[4C14/Solar Physics/2000]

Answer THREE questions

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; k – Boltzmann's constant; n – number density; T_e – electron temperature; g – acceleration due to gravity; ln Λ - Coulomb logarithm; r_0 – classical electron radius; α - fine structure constant; S – flare area, σ_B – Bremsstrahlung cross-section; ε - photon energy; m_e – electron mass; c – velocity of light, Z – atomic number; m_p – proton mass; E – electron energy; Ω - gravitational potential energy

$G=6.67\text{x}10^{-11}\text{Nm}^2\text{kg}^{-2}$ (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);
1AU= 1 Astronomical Unit or mean Sun-Earth distance=$1.5\text{x}10^{11}$m
$m_p=1.67\text{x}10^{-27}$kg
$k=1.38\text{x}10^{-23}\text{JK}^{-1}$

1.
Describe the Sun's evolution from the start of the initial gravitational collapse to the formation of a red giant star. Indicate, with diagrams, how the solar luminosity, radius and effective temperature evolve with time.

[7]

Assuming the relevant form of the Virial theorem to be

$$3\int_0^{M_0} \frac{P}{r} dM + \Omega = 0$$

where M_0 is the mass of the Sun and Ω is the gravitational potential energy, show that

i) the Sun could not have sustained its luminosity for 4.6×10^9 years on its originally available gravitational potential or thermal energy and

ii) the decrease in gravitational potential energy as the primordial gas cloud collapses to form the Sun leads to an increase in the Sun's internal energy

[6]

Indicate the mechanisms that are believed to transport energy from the core to the solar surface and derive an expression for the temperature gradient $\frac{dT}{dr}$ established by the process that operates in the range $0.25\ R_0 < r < 0.79\ R_0$.

What sets the above radial boundaries?

[7]

CONTINUED

2.
What is the principal source of the Sun's energy supply? [2]

Discuss fully the proton-proton chain of reactions for the Sun. Name the nuclear reaction chain which operates at higher temperatures in more massive and evolved stars.

[6]

The standard model of the Sun's interior suggests the production of about three times more neutrinos than are in fact observed in the earth-based ^{37}Cl neutrino detection system. Discuss possible reasons for the deficit.

[6]

Describe the basic principles of the Super-K atmospheric neutrino experiment and outline the results. How does the MINOS Earth-based experiment, which employs an accelerator at a large distance from a neutrino detector, operate? Indicate how MINOS could confirm the results of Super-K.

[6]

CONTINUED

3.

What is the sunspot cycle? Describe how it is characterized and 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 $4x10^4$ Nm^{-2} where the gas density is $1.5x10^{24}$ particles m^{-3} and the temperature of the surrounding gas is 5700 K, 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 can be considered in five stages. [8]

Outline the methods available for measuring the magnetic field strength in the solar atmosphere. What difficulties arise for measurement in the corona and how are they reconciled so that information on the field in this region can be obtained? [3]

CONTINUED

4.
What information can be obtained about the physical state of the corona by observing the visible F and K components? Explain also the importance of space observations in understanding the transition region and corona of the Sun.

[8]

What is meant by Local Thermodynamic Equilibrium? Where in the solar atmosphere is this a valid assumption? Describe the processes responsible for establishing the ionization state of the corona and how a knowledge of this allows emission line intensities to be calculated.

[8]

Explain what is meant by the magnetic Reynolds number and describe its significance. Indicate its typical value in the solar atmosphere and the implications of this for coronal heating theories?

[4]

5.
Sketch a typical flare spectrum for soft X-ray (SXR) emission from Ca XIX, hard X-ray and γ-ray wavelengths. Identify the radiation processes responsible for the emission in each case, including the SXR continuum.

[5]

Outline the differences between the thin and thick target cases for hard X-ray production in flares and then discuss the difficulties in deducing the injected electron spectrum from observations. What impact will the NASA HESSI space mission have on this problem? Describe also the standard thick target flare model – what is the observational evidence in favour and against this scenario?

[9]

Assuming that the injected electron spectrum $F(E_0)$ has the form

$$F(E_0)=AE_0^{-\delta}$$

and that the resulting thick target Bremsstrahlung flux at the Earth is given by

$$I(e) = \frac{S}{4pR^2}\frac{1}{C}\int_{E_0=e}^{\infty} F(E_0)\int_{e}^{E_0} E s_B(e,E)\,dE\,dE_0$$

where $C=2\pi e^4 \ln\Lambda$

and $$s_B(e,E) = \frac{8ar_0^2 m_e c^2 \overline{Z^2}}{3eE}\ln\frac{1+(1-e/E)^{1/2}}{1-(1-e/E)^{1/2}}$$

show that the observed hard X-ray spectrum also has a power-law form.

[6]

END OF PAPER