Answer THREE questions

The numbers in square brackets indicate the provisional allocation of maximum marks per sub-section of a question.

Relevant symbols and numerical values are as follows -

γ - ratio of specific heats (C_P/C_V); P - pressure; ρ - density; B – magnetic induction; j – current density; t –time; v – velocity; g – acceleration due to gravity; T –temperature; r – radial distance; E – energy; g_s – statistical weight
T_e - electron temperature; ε_λ - emission coefficient;
κ_λ - mass absorption coefficient;
$\tau_\lambda = \kappa_\lambda \rho$ - optical depth; $S_\lambda = \varepsilon_\lambda/\kappa_\lambda$ - source function; I_λ - specific intensity
$\mu = \cos\theta$ where θ is the angle between the radiation slant path and the vertical direction;

1 AU - 1 Astronomical Unit or mean Sun-Earth distance = $1.5\text{x}10^{11}$ m;
G = $6.67\text{x}10^{-11}$ Nm^2/kg^2 (Universal gravitation constant);
$M_0 = 1.989\text{x}10^{30}$ kg (Solar mass);
$R_0 = 6.96\text{x}10^8$ m (Solar radius);
$L_0 = 3.85\text{x}10^{26}$ W (Solar luminosity);
k_B - Boltzman's constant = $1.38\text{x}10^{-23}$ Joule K^{-1};
$m_p = 1.67\text{x}10^{-27}$ kg (Proton mass);
c = $2.997\text{x}10^8$ m/s (Velocity of light).
$\mu_0 = 4\pi \text{ x } 10^{-7}$ Hm^{-1} (magnetic permeability of free space)
h = 6.63 $\text{x}10^{-34}$ Js (Planck's constant)

Equations given:

Collision rate for an allowed transition is approximated to:

$$C \approx \frac{const}{T^{1/2}} e^{-E/k_B T}$$

The Saha equation for dielectronic capture and the reverse process of autoionization is:

$$\frac{A_a}{C_s} = \frac{2(2\pi mkT)^{3/2}}{h^3} \frac{1}{g_s} e^{E_s/kT}$$

PLEASE TURN OVER

1. Energy is transported from the Sun’s core to the photosphere by radiation and convection. With the aid of a simple diagram of the solar interior, indicate those regions of the sun in which each process dominates. Show also the variation of temperature and density from Sun centre to Photosphere. **[4]**

Describe the granulation pattern seen on the surface of the Photosphere and indicate how this provides evidence for the operation of convection in the interior. Explain, with reference to the temperature gradient that exists between core and surface, why you would expect convection to replace radiation as the dominant energy transfer process. **[5]**

Specify the condition for the onset of convection and derive an expression for the critical value of the temperature gradient at which convection will occur. **[6]**

Describe the supergranulation, indicating its relationship to the observed chromospheric network and the photospheric magnetic field. Describe how the network changes in appearance with increasing temperature and explain how present day models account for this. **[5]**

CONTINUED

2. Given that nuclear energy release is required to explain the observed solar luminosity, what are the factors that determine the most likely nuclear reactions for energy generation in the solar interior?

[4]

Describe fully the proton-proton chain of reactions, paying particular attention to the production of neutrinos. With the aid of a diagram indicate the energy spectra of the neutrinos that are produced in the proton-proton chain. **[5]**

Outline the principal experiments that have been undertaken to detect solar neutrinos and indicate their energy thresholds for neutrino detection on the neutrino spectral diagram. Summarize the results of these experiments that have been obtained to date.

[6]

A comparison of the above results with the calculated neutrino fluxes that result from the standard solar model indicates a significant discrepancy. Summarize briefly the possible explanations for this discrepancy. State which explanation you favour and give reasons for your choice. **[5]**

PLEASE TURN OVER

3. What is the sunspot cycle? Describe how it is characterized and say what information about solar magnetic activity can be obtained from such studies. Indicate the observed characteristics of active regions in the photosphere, chromosphere and corona. **[5]**

If the magnetic pressure inside a sunspot is 4×10^4 Nm^{-2} where the gas density is 1.5×10^{24} particles m^{-3} and the temperature of the surrounding gas is 5700K, what is the temperature of the sunspot assuming the density to be the same for both the sunspot and the surrounding photosphere? **[4]**

Describe the Babcock model of the solar cycle with appropriate diagrams and show how the operation of the cycle may be considered in five stages. **[8]**

Outline the methods available for measuring the magnetic field strength in the solar atmosphere. What are the difficulties encountered in measuring the field in the corona? How are they overcome so that information on the field in this region may be obtained? **[3]**

CONTINUED

4. Give an account of the discovery of high coronal temperatures by Grotrian and Edlén, and describe the appearance of the corona in the visible, EUV and X-ray regimes. Include a description of the changes in appearance of the white-light corona over the solar cycle and the reasons for this.

[6]

Calculate the typical speed of coronal electrons and explain **quantitatively** why the Fraunhofer lines are essentially invisible in the K-corona. Use the Hα line at 6563 Å as an example.

[5]

Describe the dominant atomic processes operating in the corona, including a description of the formation of dielectronic satellite lines. Discuss the two principal methods for determining the temperature of the coronal plasma in solar flares.

[9]

PLEASE TURN OVER

5 a) Describe the differences in the properties and origins of the fast and slow components of the solar wind, including results from spectral line observations made by the UVCS instrument on SOHO.

[4]

Estimate the temperature of the plasma involved if protons are observed to have an outflow velocity of $v=2.5\text{x}10^5$ ms^{-1} from a coronal hole.

[2]

Using the approximation that this plasma is in thermal equilibrium, what velocity would you expect to be obtained by the O ions present? Discuss how this compares with the actual measured velocities for O ions and draw conclusions from the comparison. Outline any other observational evidence to support these conclusions.

[6]

b) Describe what is meant by a coronal mass ejection (CME): specifying general properties and methods of observation.

[2]

Assuming that a CME can be well represented by a sphere of radius R_0, and that the corona is fully ionised, calculate the mass of a CME for a typical coronal density $N_e=10^{13}$ m^{-3}. What then is the mass flow rate due to CMEs at solar maximum? How does this compare to with the solar wind mass flux?

[5]

By considering the typical average speed of a CME, calculate the time it would take for the disturbance to reach the Earth, in the case of an Earth-directed halo event.

[1]

END OF PAPER