SEMESTER 2 EXAMINATION 2014-2015

INTRODUCTION TO ENERGY AND THE ENVIRONMENT

Duration: 120 MINS (2 hours)

This paper contains 8 questions.

Answer **all** questions in **Section A** and **only two** questions in **Section B**.

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins on it.

An outline marking scheme is shown in brackets to the right of each question.

A Sheet of Physical Constants is provided with this examination paper.

Only university approved calculators may be used.

A foreign language word to word® translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

Section A

A1. An exponentially growing population starts at N_0 and grows at a constant annual rate $r_1 = 1.2\%$ for ten years until it reaches a value N_1. The growth rate then changes to $r_2 = 0.9\%$ and stays constant for another ten years until the population reaches N_2. Sketch what the population vs time would look like on a $\log_{10}$-linear graph, indicating the slope of each section. How much longer will it take the population to reach $2N_1$ at the new growth rate r_2 than if the growth rate had remained unchanged at r_1? [6]

A2. Briefly describe the two Suess Effects and explain their relevance to discussions about human-induced climate change. [5]

A3. Calculate how many minutes it takes to boil 1.7 litres of water using a 2000 W electric kettle. You may assume that the starting temperature of the water is 10°C and that the kettle is 100% efficient at converting electrical energy to heat. The volumetric heat capacity of water is 1.2 Wh/(l°C). [2]

A4. The power usage of a moving car can be modelled as

$$P = \frac{1}{\epsilon}\left(\frac{m_{car}v^3}{2d} + \frac{c_d \rho_{air} A_{car} v^3}{2} + C_{rr} m_{car} g v\right).$$

Briefly explain, in one or two sentences each, the physical source of energy loss that each of the three terms in this equation refers to. What is the significance of the factor ϵ? [4]

A5. Give a short definition of each of the two types of nuclear reaction that can (in theory) be used to generate power. List one advantage and one disadvantage of each. [3]

Section B

B1. (a) Sketch a simple model of the Earth's surface and atmosphere that can be used to predict the surface temperature T_S. The model should incorporate the direct reflection of sunlight due to albedo and a single layer of atmosphere. Draw and label all the incoming and outgoing fluxes. [5]

(b) Summarise Kirchhoff's law of thermal radiation and give a brief physical justification of why it must be true. [2]

(c) Using the model sketched in (a), apply Kirchhoff's law at the surface level and at the atmosphere level to derive two equations for the surface temperature T_S and the atmosphere temperature T_A. [4]

(d) Explain how a change in any parameter of the model can be expressed in terms of the radiative forcing ΔF. Show that the radiative forcing due to a change in albedo ΔA is given by

$$\Delta F = \frac{-\Delta A S_\odot}{4}.$$

[7]

(e) The radiative forcing due to the eruption of Mount Pinatubo in 1991 was $\Delta F = -2.5$ W/m^2. Assuming that this radiative forcing was caused by a change in albedo, calculate the change in albedo ΔA needed to produce this amount of radiative forcing. You may assume that the solar constant $S_\odot = 1400$ W/m^2. How does this compare to the level of radiative forcing produced by CO_2 doubling (that is, doubling of atmospheric CO_2 concentrations over pre-industrial levels)? [2]

TURN OVER

B2. (a) Estimate how much power, in kWh/day, is used on average per passenger on plane flights, assuming one long-distance round trip per year. You may assume a range of 8000 miles with a fuel capacity of 240000 litres, and a passenger capacity of 400 persons for a B747 jet. You may further assume an energy density of 10 kWh/litre of fuel. [2]

(b) Show that the power required to keep an airplane up in the air and moving forward can be described as

$$P = \frac{1}{\epsilon}\left(\frac{m_{plane}^2 g^2}{2\rho_{air}A_{tube}v} + \frac{\rho_{air}A_{tube}v^3}{2}\right),$$

where ϵ is the engine efficiency, m_{plane} the mass of the plane, ρ_{air} the air density, v the speed of the plane, and A_{tube} the cross sectional area of the air tube created by the plane as it moves through the air. [13]

(c) The plane-based energy cost can be expressed as $EC = \frac{1}{\epsilon} m_{plane} g (c_d f_A)^{1/2}$ where $(c_d f_A)^{1/2}$ is the drag-to-lift ratio. Based on this equation, how can the energy consumption of planes be improved? Are any of these approaches realistic? [5]

B3. (a) Solar energy is a pervasive form of energy that has many effects on Earth. List four modes of solar energy that can be used for power production. You may include direct (i.e. first order) and indirect (second order) modes of power production. [4]

(b) On average, the solar power reaching the surface of the Earth (after albedo reflection and atmospheric absorption) is 170 W/m^2. This is, however, derived assuming that the sun is directly overhead. The UK is at a latitude of 52° North, and Earth's spin axis has a tilt of 23°. How much solar power does the UK receive in mid-summer, in mid-winter, and on average? Hint: in summer, the spin axis is tilted towards the Sun, in winter, it is tilted away from the Sun. [8]

(c) Assuming an average incoming solar power of 110 W/m^2 for south-facing roofs, and further assuming an efficiency of 50% for solar thermal panels, how much power can be produced in the UK using solar thermal? You may further assume an average 10 m^2 of south-facing roof area per person to put the solar thermal panels on, and a population of 60 million people in the UK. [2]

(d) Explain in no more than 100 words the basic physics behind the photovoltaic effect and why there is a limit to the efficiency of photovoltaic cells. [6]

END OF PAPER