D1 : Introduction to Electromagnetic exploration methods

- So far we have considered electrical methods (section B) and magnetic methods (section C) of geophysical exploration.

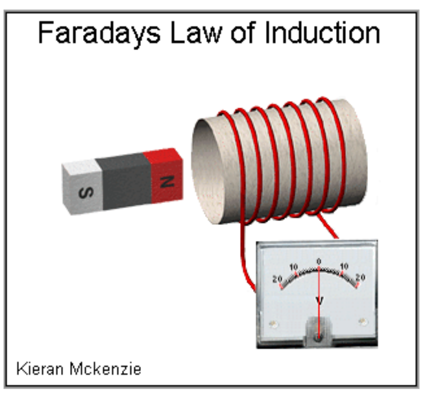
- The next class of geophysical methods that we will consider are **electromagnetic methods** that are used to measure the **electrical resistivity** of the Earth.

- This method of measuring resistivity is different to that used in DC resistivity. The most important difference is that direct contact with ground is not needed. This allows EM data to be collected from a moving platform such as a helicopter or aircraft.

- The conductivity measured by these instruments is often called **terrain conductivity**

- Review the notes from section B about the causes of high and low electrical resistivity.

D1.1 Electromagnetic induction



- Faraday's Law of induction

- Time variation of a magnetic field generates a voltage.

- This can cause electric current to flow.

- In-phase and quadrature sinusoidal waves (see diagram on board)

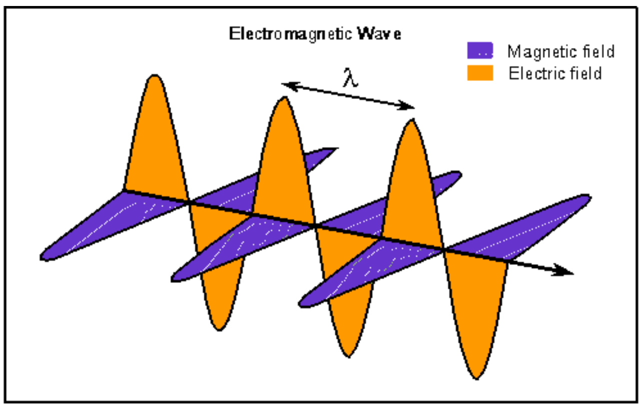
- Frequency domain and time domain (see diagram on board)

D1.2 Electromagnetic wave propagation and diffusion

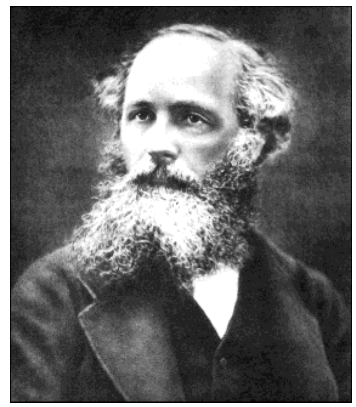
Wave propagation

- When electromagnetic (EM) signals travel in the air, they travel as waves because the conductivity is zero.

- The energy is transformed from the electric field to the magnetic field and back again. If there is no loss during this conversion, the EM wave will propagate indefinitely.



http://www.warren-wilson.edu/~physics/physics2/Formal2000/sstephens/bragg2.html



James Clerk Maxwell

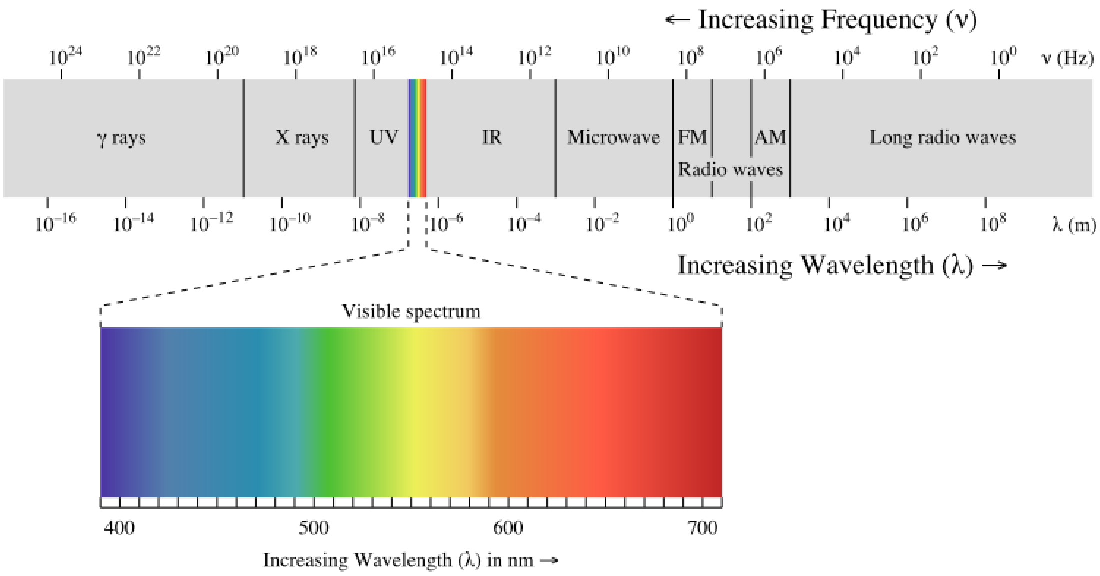
- Propagation of EM waves is described by Maxwell's equations and includes displacement current.

- Amplitude of the only decreases through geometric effects ($1/r^2$)

- The wave travels at velocity v (m/s) with wavelength λ (m) and frequency f (Hertz or cycles per second)

- These quantities are related through the equation $v = f\lambda$

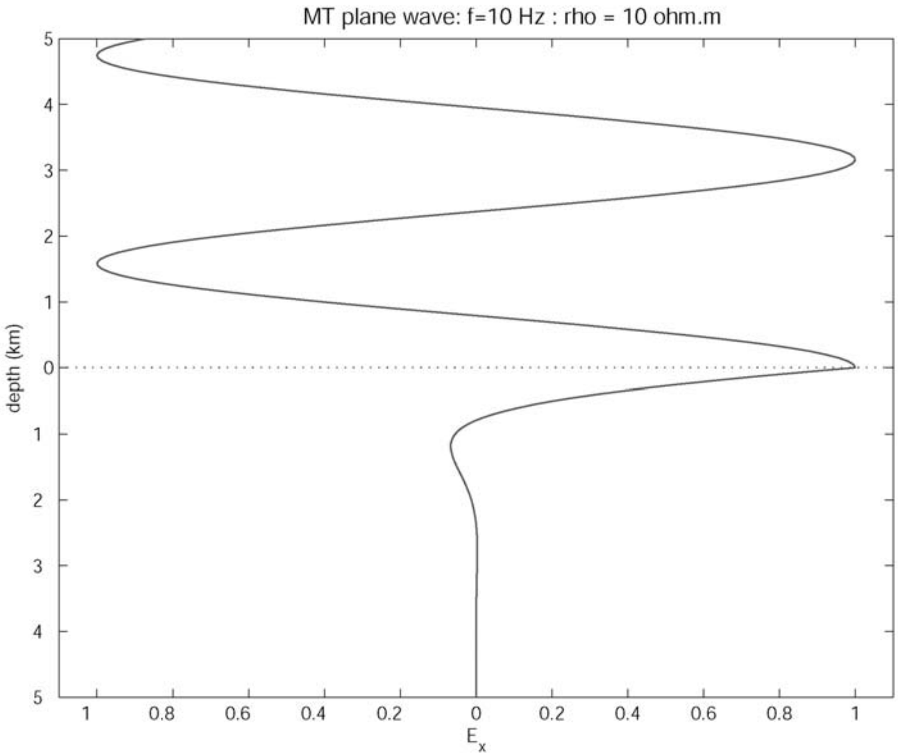
- Depending on the frequency these EM signals could be anywhere in the range radio waves to γ-rays



(from Wikipedia)

Diffusion

- When electromagnetic signals enter the Earth, they propagate by **diffusion**
- The time-varying magnetic field induces an oscillating electric current in the Earth.
- As this electric current flows, energy is converted to heat.
- This energy cannot be converted back into electric or magnetic fields and is lost from the signal
- This causes the amplitude of the EM signal to decrease
- Can show the amplitude decreases exponentially with distances as $E(z) = E_o e^{-\frac{z}{\delta}}$
- δ is called the **skin depth**, and in metres it is defined as $\delta = \frac{500}{\sqrt{\sigma f}}$
- As frequency increases, the skin depth decreases.
- Similarly, as conductivity increases, the skin depth decreases.
- Thus deep imaging requires a low conductivity or a low frequency.



- Amplitude decreases by both **geometrical spreading** and **attenuation**

- To determine if wave propagation or diffusion will dominate, can consider the ratio defined as $r = \dfrac{\sigma}{2\pi f\varepsilon}$, where f is the frequency, ε is the permittivity of the subsurface and σ is the electrical conductivity.

- Assume that the permittivity has the free space value $\varepsilon = \varepsilon_0 = 8.85\ 10^{-12}$ F/m

- If r is large, then EM diffusion will occur.

- If r is small then wave propagation occurs

Calculation – wave propagation or diffusion?

Consider the following scenarios. Will the EM signals travel by wave propagation or diffusion?

(a) A ground penetrating radar survey is being used to study a glacier. The EM signals have a frequency of 100 MHz and the ice has a resistivity of 10000 Ωm

(b) An EM31 survey is mapping the location of a contaminant plume. The instrument uses a frequency of 9800 Hz and the resistivity of the ground is 10 Ωm

Calculation – skin depths

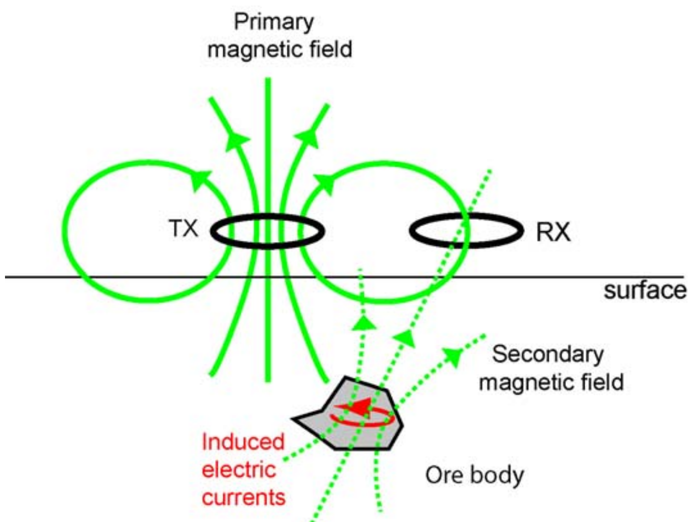
What will the skin depth be for EM diffusion in the following scenarios?

(a) Ground-penetrating radar is being used in a area where clay is present with resistivity of 5 Ωm. The radar generates signals at a frequency of 100 MHz

(b) Low frequency radio waves from the magnetosphere have a frequency of 0.001 Hz. The crust has a resistivity of 200 Ωm. What depth will the signals travel to?

D1.3 Summary of how EM methods work

Before we get into details, let's consider how EM methods work.



(1) A **primary magnetic field** is generated by electric current flowing in the transmitter loop (TX).

(2) The transmitter current oscillates with time to produce a primary magnetic field that also oscillates with time.

(3) Time variations of the primary magnetic field induce **secondary electric currents** in a conductor (ore body).

(4) The secondary magnetic field passes through the RX, which is also a loop of wire. Time variations (oscillations) in the secondary magnetic field generate a **secondary voltage in the RX**.

(5) Measurement of the secondary voltage gives information about the size and location of the conductor.