Candidates are admitted to the examination room ten minutes before the start of the examination. On admission to the examination room, you are permitted to acquaint yourself with the instructions below and to read the question paper.

Do not write anything until the invigilator informs you that you may start the examination. You will be given five minutes at the end of the examination to complete the front of any answer books used.

April 2011

Answer Book
General Data Sheet
Any bilingual English language dictionary permitted
Only Casio-fx83 calculators are permitted

THE UNIVERSITY OF READING

MSc Examination for Courses in Sciences

Remote Sensing

MTMG38

2 hours

Answer **ANY TWO** questions

The marks for the individual components of each question are given in [ ] brackets. The total mark for the paper is 100

1.

(a) (i) Consider a slab of material with an infinite depth and a flat surface. Which of the following refraction indices results in the smallest penetration depth at a given wavelength?

A. 1.5
B. 8.35 – 0.2i
C. 1.33 – 1.5i
D. –0.1i
E. 1.78 – 0.0001i

[5 marks]

(ii) Which of the following processes results in polarization of radiation?

A. Backscattering of sunlight by air molecules
B. Emission from a raindrop at infrared wavelength
C. Reflection arising from the normal incidence of microwave radiation on a plane water surface
D. Reflection arising from 45° incident angle of microwave radiation on a plane water surface
E. A., C. and D.

[5 marks]

Question 1 continued overleaf

Question 1 continued

(iii) Suppose you need to design an instrument to measure aerosol effective size for this case from space using polarized reflected sunlight. Unfortunately, the funding is limited and you are given only two options. Option 1 is to measure directional polarized reflectance at *only* one wavelength; Option 2 is to measure *only* one direction at multiple wavelengths. Based on Fig. 1, explain which option is better.

[5 marks]

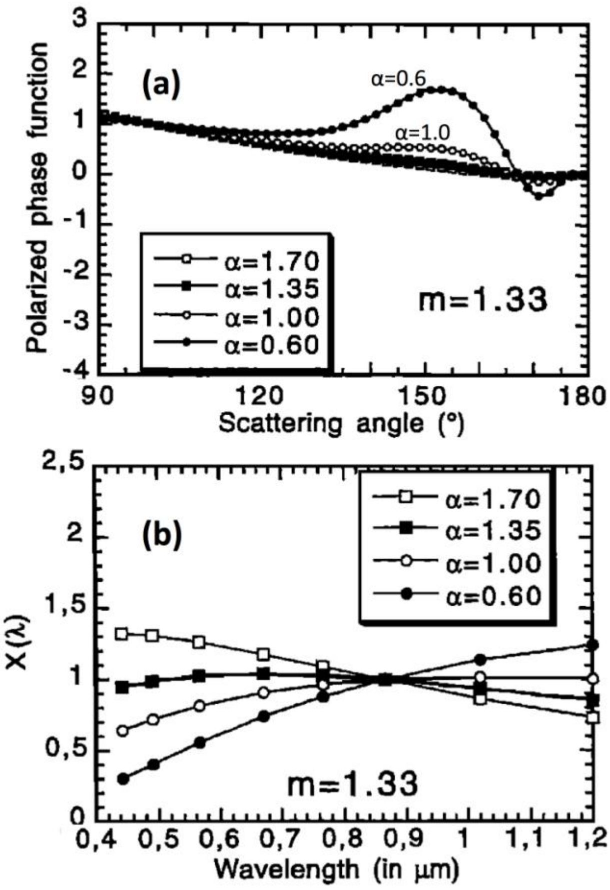

Fig. 1. (a) *Directional* dependence of the polarized light at the 865 nm wavelength. Behavior of $q_a(\Theta)/q_a(\Theta = 100^o)$ as a function of Θ (scattering angle) for mono-modal models with refractive index *m* = 1.33. q_a is the polarized phase function; *α* is Ångström exponent. (b) *Spectral* dependence of the polarized light. Behaviors of $X(\lambda)$ as a function of λ for the mono-modal models of (a), where $X(\lambda) = \delta_a(\lambda) q_a(\lambda,\Theta_0) / \delta_a(\lambda_0) q_a(\lambda_0,\Theta_0)$ with Θ_0=100° and λ_0=850 nm. $\delta_a(\lambda)$ is the aerosol optical depth.

Question 1 continued overleaf

Question 1 continued

(b) Figure 2 illustrates the weighting functions from the tropical and mid-latitude atmospheres.

(i) Explain whether these weighting functions represent a typical nadir or zenith sounding.

[5 marks]

(ii) Explain which meteorological variable you could retrieve from these weighting functions.

[5 marks]

(iii) Please identify and explain which one shows results derived from the tropical atmosphere.

[5 marks]

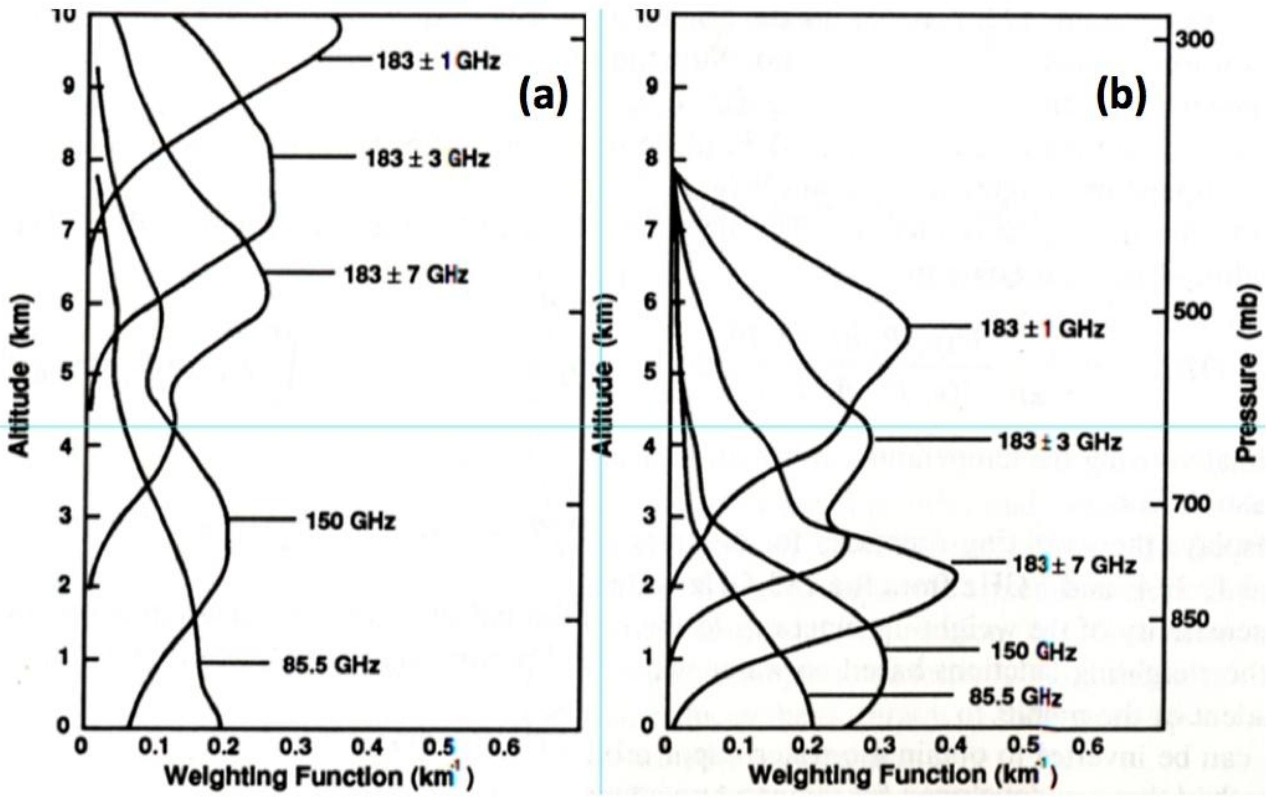

Fig. 2. Weighting functions.

Question 1 continued overleaf

Turn Over

Question 1 continued

(c) The fundamental vibration of CO occurs at 2143 cm^{-1}. The rotational constant (B) of CO is 1.93 cm^{-1}. Consider a transition in which the vibrational quantum number changes from v = 0 to v = 1 and the rotational number changes from J = 11 to J = 10.

(i) Explain whether this transition should be in P, Q or R branch.

[5 marks]

(ii) Explain whether this transition is emission or absorption.

[5 marks]

(iii) The discrete rotational energy level is given as $E_J = J \cdot (J+1) \cdot B$. Calculate the wavenumber (<u>**cm^{-1}**</u>) of this transition.

[10 marks]

2.

(a) (i) If the refractive index of a material is 2 - *i*, its dielectric constant is

A. 2
B. 2 + *i*
C. 4 - *i*
D. 3 – 4i
E. none of the above

[5 marks]

(ii) Which of the following remote sensing techniques is **not** based on emission?

A. Use 0.7 µm radiometer to measure cloud optical depth
B. Use satellite microwave radiometer to detect sea ice
C. Use infrared camera to detect people during night
D. Use 4.3 µm absorption line to sense temperature profile
E. Use 37 GHz microwave radiometer to measure cloud liquid water

[5 marks]

(iii) A CIMEL sunphotometer has a silicon detector that is highly linear in measuring the direct solar flux. When calibrated with the Langley plot method at Mauna Loa Observatory in Hawaii, the voltage extrapolated to the top of the atmosphere is $V_0 = 2.5$. One day when the solar zenith angle is 60°, the sunphotometer measures a voltage of V = 0.9 at the 440 nm wavelength. At this wavelength, molecular absorption is negligible, but the molecular Rayleigh scattering optical depth is 0.22. Calculate the aerosol optical depth.

[8 marks]

Question 2 continued overleaf

Question 2 continued

(b) A 1200 line/mm grating in a 0.25 m spectrometer is set up so that the angle of incidence of 500 nm light equals the angle of diffraction.

(i) Start with the grating equation: $m\lambda = a\sin I + a\sin D$, where *m* is the order number; λ is the wavelength; *a* is the distance between slits; *I* is the incident angle; and *D* is the diffraction angle. Prove that the value of *D* is 0.64 rad when m=2.

[7 marks]

(ii) The linear dispersion *dL* is related to the angular dispersion *dD* through the focal length of the collecting optics *f*, i.e., $\frac{dL}{d\lambda} = f \cdot \frac{dD}{d\lambda}$. If we need to resolve 0.1 nm in the spectrum, how wide (**µm**) should the input and exit slits of the spectrometer be for the spectrum in second order?

[8 marks]

Question 2 continued overleaf

Question 2 continued

(c) TRMM/Microwave imager (TMI) has an incident angle of 52.8°. One day, we observed a brightness temperature of 279 K for a rain cloud over the Atlantic Ocean. Suppose that 1) the geometry depth of the rain cloud is 3 km and raindrops are the only attenuation source; 2) the surface temperature is 292.65 K; 3) the air temperature is 282.9 K; 4) the surface reflectivity over the ocean on this incident angle at 19.35 GHz is 0.43; and 5) $k_{ext} = aR^b$, where k_{ext} is the volume extinction coefficient of rain [km^{-1}] and, *R* is the rain rate [mm/hr]. Coefficients *a* and *b* are given in Table 1.

Channel (GHz)	a	b
10.65	0.003	1.187
19.35	0.016	1.094
37.00	0.069	1.019
85.5	0.280	0.847

Table 1: Coefficients used in volume extinction coefficient approximation.

(i) What is the value of the surface emissivity?

[3 marks]

(ii) Prove that the atmospheric transmittance is 0.2.

[8 marks]

(iii) What is the value of the optical depth of the rain cloud?

[3 marks]

(iv) What is the value of the rain rate (<u>**mm/hr**</u>)?

[3 marks]

3.

(a) Consider scattering of light by a large particle in the geometric optics limit.

(i) The liming value of the extinction efficiency is

A. 0.0
B. 0.5
C. 1.0
D. 1.5
E. 2.0

[5 marks]

(ii) If the imaginary part of the index of refraction of the particle is zero, the value of the single scattering albedo is

A. 0.0
B. 0.5
C. 1.0
D. 1.5
E. 2.0

[5 marks]

(iii) If the imaginary part of the index of refraction of the particle is significant, the value of the single scattering albedo is

A. 0.0
B. 0.5
C. 1.0
D. 1.5
E. 2.0

[5 marks]

Question 3 continued overleaf

Question 3 continued

(b) A radar has specifications described in Table 2.

Table 2: Radar characteristics.

Factor	
λ (m)	0.103
Gain of the radar (g)	1.2×10^6
Peak Power (W)	5×10^5
Min. detectable signal (W)	1.3×10^{-14}

(i) The rainfall rate, R, in mm/hr is often estimated using an empirical relationship: $Z = 200\, R^{1.6}$. If the observed radar reflectivity is 30 dBZ what rainfall rate (**<u>mm/hr</u>**) is estimated?

[8 marks]

(ii) The radar equation is given as:

$P_r = \dfrac{P_t \cdot g^a \lambda^b \sigma^c}{(4\pi)^3 r^d}$, where P_r is the receiving power; P_t is the peak power.

Coefficients (a, b, c, d) should be:

A. (2, 2, 1, 2)
B. (2, 2, 1, 4)
C. (2, 1, 1, 4)
D. (1, 2, 2, 4)
E. (1, 2, 2, 2)

[8 marks]

(iii) Assume that a raindrop is a 1 cm diameter sphere and scatters as a Rayleigh particle. Suppose raindrops are distributed in the atmosphere at random, spaced 50 m apart on average. What is the radar reflectivity (**<u>dBZ</u>**) of the distribution? [Hints: $z = \sum_{UnitVolume} D_i^6$]

[9 marks]

Question 3 continued overleaf

Question 3 continued

(c) In an optically thin atmosphere, downward radiance $I^{\downarrow}$ in the direction $-\mu$ at a given optical depth τ can be given as

$$I^{\downarrow}(\tau;-\mu) = I(0;-\mu)e^{-\tau/\mu} + \int_0^{\tau} J(\tau';-\mu)e^{-(\tau-\tau')/\mu}\frac{d\tau'}{\mu},$$

where

$$J(\tau';-\mu) = \frac{\varpi_0 F_0}{4\pi} P(\mu,-\mu_0)e^{-\tau'/\mu_0};$$

F_0 is the solar flux at the top of the atmosphere ($\tau = 0$);
ϖ_0 is the single scattering albedo;
$P(\mu,-\mu_0)$ is the phase function; and
μ_0 is the cosine of the solar zenith angle.

The Atmospheric Radiation Measurement (ARM) program has a ground-based narrow field-of-view radiometer that measures spectral zenith radiance. Please derive the relationship between the observed zenith radiance and optical properties of aerosols and clouds for small optical depth case. Your relationship should be give as the form below:

$$I^{\downarrow} = f(F_0, \varpi_a, P_a, \tau_a, \varpi_c, P_c, \tau_c),$$

where ϖ_c, P_c, and τ_c are cloud single scattering albedo, phase function, and optical depth, respectively; ϖ_a, P_a, and τ_a are aerosol single scattering albedo, phase function, and optical depth, respectively.

[10 marks]

(End of Question Paper)