PH-3021

UMIST

PHYSICS DEPARTMENT

UNIVERSITY OF MANCHESTER INSTITUTE OF SCIENCE AND TECHNOLOGY

BSc/MPhys Physics

Course Code(s): PH-3021

Course Title(s): Climate and Energy

Date of Exam: Monday 19th May 2003 **Time:** 09.30 - 11.00
Duration of Exam: One and a half hours

Please Read Instructions Carefully

ANSWER TWO QUESTIONS

This paper contains FOUR pages (including front cover)

Department of Mathematics Formula Books may be used

P607 Climate and Energy Examination Questions 2003

Question 1

a) Sketch the blackbody curves for radiation emitted from the Sun and the Earth, indicating the temperatures of the blackbodies and the wavelengths at which the maximum radiation occurs. Separately illustrate the fractional absorption of both solar and terrestrial radiation through the entire column of the atmosphere as a function of wavelength and indicate the main absorbing gases.

(8 marks)

b) The Grey Atmosphere is a one-dimensional model of radiative transfer through the atmosphere that considers radiative transfer solely in terms of the wavelength independent upwelling and downwelling long wave radiation without scattering or local heating or cooling. By considering the rates of change of radiation flux in the upward and downward directions as a function of the optical depth through a slice of the grey atmosphere ($dF^{\uparrow}/d\chi$ and $F^{\downarrow}/d\chi$, where $F^{\uparrow}$ and $F^{\downarrow}$ are the upwelling and downwelling fluxes at a level in the atmosphere with optical depth χ), show that the blackbody emission from the layer is given by:

$$B = \frac{F_S}{2\pi}(\chi + 1),$$

where F_S is the short wave flux absorbed at the surface.
Show that the model predicts a discontinuity of $F_s/2$ at the surface and sketch the variation of the up and downwelling radiation fluxes and the blackbody radiation predicted by the model as a function of the optical depth through the atmosphere.

(11 marks)

c) The lower atmosphere is convectively driven with an average lapse rate of 6.5 K km^{-1}. If the optical density in the above model is assumed to vary as
$\chi = \chi_s \exp(-z / H_S)$,
show that the radiative transfer model predicts a temperature of 223 K at a height of 9.1 km. What is the temperature predicted from the lapse rate at this altitude? Using these results, what can you deduce about the transfer of heat above and below this altitude? Assume that the optical density at the surface, χ_s, is unity, z is the altitude and H_S, the scale height, is 5 km. The absorbed short wave flux, F_s, is 240 W/m^2, the surface temperature is 282 K and σ=5.67x10^{-8} $Wm^{-2}K^{-4}$.

(6 marks)

Question 2

a) Discuss the current evidence for climate change

(6 marks)

b) Outline the recent changes in the atmospheric abundance of climatically active gases and aerosols.

(8 marks)

c) What evidence is there for human influenced climate change?

(4 marks)

d) What effects are these changes predicted to have on the future climate of the Earth?

(7 marks).

Question 3

a) Explain the terms "reserve" and "resource" of a fossil fuel.

(2 marks)

b.) The Verhulst Equation describes the change in the amount of cumulative fossil fuel reserve (r), dr/dt, with time in terms of the reserve and total resource, R:

$$\frac{dr}{dt} = cr(R - r) .$$

Sketch how the cumulative reserve, cumulative production and the reserve vary with time.

(4 marks)

c.) Show that the Verhulst equation can be solved to give

$$\frac{r(t)}{R} = \frac{r_0/R}{r_0/R + \left(1 - r_0/R\right)e^{-cR(t-t_0)}} ,$$

where r_0 is the amount of reserve held at some time t_0.

(9 marks)

d.) In 1932 the world's proven cumulative reserves of crude oil stood at 0.3 Q, by 1969 this figure had risen to 3.1 Q. One estimate of the total crude oil resource is 7.4 Q. In which year will 95 % of the world's crude oil resource have been consumed (state any assumption you need to make)? If the total resource estimate is doubled, in what year will only 5 % remain?

(8 marks)

e.) Comment on the role oil will play as a future world energy resource in the light of your answer

(2 marks)

Question 4

a) The Carnot engine is an idealized thermodynamic heat engine. Describe the four parts of the engine cycle in terms of the thermodynamic processes taking place, sketch how the pressure varies as a function of volume and the temperature as a function of entropy. Derive the Carnot efficiency, ε, in terms of the temperature of the heat source and sink by defining the heat and entropy changes through the cycle.

(12 marks)

b) Using typical values for the hot and cold reservoirs in a power station, calculate its ideal Carnot efficiency. What are the major losses that prevent this ideal efficiency being achieved in a real system?

(5 marks)

c) A business plans to replace its current heating system that must deliver 300 MWh of space heating per year with either an oil fired heating system or an electrically driven heat pump. The business requires an office temperature of 20 C, what must the maximum temperature of the cold heat sink be for the heat pump option to be a more economical option? The cost of oil is around 15 p/litre and electrical power is charged at around 6.5 p/kWh. Neglect installation costs. The energy of combustion of heating oil is 3×10^7 J/litre.

(6 marks)

d) Why can a water cooled heat pump offer improved performance over an air cooled system?

(2 marks)