Geophysics 424 A1 - Final exam - Fall term
Electromagnetic and Potential field methods

Date :	Tuesday December 16th 2014, 2-5 pm
Location	CCIS L1-029
Instructor :	Dr. Martyn Unsworth
Time allowed	3 hours
Total points	**104**

Instructions

Attempt all questions.

Notes and books may ***not*** *be used.*

Calculators may be used.

Cell phones and all other electronic devices must be switched off and stored.

All questions must be directed to the invigilator.

A separate formula sheet will be distributed

Question 1 : Resistivity of rocks (Total = 10 points)

(1a) Electric current flows in a material that contains a single type of charge carrier.
There are n charge carriers per unit volume and each has a charge q.
The charge carriers have a mobility μ which is defined as the drift velocity per unit electric field. $\mu = \frac{\bar{v}}{E}$
Show that the electrical conductivity of the material is given by $\sigma = n\mu q$

(5 points)

(1b) A brine is formed by dissolving 30 g of sodium chloride in 1 litre of water.
The brine has a conductivity of 3 S/m
Estimate the mobility of the sodium ions.
Assume that the sodium (Na^+) and chloride (Cl^-) ions have the same mobility

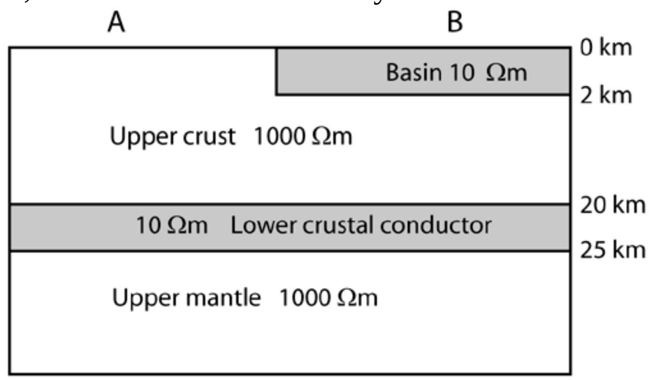
(5 points)

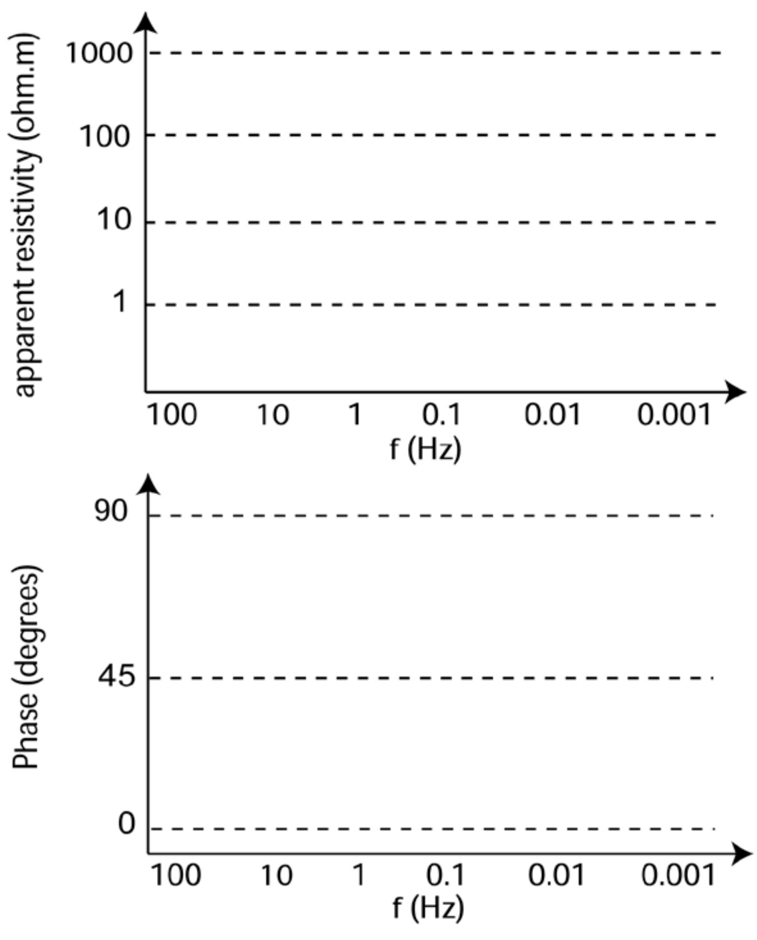
Useful data

Volume of 1 litre of water	10^{-3} m^3
Molar weight of sodium chloride	58.4 g / mol
Avogadro's number	6.02 10^{23}
Charge on electron	1.6 10^{-19} C

Question 2 : Magnetotellurics (Total = 21 points)

MT data (100-0.001 Hz) are being used to image a lower crustal conductor. Site A is located on exposed basement rocks, while B is in a sedimentary basin.





(2a) Sketch the MT apparent resistivity and phase data at sites 'A' and 'B'. You can approximate the structure at each location is 1-D. Be quantitative where possible. **(14 points)**

(2b) One theory suggests that the lower crust is conductive because of **interconnected** graphite films. The conductivity of pure graphite is 1000 S/m. What **volume fraction** of graphite is required to account for a bulk resistivity of 10 Ωm?

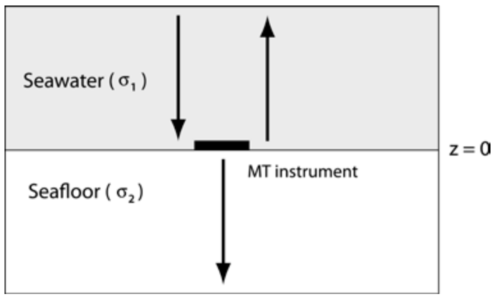
(3 points)

(2c) The other theory is that saline fluids cause the low resistivity in the lower crust. The fluid distribution is not known. Assuming a fluid conductivity of 10 S/m what **range of porosities** is required to account for a bulk resistivity of 10 ©m

(4 points)

<u>Question 3 : Maxwell's Equations (Total = 22 points)</u>

A seafloor MT survey is being used to measure the resistivity of the seafloor.
A **plane** EM wave has an angular frequency, *É*, and travels **vertically** downwards in seawater in the *z*-direction. The electric field is **polarized** in the *x*-direction.



Down going signal in seawater	$E_x(z,t) = Ae^{-k_1 z}e^{-i\omega t}$
Up going signal in seawater	$E_x(z,t) = Be^{k_1 z}e^{-i\omega t}$
Down going signal in seafloor	$E_x(z,t) = Ce^{-k_2 z}e^{-i\omega t}$

$k_1 = \sqrt{-i\omega\mu_0\sigma_1}$ and $k_2 = \sqrt{-i\omega\mu_0\sigma_2}$

(3a) Use Maxwell's equations to prove that the **horizontal electric field** is continuous at the seafloor (z = 0)

(6 points)

(3b) Use Maxwell's equations to show that for a plane, polarized EM signal

$$H_y(z) = \frac{1}{i\omega\mu}\frac{\partial E_x(z)}{\partial z}$$

(5 points)

(3c) Derive an expression for $\frac{C}{A}$ at the seafloor in terms of σ_1 and σ_2. State any boundary conditions that you use.

(6 points)

(3d) The MT instrument measures electric and magnetic fields at a frequency É.
At z = 0, the measured electric and magnetic fields is E_x^m and H_y^m
Derive an equation for the seafloor conductivity (σ_2) in terms of E_x^m and H_y^m

(5 points)

Question 4 : Marine EM methods (Total = 17 points)

(4a) How does frequency domain marine controlled source EM exploration measure variations of resistivity with depth? **(2 points)**

(4b) In a study area, the seafloor has a uniform porosity of 10% and the pore space is poorly connected. The seawater conductivity is 3 S/m. It is required to transmit EM signals over a distance of 5 km through the seafloor. What transmission frequency is needed? **(5 points)**

(4c) Draw a map of **broadside** and **inline** configurations of receivers in marine CSEM when the transmitter is a horizontal electric dipole. **(4 points)**

(4d) How are these configurations used to detect **hydrocarbon reservoirs**? Explain the physics and include a diagram in your answer. **(6 points)**

Question 5 : Frequency domain EM (Total = 14 points)

Frequency domain EM exploration can be modelled by considering the transmitter (TX), receiver (RX) and ore body as electrical circuits. An EM system generates a primary field with a frequency of 900 Hz.

(5a) Define the **mutual inductance** between the TX and RX. Include a diagram **(3 points)**

(5b) Why is relative motion between the TX and RX a problem in this type of system? **(4 points)**

(5c) The primary magnetic field has a magnitude of 100 nT at the receiver. The secondary magnetic field has in-phase and quadrature components at the receiver of 10 and 2 nT, respectively.

Draw a **phase diagram** of the primary, secondary and total magnetic fields at the RX

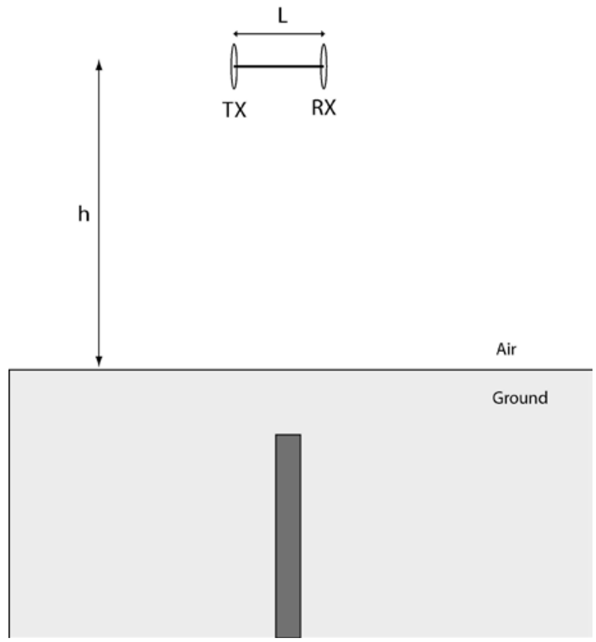
(3 points)

(5d) Calculate the **magnitude of** the total magnetic fields. **(2 points)**

(5e) Calculate the difference in **phase angle** between the total and primary magnetic fields.

(2 points)

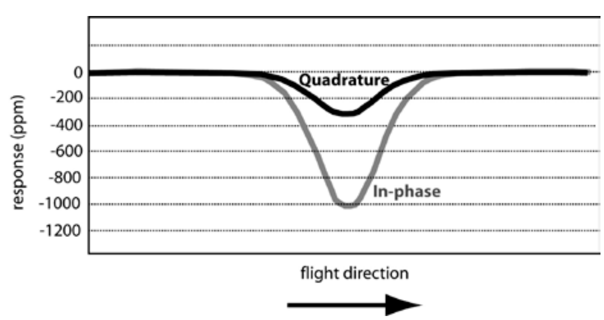
Question 6 : Frequency domain EM methods (Total = 20 pts)



A frequency domain electromagnetic system with **co-axia**l transmitter (TX) and receiver (RX) is flown beneath a helicopter. The system parameters are:

- primary field frequency, f = 10,000 Hz
- transmitter-receiver offset, L = 20 m.
- ground clearance of TX-RX bird, h= 30 m
- noise level 10 ppm (both in phase and quadrature)

(6a) The EM system was flown across a **conductor** and the following response (H_S / H_P) was measured.



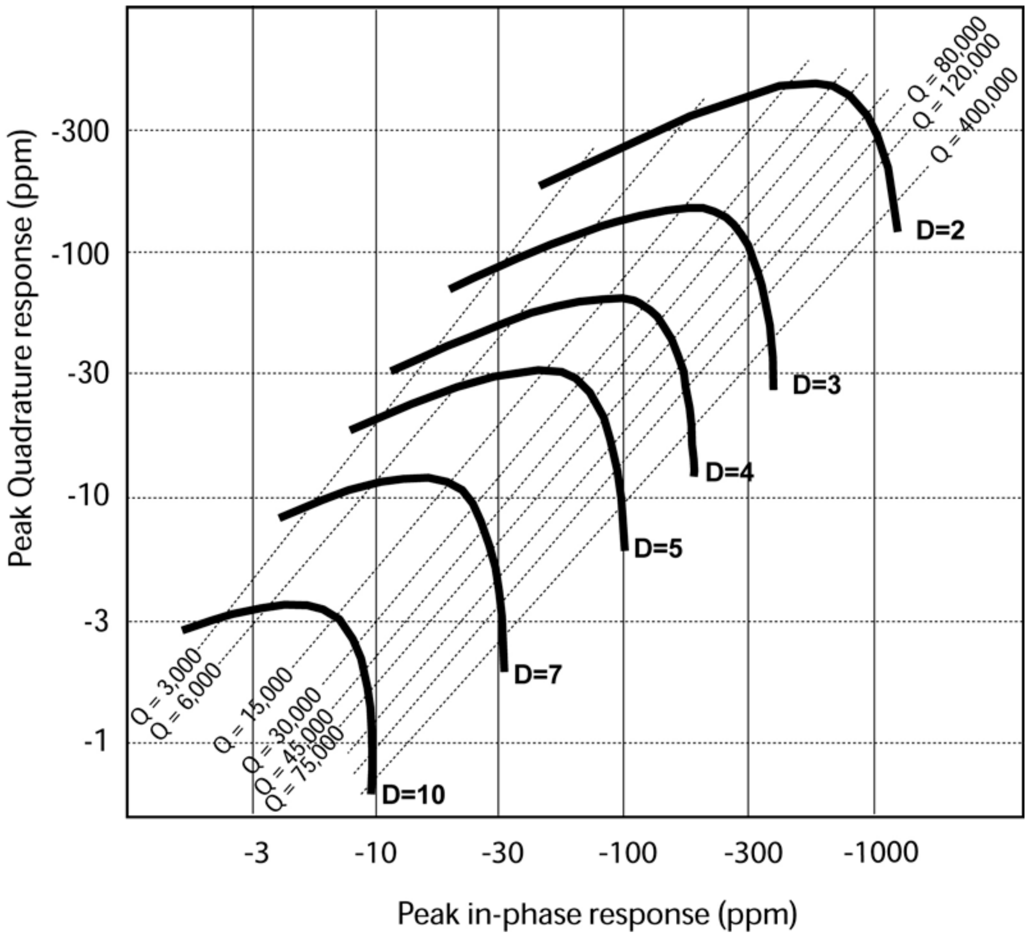
Explain the **sign** of the **in-phase** response with a **diagram** showing magnetic field lines for primary and secondary magnetic fields.

(5 points)

(6b) Determine as much as possible about the conductor.
List all the assumptions you make. **(10 points)**

(6c) A vertical conductor has a conductance of 4 S.
What is the maximum depth at which it can be detected by this system?
(5 points)

Characteristic curves for co-axial TX-RX and a vertical plate



Response parameter, Q = ÃWf Depth parameter, D = H / L

W = width of conductor
Ã = conductivity of conductor
H = depth to top of conductor below TX-RX bird
f = TX frequency (Hz)
L = TX-RX separation

Question 7 : Ground-penetrating radar (Total = 13 points)

GPR is being used to study the subsurface structure shown below.
A metal pipe is buried at a depth d = 4 m and horizontal location x = 0 m
Velocity in the soil = v_1 = 0.15 m / ns

Radar frequency is 200 MHz and TX-RX distance is 1 m

(7a) On the graph below, sketch the **travel times** for the air wave and ground wave at the RX **(4 points)**

(7b) The TX-RX are located at a distance x from the pipe. Derive an equation for the travel time of a signal **diffracted** from the pipe. Assume that the TX and RX are coincident. **(3 points)**

(7c) Add the travel time curve for the diffracted signal **(3 points)**

(7d) Calculate the moisture content of the soil (¸$_v$) **(3 points)**