PERMEABILITY EXERCISE

Many of the following exercises relate to a fictional field called the Elysian Field. The following data has been collected from cores from this field.

WATER PERMABILITY

Well: 24-1X
Depth: 3100 m

An experiment has been carried out where formation brine was pumped through a core plug obtained from this depth. The core plug was placed in a rubber sleeve in a pressure vessel. A confining pressure was placed on the sleeve using gas. Initially a single measurement was made with the sleeve pressure set to 500 psig. Subsequently permeability measurements were carried out at a range of higher sleeve (confining) pressures. For each permeability measurement, the fluid pressures at each end of the sample were measured, and the flow rate was also determined.

The following data were collected:

General Data	
Sample Length (average of 10 caliper readings)	7.8 cm
Sample Radius (average of 10 caliper readings)	1.905 cm
Sample Weight (saturated with dry air at 25^{o}C)	186.15 g
Water Viscosity (at the temperature and pressure at 3100 m)	1.007 cP

Flow Data

Sleeve Pressure (psig)	**Input Press. (psig)**	**Input Press. (atma)**	**Output Press. (psig)**	**Output Press. (atma)**	**Flow Rate (cm^3/min)**	**Perme ability (mD)**	**Norm. Perm. (-)**	***f*** **(-)**	**Norm. *f* (-)**
500	101		30		20			0.21	
1500	121		31		19.27			0.197	
2500	116		33		14.50			0.190	
3500	111		32		12.51			0.188	
4500	107		30		11.5			0.185	
5500	108		33		10.565			0.184	

Note the following conventions:

- psi = pressure unit, pounds per square inch.
- atm = pressure unit, atmospheres.
- To convert psi to atm **divide** by 14.7 psi because there are 14.7 psi in one atmosphere at standard conditions at sea level.
- Postscript ‘g’ means gauge. Mechanical gauges read relative to the atmospheric pressure on the day.
- Postscript ‘a’ means absolute, which is the pressure relative to a perfect vacuum. Values for the calculation must be in atmospheres absolute.
- To convert pressure in psig to psia **add** 14.7 psi, which is the standard mean atmospheric pressure at sea level.

- To convert pressure in atmg to atma **add** 1.00 atm, which is the standard mean atmospheric pressure at sea level.
- To convert pressure in psig to atma **add** 14.7 psi, which is the standard mean atmospheric pressure at sea level, then **divide** the result by 14.7 psi.
- The above calculations can be carried out using the measured value of the atmospheric pressure in psi on the day of the experiment. The results are then marginally more accurate.

(a) Calculate the relevant pressures in atma and insert them into the table.

(b) Calculate the permeability of the core plug at each of the sleeve (overburden) pressures.

(c) Calculate the normalised permeability (permeability at a given sleeve pressure divided by the permeability at 500 psig).

(d) Calculate the normalised porosity (porosity at a given sleeve pressure divided by the porosity at 500 psig).

(e) Draw a graph of normalised permeability and porosity (y-axis, linear scale 0 to 1) against sleeve (overburden) pressure (x-axis, linear scale 0 to 6000 psig).

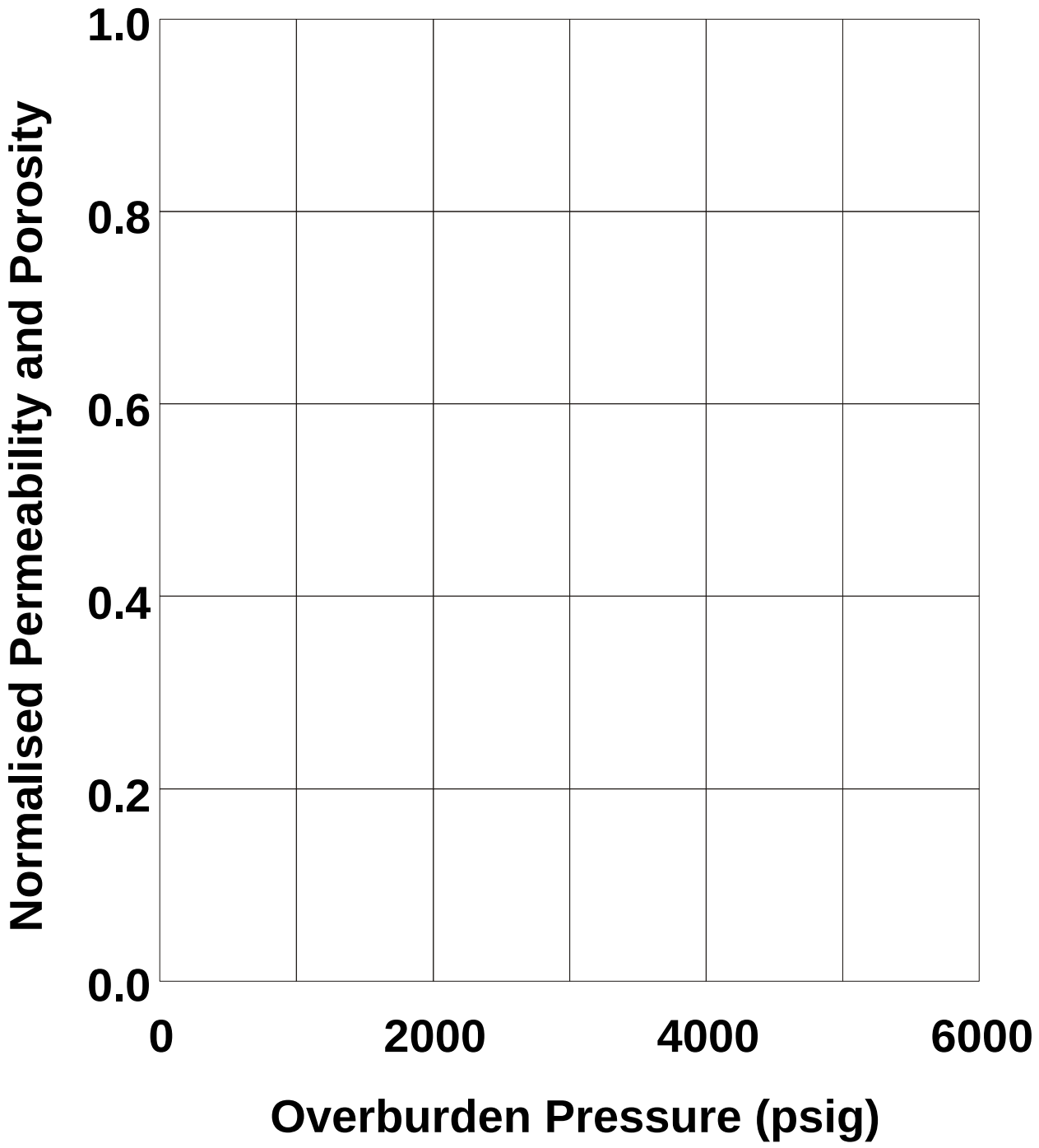
(f) Why does permeability decrease with increasing overburden pressure?

(g) Why does porosity decrease with increasing overburden pressure?

(h) Why is the effect of overburden pressure greater on permeability than on porosity?

(i) The calculated values of permeability at increasing overburden pressures are actually slightly wrong. What causes this, and infer whether these calculated values are slightly over-estimating or slightly under-estimating the true values.

Graph paper for part (e)



GAS (KLINKENBERG) PERMABILITY

Well: 24-1X
Depth: 3050 m

An experiment has been carried out where *nitrogen* gas was passed through a core plug obtained from this depth. The core plug was placed in a rubber sleeve in a pressure vessel and a single confining pressure of 500 psig was used throughout the entire experiment. The input gas pressure and output gas pressure were measured together with the volume of gas passing through the core plug for six different values of input gas pressure.

The following data were collected using nitrogen gas:

General Data	
Sample Length (average of 10 caliper readings)	7.8 cm
Sample Radius (average of 10 caliper readings)	1.905 cm
Sample Weight (saturated with dry air at 25^{o}C)	186.15 g
Nitrogen Gas Viscosity	0.0176 cP

Flow Data

Sleeve Press. (psig)	**Input Press. (psig)**	**Input Press. (atma)**	**Output Press. (psig)**	**Output Press. (atma)**	**Flow Rate (cm^3/min)**	**N_2 Permea-bility (mD)**	**Mean Press. (atma)**	**$1/P_{mean}$ ($atma^{-1}$)**
500	2		0.2		3.27			
500	4		0.3		7.02			
500	8		0.5		15.47			
500	16		0.9		36.12			
500	32		1.5		92.18			
500	64		3.1		265.56			

Note the following conventions:

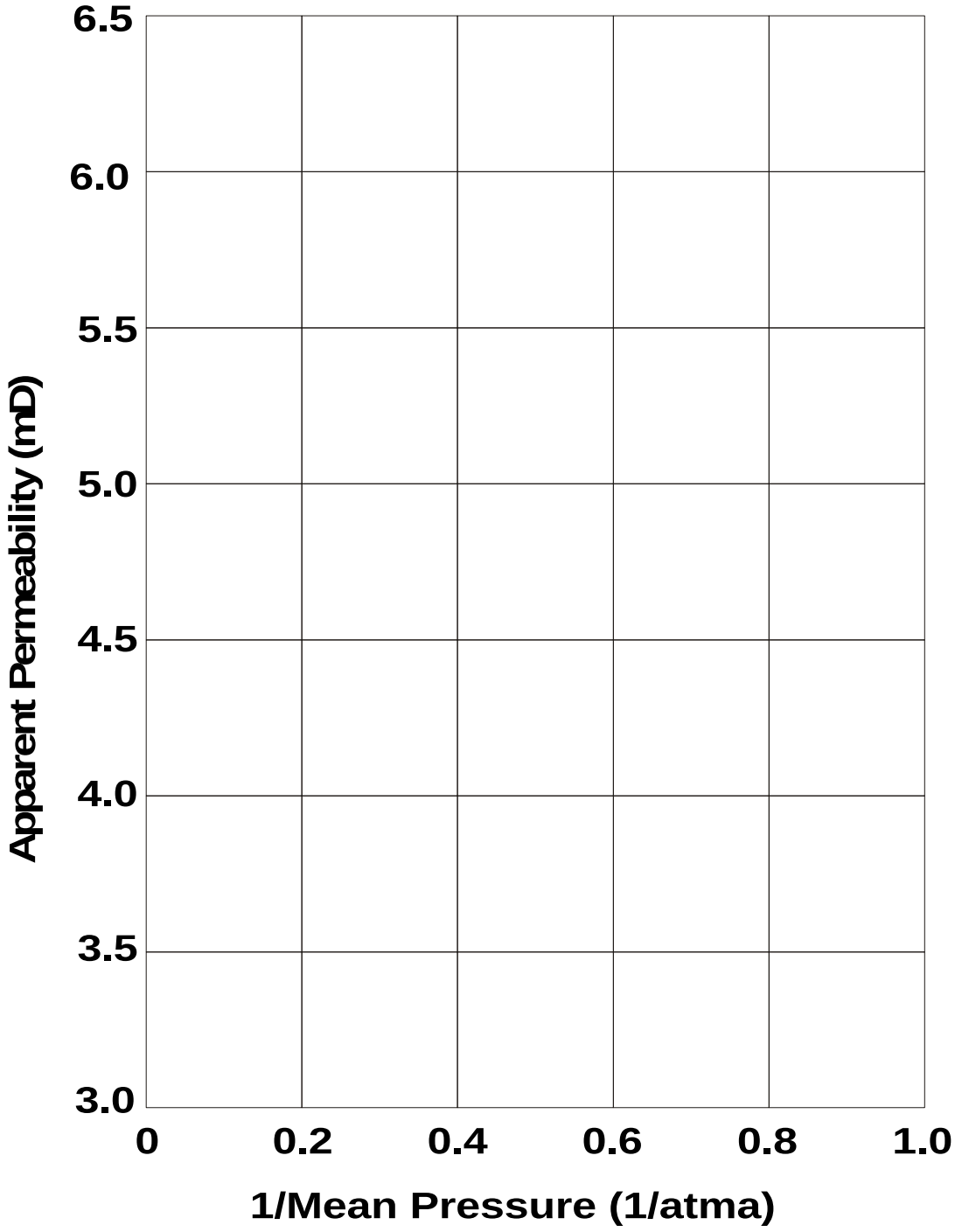
- psi = pressure unit, pounds per square inch.
- atm = pressure unit, atmospheres.
- To convert psi to atm **divide** by 14.7 psi because there are 14.7 psi in one atmosphere at standard conditions at sea level.
- Postscript ‘g’ means gauge. Mechanical gauges read relative to the atmospheric pressure on the day.
- Postscript ‘a’ means absolute, which is the pressure relative to a perfect vacuum. Values for the calculation must be in atmospheres absolute.
- To convert pressure in psig to psia **add** 14.7 psi, which is the standard mean atmospheric pressure at sea level.
- To convert pressure in atmg to atma **add** 1.00 atm, which is the standard mean atmospheric pressure at sea level.
- To convert pressure in psig to atma **add** 14.7 psi, which is the standard mean atmospheric pressure at sea level, then **divide** the result by 14.7 psi.
- The above calculations can be carried out using the measured value of the atmospheric pressure in psi on the day of the experiment. The results are then marginally more accurate.

(j) Calculate the relevant pressures in atmospheres absolute, and update the table.

(k) Calculate the apparent permeability for each set of input pressure, output pressure and flow rate, using the viscosity of nitrogen and filling in the table as you go.

(l) Calculate 1/Mean Pressure for each set.

(m) Draw a Klinkenberg Plot by plotting the apparent permeability (y-axis, scale linear) against 1/Mean Pressure (x-axis, scale linear from zero).



(n) Determine the Klinkenberg Permeability (K_L). Comment upon the accuracy of the determination.

(o) Determine the Slip Factor α, where $K_{app}=K_L(1+\alpha/P_{mean})$. Note that this is the gradient of the line divided by K_L. Remember to include the units.

(p) The values of the apparent permeabilities are different if a different gas is used in place of nitrogen. Recalculate all apparent permeabilities if either helium or dry air were used instead of nitrogen. Plot these on the Klinkenberg plot too.

The following data were collected using dry air:

General Data	
Sample Length (average of 10 caliper readings)	7.8 cm
Sample Radius (average of 10 caliper readings)	1.905 cm
Sample Weight (saturated with dry air at 25°C)	186.15 g
Dry Air Viscosity	0.0184 cP

Flow Data

Sleeve Press. (psig)	**Input Press. (psig)**	**Input Press. (atma)**	**Output Press. (psig)**	**Output Press. (atma)**	**Flow Rate (cm^3/min)**	**Dry Air Permea-bility (mD)**	**Mean Press. (atma)**	**$1/P_{mean}$ ($atma^{-1}$)**
500	2		0.2		3.52			
500	4		0.3		7.53			
500	8		0.5		16.45			
500	16		0.9		37.88			
500	32		1.5		95.50			
500	64		3.1		267.44			

The following data were collected using helium gas:

General Data	
Sample Length (average of 10 caliper readings)	7.8 cm
Sample Radius (average of 10 caliper readings)	1.905 cm
Sample Weight (saturated with dry air at 25°C)	186.15 g
Helium Gas Viscosity	0.0196 cP

Flow Data

Sleeve Press. (psig)	**Input Press. (psig)**	**Input Press. (atma)**	**Output Press. (psig)**	**Output Press. (atma)**	**Flow Rate (cm^3/min)**	**He Permea-bility (mD)**	**Mean Press. (atma)**	**$1/P_{mean}$ ($atma^{-1}$)**
500	2		0.2		3.68			
500	4		0.3		7.84			
500	8		0.5		16.99			
500	16		0.9		38.69			
500	32		1.5		95.97			
500	64		3.1		263.68			

(q) Clearly, the apparent permeabilities depend upon the type of gas used. Determine the klinkenberg permeabilities and slip factors for the klinkenberg permeability measurement using helium and dry air. Do the Klinkenberg Permeability (K_L) and slip factor depend on the type of gas used?

(r) List four advantages of the klinkenberg permeability method over a single measurement of gas permeability at an arbitrary input gas pressure.