Part I. Write your answer in the space provided. Use equations and sketches in addition to words (as needed).

1. a. Give a qualitative definition of water saturation.

Water saturation is the fraction of the pore volume occupied by water. It an intensive property of a rock-fluid system

b. Give a quantitative definition of water saturation (S_w). Define all terms.

$S_w = \frac{V_w}{V_p}$ V_w = Volume of water, V_p = pore volume

c. Name two direct methods used to determine water saturation from core plugs.

- retort distillation
- solvent extraction

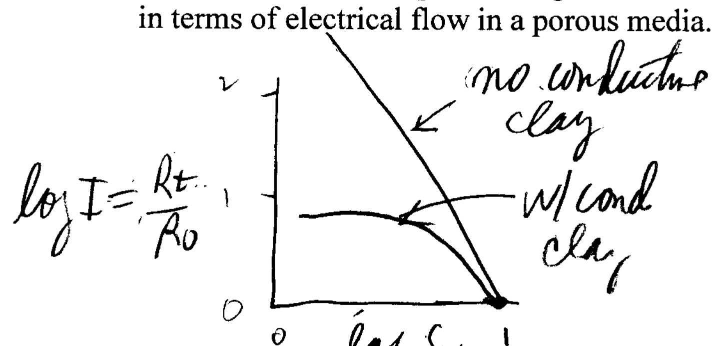
2. a. Give a qualitative definition of resistivity.

Resistivity is measure of (the inverse of) the electrical flow capacity of body of matter. It is an intensive property, measured in ohm-m

b. Give a quantitative definition of resistivity (R). Define all terms.

$R = \frac{rA}{L}$ r = resistance (ohm), A = x section area (m^2), L = length (m)

c. Make a graph showing the effect of conductive clays on resistivity index and explain it in terms of electrical flow in a porous media.



With no conductive clay present, $R_t \to \infty$ as $S_w \to 0$.

With conductive clay present $R_t \to R_{clay}$ as $S_w \to 0$

3. a. Give a qualitative definition of effective permeability to the wetting phase

Effective permeability to the wetting phase is a measure of the fluid conductance of a rock-fluid system to the wetting phase when the system is saturated with more than one fluid.

b. Give a quantitative definition of effective permeability to the wetting phase (k_w). Define all terms.

$$k_w = \frac{q_w \mu_w L}{A \Delta\Phi_w}$$

for linear flow

q_w = flow rate of wetting phase
μ_w = viscosity of wetting phase
Φ_w = flow potential of wetting phase
L = length of flow path
A = X section area of flow path

c. List four factors affecting effective permeability-saturation relationships.

- pore size
- pore size distribution
- wettability
- saturation history

4. a. Give a qualitative definition of relative permeability to a non-wetting phase.

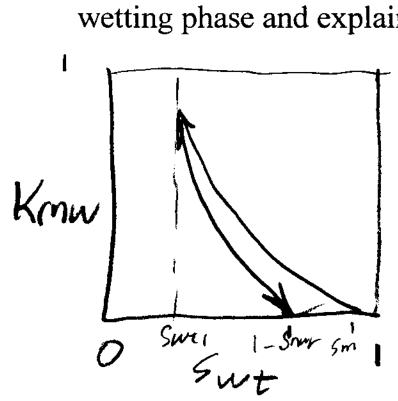
The ratio of the effective permeability of a non-wetting phase to some base permeability.

b. Give a quantitative definition of relative permeability to a non-wetting phase (k_{rnw}). Define all terms.

$$k_{rnw} = \frac{k_{nw}}{k}$$

k_{nw} = eff perm of non-wetting phase
k = base perm

c. Make a graph showing the hysteresis effect in the relative permeability to a non-wetting phase and explain it in terms of the interaction between capillary and viscous forces.



- capillary forces act to retain wetting phase in small pores
- viscous forces act to displace fluid from larger pores
- during drainage, forces act together to desaturate the pores
- during imbibition, forces oppose causing some non-wetting phase to be trapped.

Part II. Work out the answer in the space provided. Show details of your work and clearly identify your answer. Grading will be on the basis of approach and answers.

5. The equation shown below is used to average capillary pressure data.

$$J(S_w) = \frac{p_c}{\sigma\cos\theta}\sqrt{\frac{k}{\phi}}$$

Determine the constant, and its units to calculate $J(S_w)$ *[dimensionless]*, when capillary pressure, p_c, is in psi; interfacial tension, σ, is in dyne/cm; the permeability, k, is in md; and the porosity, ϕ, is expressed as a fraction.

"1" has units $\frac{\text{dyne/cm}}{\text{dyne/cm}^2\ \sqrt{\text{cm}^2}}$ (consistent units)

$$\frac{\text{dyne/cm}}{\text{dyne/cm}^2\ \sqrt{\text{cm}^2}} \left| \frac{1.01325\times10^6\ \text{dynes/cm}^2}{14.696\ \text{psi}} \right| \frac{\sqrt{\text{cm}^2}}{\sqrt{1.01325\times10^8}\ \sqrt{d}} \left| \frac{\sqrt{d}}{\sqrt{10^3}\ \sqrt{md}} \right| =$$

$$0.2166\ \frac{\text{dyne/cm}}{\text{psi}\cdot(\text{md})^{1/2}}$$

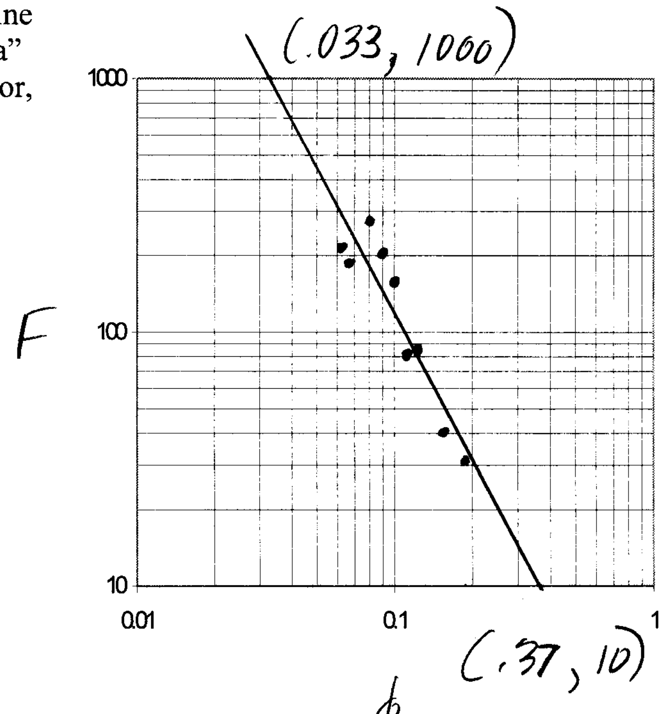
OR

$$J = \frac{p_c\left[\text{psi}\cdot\frac{1.01325\times10^6\ \text{dynes/cm}^2}{14.696\ \text{psi}}\right]\sqrt{k}\left[\frac{\sqrt{md}\ \sqrt{d}}{\sqrt{10^3}\ \sqrt{md}}\ \frac{\sqrt{\text{cm}^2}}{\sqrt{1.01325\times10^8}\ \sqrt{d}}\right]}{\sigma\ [\text{dyne/cm}]}$$

$$= 0.2166\ \frac{p_c(\text{dyne/cm}^2)}{\sigma(\text{dyne/cm})\cos\theta}\sqrt{\frac{\text{cm}^2}{1}}\ \text{(consistent units)}$$

6. Plot the following data and use a trend line to determine the values of the parameters "a" and "m" in the equation for Formation Factor, $F = a\phi^{-m}$.

Sample	Porosity (fraction)	Formation Factor $F=R_o/R_w$
5S	0.126	84.1
12J	0.090	203.0
14P	0.162	40.7
16J	0.080	286.8
16S	0.063	217.5
31P	0.195	31.4
48P	0.067	197.6
77J	0.101	165.7
77P	0.120	79.8



$$-m = \frac{\log(F_2/F_1)}{\log(\phi_2/\phi_1)} = \frac{\log(100)}{\log(.033/.37)} = -1.91$$

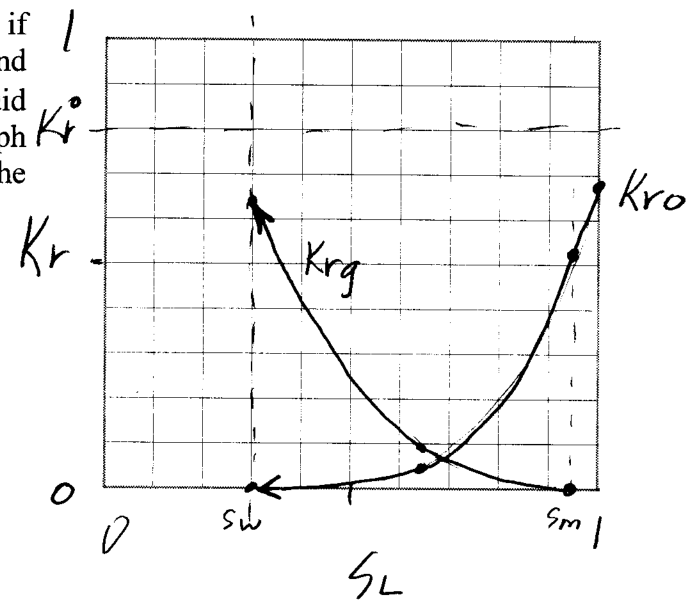
$$\log F = \log a - m \log \phi$$

$$\log a = \log 10 + 1.91 \log(0.37) = 0.177$$

a = 1.50 , m = 1.91 by hand

a = 1.49, m = 1.92 by regression

7. Calculate $k_{rw}]_{dr}$, $k_{ro}]_{dr}$, and $k_{rg}]_{dr}$ for a water-wet rock for the values of S_g shown below if $S_w = 0.3$, $S_{iw} = 0.2$, $S_m = 0.95$, $k_r^o = 0.9$, and $\lambda = 2$. Graph $k_{ro}]_{dr}$ and $k_{rg}]_{dr}$ vs liquid saturation. Clearly label the axes of your graph and all endpoints. Show the direction of the saturation change.



S_o	S_L	S_g	$k_{rw}]_{dr}$	$k_{ro}]_{dr}$	$k_{rg}]_{dr}$
0.7	1	0.00	2.4×10^{-4}	0.678	0.0
0.35	0.65	0.35	↓	0.052	0.098
0	0.3	0.70		0.0	0.665

NOTES:

1) $K_{rg} > 0$ begins at $S_L = S_m$ ($S_g = 0.05$)
2) K_{ro} does not begin at K_r^o because of mobile water ($S_w > S_{iw}$)
3) K_{rg} does not end at K_r^o because of mobile water

Water

$$k_{rw]dr} = \frac{k_w}{k} = \left(\frac{S_w - S_{iw}}{1 - S_{iw}}\right)^{3+2/\lambda}$$

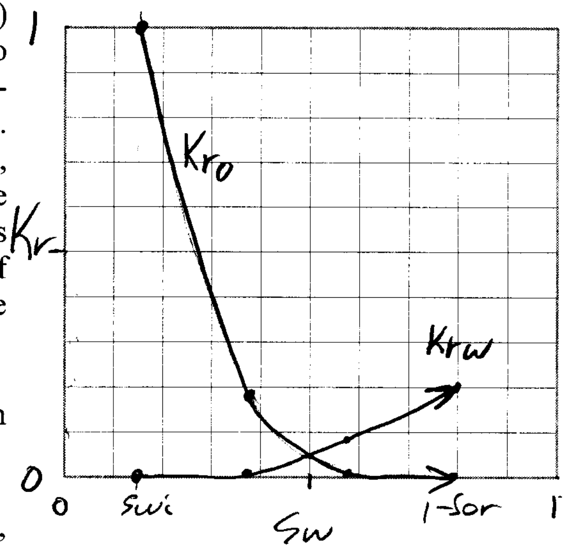
Oil

$$k_{ro]dr} = \frac{k_o}{k} = k_r^o\left(\frac{S_o}{1 - S_{iw}}\right)^2\left[\left(\frac{S_L - S_{iw}}{1 - S_{iw}}\right)^{1+2/\lambda} - \left(\frac{S_w - S_{iw}}{1 - S_{iw}}\right)^{1+2/\lambda}\right]$$

Gas

$$k_{rg]dr} = \frac{k_g}{k} = \begin{cases} k_r^o\left(\dfrac{S_g + S_m - 1}{S_m - S_{iw}}\right)^2\left[1 - \left(\dfrac{S_L - S_{iw}}{1 - S_{iw}}\right)^{1+2/\lambda}\right]; & (S_g + S_m > 1) \\ 0; \quad (S_g \le 1 - S_m) & \end{cases}$$

8. Assume Sample 77J (Problem 6, above) is used in a series of steady state flow tests to determine the saturation exponent and oil-water imbibition relative permeability data. Water is the wetting phase. Calculate S_w, $k_{ro}]_{Imb}$, and $k_{rw}]_{Imb}$. Use $k_o(S_{wi})$ for the base permeability. Graph $k_{ro}]_{Imb}$ and $k_{rg}]_{Imb}$ vs water saturation. Clearly label the axes of your graph and all endpoints. Show the direction of the saturation change.



Shown below are some of the results from the flow tests:

- Assume F = $\phi^{-2.23}$ (Problem 6), the saturation exponent, n = 2.02, and R_w = 0.055 ohm-m
- Sample initially saturated with water:

R_o (ohm-m)	k_o (md)	k_w (md)
9.08	0.0	140.0

- Oil displaces water to S_{wi}:

R_t (ohm-m)	k_o (md)	k_w (md)
431.	130.0	0.0

- Water displaces oil to S_{or}:

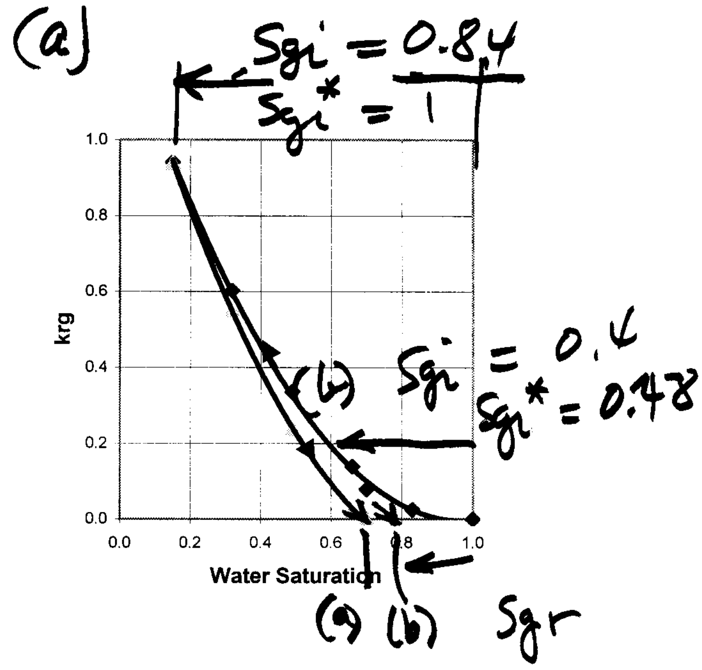
R_t (ohm-m)	k_o (md)	k_w (md)
69.6	25.0	2.6
27.8	1.8	12.0
14.3	0.0	26.0

S_w	$k_{ro}]_{Imb}$	$k_{rw}]_{Imb}$
0.15	1.0	0.0
0.37	0.192	0.02
0.58	0.014	0.092
0.80	0.0	0.20

$$S_w = \left(\frac{a R_w}{\phi^m R_t}\right)^{\frac{1}{n}} = \left(\frac{0.055}{(.101)^{2.23} R_t}\right)^{1/2.02}$$

$$C = \frac{1}{S_{gr}^*} - \frac{1}{S_{gi}^*}$$

9. Consider the relative permeability data graphed at right. Assume the irreducible water saturation is 0.16. The bottom curve shows that the maximum residual gas saturation is 0.32



a. Calculate the value of the trapping constant, C.

$$S_{gr}^* = \frac{0.32}{1-0.16} = 0.381 \text{ at}$$

$$S_{gi}^* = \frac{1-0.16}{1-0.16} = 1.0$$

$$C = \frac{1}{0.381} - 1 = 1.625$$

b. Calculate the value of the residual gas saturation if the initial gas saturation is 0.4

$$S_{gi}^* = \frac{0.4}{1-0.16} = 0.476$$

$$S_{gr}^* = 1/\left(C + \frac{1}{S_{gi}^*}\right) = 1/\left(1.625 + \frac{1}{0.476}\right) = 0.268$$

$$\Rightarrow S_{gr} = (0.268)(0.84) = 0.226$$

10. Consider the following core analysis data.

Sample Number	Depth (ft)	Horizontal Permeability (md)	Vertical Permeability (md)	Porosity (fraction)	Water Saturation (fraction)
41	9161.0- 62.0	30.9	44.2	0.158	0.241
42	9162.0- 63.0	17.1	18.9	0.134	0.155
43	9163.0- 64.0	40.6	55.1	0.149	0.215
44	9164.0- 65.0	4.28	3.38	0.141	0.172
45	9165.0- 66.0	14.1	17.6	0.130	0.165
46	9166.0- 67.0	41.9	22.1	0.135	0.351

a. The core was cut with a water base mud. What do you conclude about the water saturation data? Justify your answer.

It's likely to be too high because of invasion by water (mud filtrate) from the drilling mud

b. Determine the average horizontal permeability, the average vertical permeability, the average porosity, and the average water saturation of these data.

$$k_h = \frac{\sum k_i h_i}{h_T} = 24.8 \text{ md}$$

$$k_v = \frac{L}{\sum \frac{L_i}{k_i}} = 12.2 \text{ md}$$

$$\phi = \frac{\sum \phi_i h_i}{h_T} = 0.141$$

$$S_w = \frac{\sum S_{w_i} h_i}{h_T} = 0.217$$