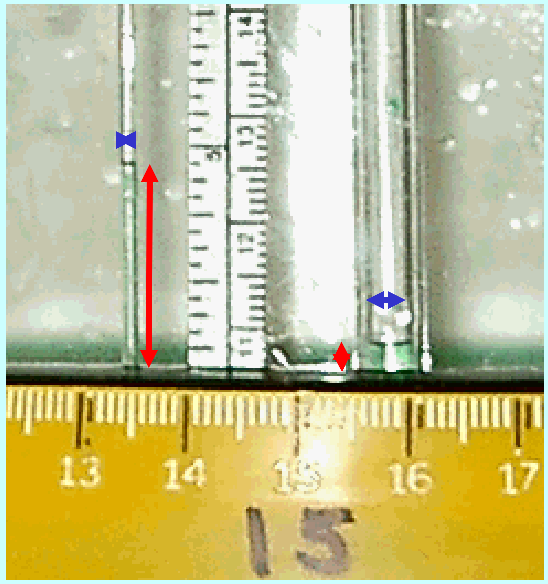
CAPILLARITY (suction or negative pressure)
due to inter-molecular attraction at the liquid boundary

Adhesion - the attractive (wetting), or repulsive (non-wetting), force between the molecules of the liquid and solid
Cohesion - the attractive force between molecules of the liquid

upward force of the attraction of the liquid to the solid
would cause the liquid to continue rising
except that it is balanced by
downward force of gravity on the liquid

In a tube the HEIGHT of RISE is controlled by the SIZE of TUBE
because as radius increases
downward force of gravity increases more rapidly than
upward force of attraction of liquid to solid
(note the area grows as r^2 while the circumference grows as r)

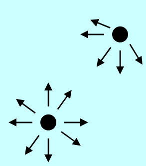
Capillary Rise



In a droplet
molecules within the liquid are attracted equally from all sides
molecules near the surface are attracted toward the center of the liquid mass by this net force

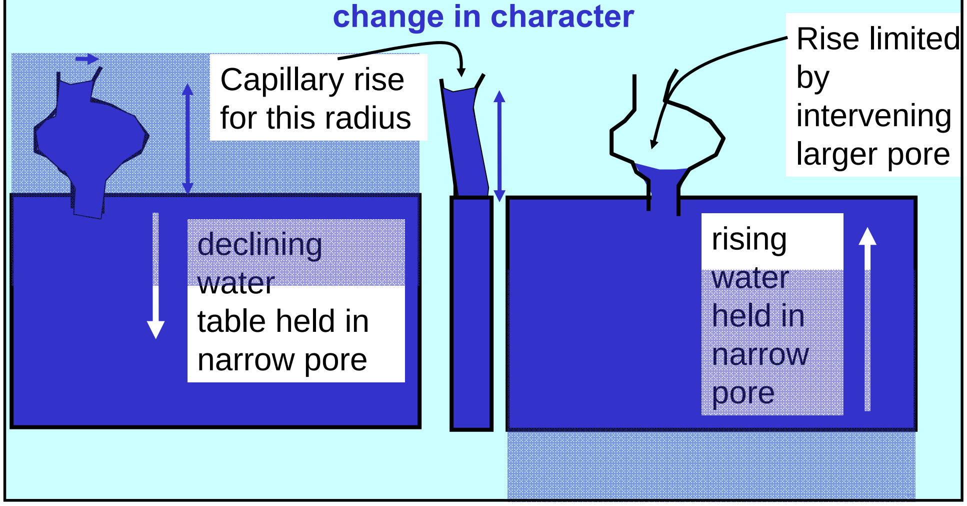
thus the surface acts like a membrane

so a drop of liquid forms a sphere
and liquid in a tube forms a meniscus



the capillary fringe will show hysteresis effects

Hysteresis (dependent on history)
describes a phenomenon which is dependent on previous history
as the water table moves up and down the capillary fringe will change in character



For a cylinder capillary pressure can be calculated as:

$P_c = \frac{2 \text{ (surface tension)} \cos\lambda}{\text{radius}}$ λ contact angle

Pressure = specific-weight*height

so height of capillary rise is h_c

$$P_c = \frac{2\sigma\cos\lambda}{r} \quad and \quad P = \gamma h \quad \text{so} \quad h_c = \frac{2\sigma\cos\lambda}{\gamma r}$$

Surface Tension - force (perpendicular to the surface) along a line of unit length, or work done per unit area

The numerical value of surface tension depends on the nature of the fluid and solid

Let's take a minute to think about units

Beware! of your units .... that is BE AWARE of your units

Force = mass * acceleration

F = ma ...... W = Weight = mg

g is gravitational acceleration

weight has same units as force (not mass)

SI

Basic units:	L	M	T	length	mass	time
	m	kg	s	meter	kilogram	second

Derived unit F - force, N Newton

English

Basic units	L	F	T	length	force	time
	ft	lb	s	foot	pound	second

Derived unit M - mass, S slug

In SI (meter-kilogram-second) definition:

1 Newton (N) of force will accelerate

1 kilogram mass (kgm) 1 meter per second squared

$$F = ma$$

$$1 \text{ Newton} \quad 1 \text{ kgm} \frac{1 \text{ m}}{\text{sec}^2}$$

In English Units (foot-slug-second)

1 pound force (lbf) accelerates

1 slug mass 1 ft per second square

$$F = ma$$

$$1 \text{ lbf} \quad 1 \text{ slug} \frac{1 \text{ ft}}{\text{sec}^2}$$

it can be confusing

often mass is given in pounds mass (lbm)

given that one slug equals 32.2 lbm

Weight in US: a cubic foot of water weighs 62.4 lbs
In Europe we say a cubic foot of water weighs 28.3 kg
We mean it has a mass of 28.3kg in earth's gravity : It weighs 273N

Density is MASS per VOLUME : kg/m^3 slugs/ft^3
Specific Weight is WEIGHT per VOLUME : N/m^3 lb/ft^3

We tend to use Density when working in SI and What looks like Specific Weight in English Units

Density of water is 1.94 slugs/ft^3

Recall 1 pound force (lbf) accelerates 1 slug mass 1 ft per second squared

$$1lbf = 1slug \frac{ft}{\sec^2} \quad \text{so there is} \quad 1 \text{ slug per } 1 \left(\text{lbf} \frac{\sec^2}{ft} \right)$$

$$\gamma = \rho g = \frac{1.94 slug}{ft^3} \frac{1\, lbf \sec^2}{slug\ \ ft} 32.2 \frac{ft}{\sec^2} = 62.4 \frac{lbf}{ft^3}$$

Note same numerical value

$$\rho = \frac{1.94 slug}{ft^3} \quad \text{so given that } 1 \text{ slug} = 32.17 \text{ lbm, then } \rho = \frac{62.4 lbm}{ft^3}$$

From your text, Fetter

Table 3.1 English and SI Units

Parameter	English Unit	SI Unit	Conversion Factor	Dimensional Formula
Force	pound (lb)	newton (N)	1 lb = 4.448 N	$M L/T^2$
Mass	slug	kilogram (kg)	1 slug = 14.594 kg	M
Length	foot (ft)	meter (m)	1 ft = 0.3048 m	L
Time	second (s)	second	1 s = 1 s	T
Density	slug/ft^3	kg/m^3	1 slug/ft^3 = 515.4 kg/m^3	M/L^3
Specific weight	lb/ft^3	N/m^3	1 lb/ft^3 = 157.1 N/m^3	M/L^2T^2
Pressure	lb/ft^2	N/m^2	1 lb/ft^2 = 47.88 N/m^2	M/LT^2
Dynamic viscosity	lb-s/ft^2	N·s/m^2	1 lb-s/ft^2 = 47.88 N·s/m^2	M/LT
Bulk modulus	lb/ft^2	N/m^2	1 lb/ft^2 = 47.88 N/m^2	M/LT^2

Surface tension for distilled water in contact with air in a clean glass tube is 72.8 dynes/cm, contact angle is zero, cos is 1

1 dyne imparts an acceleration of 1 cm/sec^2 to a mass of 1 gram or an acceleration of g = 981 cm/sec^2 to 0.00102 grams force

$$\sigma = \frac{72.8\text{dyne}}{\text{cm}}\left(\frac{0.00102\ g_f}{\text{dyne}}\ \frac{981\ \text{cm}}{\text{sec}^2}\right) = \frac{72.8\text{g}}{\text{s}^2}$$

$$\gamma = \rho g = \frac{1\text{g}}{\text{cm}^3}\ \frac{980\text{cm}}{\text{s}^2} = \frac{980\text{g}}{\text{cm}^2\ \text{s}^2}$$

$$h_c = \frac{2\sigma(\cos\lambda)}{\gamma r}$$

Surface tension for distilled water in contact with air in a clean glass tube is 72.8 dynes/cm, contact angle is zero, cos is 1

1 dyne imparts an acceleration of 1 cm/sec^2 to a mass of 1 gram or an acceleration of g = 981 cm/sec^2 to 0.00102 grams force

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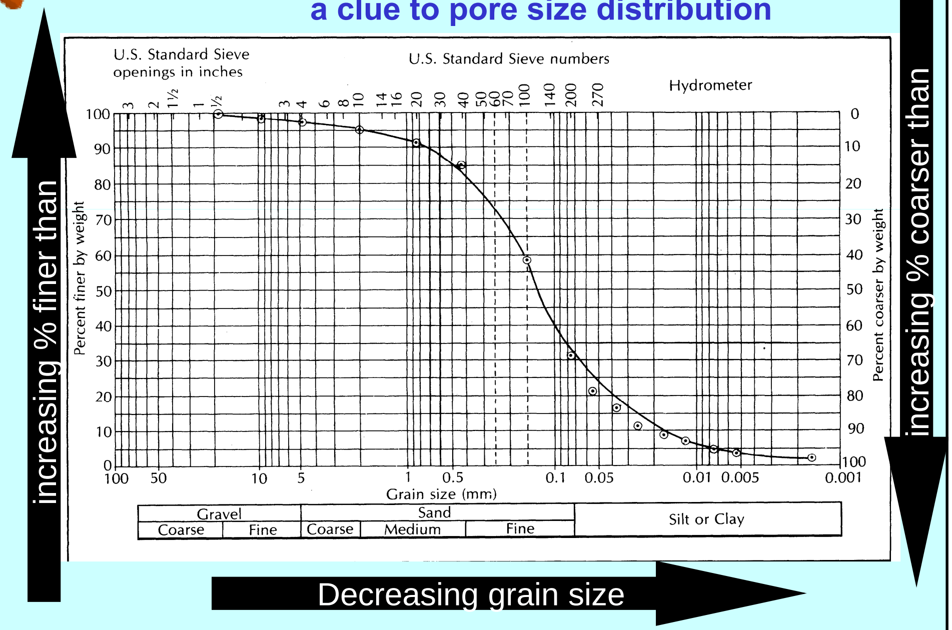
$$\gamma = \rho g = \frac{1\text{g}}{\text{cm}^3}\ \frac{980\text{cm}}{\text{s}^2} = \frac{980\text{g}}{\text{cm}^2\ \text{s}^2}$$

$$h_c = \frac{2\sigma(\cos\lambda)}{\gamma r} = \frac{2\,\frac{72.8\text{g}}{\text{s}^2}\,1}{\frac{980\text{g}}{\text{cm}^2\text{s}^2}\,r} \approx \frac{0.15}{\text{r}}\,\text{cm} \quad (\text{for}\quad \text{r}\quad \text{in}\quad \text{cm})$$

Grain size distribution:
a clue to pore size distribution



Estimate the height of capillary rise for water in sand.

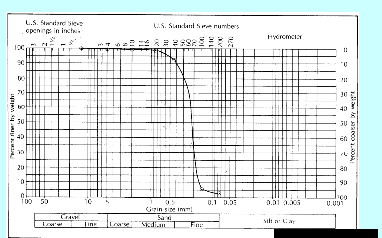
Grain size distributions in Fetter (pg74-75)

Smallest ~ 0.08 mm 10% ~ 0.17mm = 0.017cm

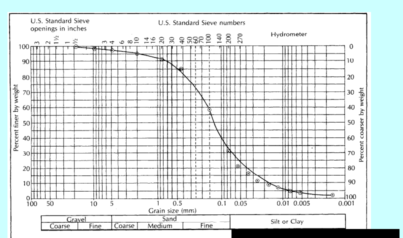
What if the soil is a silty sand?

Grain size distributions in Fetter (pg74-75)

Smallest ~ 0.002 mm 10% ~ 0.017mm = 0.0017cm



▲ FIGURE 3.5
Grain-size distribution curve of a fine sand.



▲ FIGURE 3.4
Grain-size distribution curve of a silty fine to medium sand.

What if the fluid is gasoline?

Substance Surface Tension (dyne/cm)

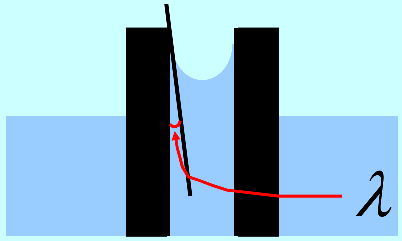
Water 72.8 dyne/cm

Gasoline ~33 dyne/cm (note < tension for water)

specific weight? check the web (~0.68 density of water)

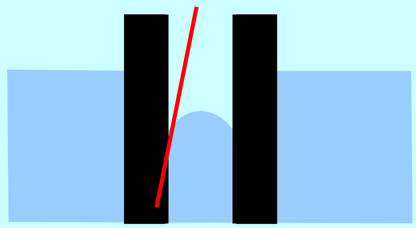
Which will dominate, surface tension decrease or specific weight decrease?

Thus far we have looked at fluids with a contact angle near zero and the cosine of zero is one, so we have not had to consider it



Some fluids have a contact angle approaching 90° and that needs to be considered in estimating capillary rise

$$h_c = \frac{2\sigma \cos\lambda}{\gamma r}$$



For a nonwetting fluid that angle will result in a depression rather than rise

What is the MAXIMUM HEIGHT (in feet) THAT YOU CAN RAISE WATER BY SUCTION?

NOTE: IT IS LIMITED BY THE PREVAILING ATMOSPHERIC PRESSURE so choose your location

(lb/in^2 sea-level ~14.7, Denver ~12.2, Mexico City ~11.1, Mt. Everest ~4.9)

$$\text{Recall:} \quad P = \gamma h$$