**Physics of Atmospheres and Oceans: Class Question Sheets**

INSTRUMENTS and MEASUREMENT PROGRAMMES (EARTH)

**IMP.1** A radiometer with a mirror square wave chopper reflecting space (zero radiance) views a black source which fills the field of view. The power incident on the detector is a square wave oscillating between zero and the value

$$P = A\Omega \int_0^\infty B(\tilde{\nu}, T) f(\tilde{\nu})\, d\tilde{\nu}$$

where $A$ is the collecting area, $\Omega$ is the field of view solid angle, $f(\tilde{\nu})$ is the optics transmitance (usually dominated by the bandpass filter) and $B(\tilde{\nu}, T)$ is the Planck spectral radiance of the black source at temperature $T$.

The r.m.s. value of the fundamental component of this square wave is

$$\frac{1}{\sqrt{2}} \cdot \frac{4}{\pi} \cdot \frac{1}{2} P$$

and the signal at the output of the radiometer is

$$S = \frac{\sqrt{2}}{\pi} PGt$$

where $G$ is the overall gain (volts/energy) and $t$ is the measurement (integration) time.

The noise at the output of the radiometer with a detector of given noise equivalent power (NEP) $\epsilon$ is $N = \epsilon G \sqrt{t}$.

Assume the optical bandpass $\Delta\tilde{\nu}$ to be narrow so that the integral can be approximated by $B(\tilde{\nu}, T)\tau_0 \Delta\tilde{\nu}$ where $\tau_0$ is the mean optics transmission in the passband.

(i) Obtain an expression for the signal to noise ratio, and thereby show that the noise equivalent temperature (NET) of the radiometer is given by:

$$\mathrm{NET} = \frac{\pi \epsilon}{\sqrt{2t} A \Omega \tau_0 \Delta\tilde{\nu} (dB/dT)}$$

where $T$ is the source temperature. (NET is defined to be the change in temperature of a black source filling the field of view which produces a change in the signal output equal to the noise).

(ii) Calculate the NET for a source temperature of 240 K for a radiometer with the following characteristics: $A = 0.01$ m$^2$, $\Omega = 10^{-4}$ ster, $\tau_0 = 0.5$, $\epsilon = 10^{-10}$ W Hz$^{-\frac{1}{2}}$ and $t = 1$ s for (a) a filter of width $\Delta\tilde{\nu} = 5$ cm$^{-1}$ at 667 cm$^{-1}$ and (b) a filter of width $\Delta\tilde{\nu} = 20$ cm$^{-1}$ at 2300 cm$^{-1}$. How long would be needed to achieve a NET of 1 K in case (b)? [Answers: (a) $\sim 0.08$ K, (b) $\sim 2.7$ K, $\sim 7$ sec.]

(iii) Assuming that the condensing optics increases the solid angle of illumination at the detector to 1 steradian, what should the area of the detector be? [Answer: 1 mm$^2$.]

Explain why it is necessary to perform frequent radiometric calibrations on orbiting instruments, and describe how this can be done.

**IMP.2** What different kinds of spacecraft orbits can be used for remote sensing of the Earth, and what are their advantages?

For a side scanning satellite instrument in a Sun synchronous orbit at 700 km altitude, calculate to the nearest degree the scan angle needed (assumed symmetric either side) for the extreme profiles on adjacent orbits to be at the same locations at the equator. What is the corresponding zenith angle at the surface?

What (qualitatively) is the effect on the weighting functions if the instrument is a microwave sounder viewing in the 57 GHz oxygen band of scanning to this angle compared with the nadir view?

A satellite instrument in a 90°inclination orbit views the Earth's limb either (a) at 90°to the satellite velocity vector or (b) in the orbit plane. How does the Doppler shift observed due to Earth's rotation and/or satellite velocity compare with typical $CO_2$ line widths in the mesosphere in the two cases if the satellite is at the equator?

How do the results differ when the satellite is at the extreme northern limit of its orbit?

**IMP.3** *(Part of Finals question, 1987)* The transmission, $\tau$, at frequency $\nu$ in the vicinity of a spectral line of strength $S$ centred at frequency $\nu_0$ is given by

$$\tau = \exp\left( - \left\{ \frac{1}{\pi} \frac{S\alpha m}{\alpha^2 + (\nu - \nu_0)^2} \right\} \right),$$

where $\alpha$ is the line width, which is proportional to pressure, and $m$ is the mass per unit cross sectional area of absorber in the path. A selective chopper radiometer consists of two absorption cells of equal length, together with a means of alternately switching radiation emitted by the atmosphere through one or the other cell and onto a detector. The detector output is passed through a phase sensitive detector which selects the component of detector output signal at the chopping frequency. The cells contain the same gas at the same temperature but at different pressures $p_1$ and $p_2$. In both cases the spectral lines are weak and well isolated from each other. The overall response $R(\nu)$ of the system is proportional to the difference $\tau_1 - \tau_2$ between the transmissions of the two cells.

Show that the response at the line centre is zero. Sketch the absorption as a function of frequency for a single line at the two different pressures, and sketch also the resulting radiometer response function.

Show that $R(\nu)$ has maxima at frequencies $\nu_0 \pm \sqrt{\alpha_1 \alpha_2}$ where $\alpha_1$ and $\alpha_2$ are the line widths corresponding to the pressures in the cells.

What are the advantages of such a radiometer? How would it be affected by wind or satellite velocities which cause the atmospheric spectrum to be Doppler shifted?

**IMP.4** *(Finals question 1983)* Draw a block diagram indicating the major components required for an infrared radiometer designed to measure temperature between 10 and 80 km as a function of height with 1.5 km vertical resolution by viewing the limb of the atmosphere from a spacecraft at a height of 700 km

What region of the spectrum, angular field of view, and elevation scan range would be appropriate for such a measurement? Give reasons for your choice, and discuss the implications for the design of the radiometer.

Discuss also the major considerations which determine the size of the entrance optics, and indicate how the radiometer would be accurately calibrated radiometrically in flight.

A radiometer has entrance aperture 0.01 $m^2$, and its bandpass is from 660–670 $cm^{-1}$. The transmittance of the optics is 50% and the field of view is $0.1° \times 1°$. Using the expression for NET given in IMP.1, estimate the integration time needed to obtain a NET of 1 K if the detector NEP is $10^{-9}$ W $(Hz)^{-1/2}$, and the target temperature is 250 K.

How would you choose the orbit to obtain maximum global coverage?

[You may assume that the Planck function is give by $B(\nu, T) = 2\times10^{-11}T^4$ W $m^{-2}$ $ster^{-1}$ $(cm^{-1})^{-1}$ at $\nu = 665$ $cm^{-1}$.]

[10.04]