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); h - Planck's constant; P - pressure; ρ - density; B – magnetic induction; j – current density; t –time; v – velocity; g – acceleration due to gravity; T –temperature; r –radial distance

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 = 1.5×10^{11} m;

G = 6.67×10^{-11} Nm^2/kg^2 (Universal gravitation constant);

M_0 = 1.989×10^{30} kg (Solar mass);

R_0 = 6.96×10^{8} m (Solar radius);

L_0 = 3.85×10^{26} W (Solar luminosity);

k_B - Boltzman's constant = 1.38×10^{-23} Joule K^{-1};

m_p = 1.67×10^{-27} kg (Proton mass);

c = 2.997×10^{8} m/s (Velocity of light).

$\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1} (magnetic permeability of free space)

Equations given:

Ampere's law: $\tilde{N}xB= m_0 j$

Faraday's law: $\tilde{N}xE = -¶B/¶t$

Gauss' Law: $\tilde{N}.B = 0$

Ohm's Law: $j = \sigma(E + vxB)$

$\nabla x(\nabla xB) = \nabla(\nabla.B) - \nabla^2 B$

PLEASE TURN OVER

1.

The specific intensity, I_λ, from the top of a plane parallel infinite atmosphere along a direction making an angle $\theta = \cos^{-1}\mu$ with the vertical is given by

$$I_\lambda(0, \mu) = (1/\mu) \int S_\lambda(\tau) \exp(-\tau/\mu)\, d\tau$$

By considering the case of a source function that varies linearly with optical depth, such that $S_\lambda(t_\lambda) = S_\lambda(0) + b\,\tau_\lambda$ where b is a constant, derive the Eddington-Barbier relation which states that $I_\lambda(0,\mu) = S_\lambda(\tau_\lambda)$ when $\tau_\lambda = \mu$. **[5]**

Assuming a plane-parallel photosphere in Local Thermodynamic Equilibrium, explain how the radial variation of temperature with τ_λ in the photosphere can be established from observations of solar limb darkening. The meaning and relevance of the assumptions should be clearly explained, as should the phenomenon of limb darkening. **[10]**

Show that the dependence of temperature on radial depth can be established assuming hydrostatic equilibrium applies, and that the opacity κ_λ is known. Sketch the variation of temperature with radius that is obtained from the above assumptions. Why does the real temperature variation with radius begin to depart dramatically from the derived values near the top of the photosphere? **[5]**

CONTINUED

2.
Give a brief account of the phenomenon of internal acoustic wave propagation and explain what defines the boundaries of the "cavity" within which the waves propagate. How are such waves thought to be excited? **[8]**

How can the identification and study of these wave modes provide information on

a) the location of the base of the convection zone and
b) the rotation rate in the interior of the Sun? **[6]**

Which oscillatory mode is believed to operate in the radiative interior of the Sun near the core? Show that for a parcel of gas in the interior displaced upwards by buoyancy under adiabatic conditions, the characteristic or Brunt-Vaisala frequency is given by

$$N_{BV} = [(g/T) \{ | dT/dr |_{RAD} - | dT/dr |_{AD} \}]^{1/2}$$ **[5]**

Why is the study of this mode likely to be important for understanding the solar interior? **[1]**

PLEASE TURN OVER

3.
What are the observed characteristics of solar active regions? List the three stages in their evolution and indicate how the dispersal of activity leads to the formation of a general polar magnetic field. **[6]**

The solar cycle has a period of approximately 11 years. Describe how this cyclic behaviour has been characterized since the year 1610 and indicate what information on the nature and behaviour of the sun's magnetic activity has been obtained from these studies. **[5]**

Give details of the possible sources of coronal heating. What are the energy requirements that must be met in each type of region? Sketch the variation of non-thermal velocity with temperature.

[5]

If an emission line formed in an active region in the corona has a non-thermal velocity =11 kms^{-1} and the motions that produce the broadening are isotropic, use the mechanical energy density associated with the motions to calculate the energy flux due to the passage of Alfven waves. You should assume a mass density $\rho=1.99\times10^{-12}$ kgm^{-3} and a magnetic field strength $B=3\times10^{-3}$ T.

[2]

How does this compare with the energy requirements for active region heating? Based on this and other evidence, is Alfven wave heating a viable mechanism in active regions?

[2]

PLEASE TURN OVER

4. What is a solar flare? Describe the principal observable flare phenomena.

If the energy for these events is stored beforehand in a region with a pre-flare number density, $n=10^{16}$ m^{-3}, volume $V=10^{21}$ m^3, temperature $T=2x10^6$ K and magnetic field strength B=100mT, discuss the nature of the available energy sources. **[7]**

Using the vector equations given on the first page derive the induction equation for the time variation of magnetic flux in a conducting plasma.

Assuming the classical conductivity is given by

$$\sigma_0 = 10^{-3}\ T^{3/2}\ (\text{Ohm m})^{-1}$$

and assuming a typical pre-flare temperature of $2x10^6$K and a length scale $L{\sim}2x10^6$m, derive the diffusion timescale. **[6]**

What implications does this result have for proposed models of the flare energy release? Describe what is meant by the term magnetic reconnection and sketch the geometry of the magnetic field in which neutral sheet reconnection occurs. Can this type of reconnection account for the observed energy release rates? **[7]**

PLEASE TURN OVER

5. Give a brief summary of the properties of the solar wind and describe how its existence was inferred prior to the era of space observations. Why must a solar wind exist? What are the implications of a slow and a fast wind?

[7]

What are the assumptions used in the Parker model of the Solar wind flow? Using the equations of momentum and energy conservation, show that the expression for wind velocity as a function of radial distance from the sun is given by:

$$[v^2 - kT/m_p](1/v)dv/dr = (2kT/m_p r) - (GM_\Theta/r^2)$$

You may also assume that the temperature is constant throughout the wind.

Indicate the possible solutions graphically and show which one is closest to representing the observed solar wind flow.

[6]

What have we learned about the origins of the solar wind from recent studies by. e.g Yohkoh, Ulysses and SOHO? What effect does the solar cycle have on the solar wind?

[7]

END OF PAPER

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