PRIFYSGOL ABERYSTWYTH UNIVERSITY

ADRAN FFISEG

DEPARTMENT OF PHYSICS

SEMESTER 1 EXAMINATIONS, JANUARY 2026

PH39620 – Astrophysics I: Physics of the Sun

Time allowed – 3 hours

- **Full marks can be attained for complete answers to ALL eight questions in Section A and TWO questions from Section B**
- **The numbers in brackets after the questions indicate the allocation of marks for each question.**
- **Only calculators from the Casio FX83, FX85 or FX991 range may be used.**
- **A booklet of mathematical formulae and standard constants will be provided.**
- **Only a 1 side of A4 size Summary Sheet is allowed.**
- **MAE MODD I FYFYRWYR GYFLWYNO ATEBION I'R PAPUR HWN NAILL AI YN Y GYMRAEG NEU'R SAESNEG**
- **STUDENTS MAY SUBMIT ANSWERS TO THIS PAPER IN EITHER WELSH OR ENGLISH**

Once seated, students may complete the front cover of the answer book(s) and the attendance slip ONLY.

DO NOT TURN THE EXAMINATION QUESTION PAPER OVER UNTIL INSTRUCTED TO DO SO.

Section A

Attempt ALL questions in the booklets provided

1 Describe the difference between the properties of low- and high-degree modes of solar photospheric global waves, and point out what makes low-degree modes, particularly the $l = 0$ mode, more important than the other, higher-degree, modes. [5]

2 Explain how time-distance analysis works in helioseismology and what it can be used for. [5]

3 Use the notions of 'random walk' and 'mean free path' to explain why the photons reaching the Earth from the Sun were generated about a million years ago. [5]

4 The average kinetic energy of a particle is given by $\frac{3}{2}kT$, where $k = 1.38 \times 10^{-23}\mathrm{m}^2\ \mathrm{kg}\ \mathrm{s}^{-2}\mathrm{K}^{-1}$ is the Boltzmann constant. Find the minimum temperature, which is required to overcome the Coulomb barrier, $\frac{z_1 z_2 e^2}{4\pi\varepsilon_0 r}$, between two protons assuming that $r = 10^{-15}\mathrm{m}$. Here r is the separation distance, z_1 and z_2 are the atomic numbers, e is electron charge, and $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C}^2\mathrm{s}^2\,\mathrm{kg}^{-1}\mathrm{m}^{-3}$ is the permittivity of free space. [5]

5 Parker's isothermal wind equation: $\left(1 - \frac{c_s^2}{v^2}\right) v \frac{\mathrm{d}v}{dr} = \frac{2c_s^2}{r^2}(r - r_c)$, where $c_s = \sqrt{\frac{RT}{\mu}}$ is the sound speed, $r_c = \frac{GM_\odot \mu}{2RT} = \frac{GM_\odot}{2c_s^2}$ is the critical point.

Use Parker's equation to explain why the solar wind, starting out sub-

sonically at the coronal base, $r = 1.2R_{\odot}$, cannot accelerate to become supersonic if the temperature is too high.

[5]

6 What is the role of magnetic tension and magnetic pressure in the Kippenhahn-Schlüter model of a solar prominence?

[5]

7 State the meaning of 'gyrofrequency' for a proton moving in a uniform magnetic field of 1.5 Gauss. Calculate the frequency.

[5]

8 The group velocity of the plasma wave may be written as

$$v_g = \frac{3}{2}\left[\left(\frac{\omega_p}{k}\right)^2 + \frac{3}{2}v_{th}^2\right]^{-1/2} v_{th}^2$$

where ω_p is the plasma frequency, k is the wavenumber and v_{th} is the most probable thermal speed for the electrons.

a) Find the group velocity at the small ($k = 0$) and large wavenumber ($k = \infty$) limits.

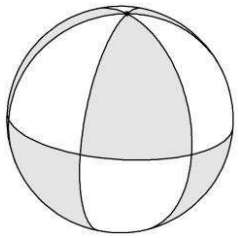
b) When the plasma temperature is 0, explain why the plasma wave becomes a non-propagating oscillation.

c) Does the plasma wave produce a magnetic field perturbation? [5]

Section B

Answer TWO questions

9 a) Give the radial order, n, eigenvalue, L, harmonic degree, l, and azimuthal order, m of a p_2 mode visualised below:

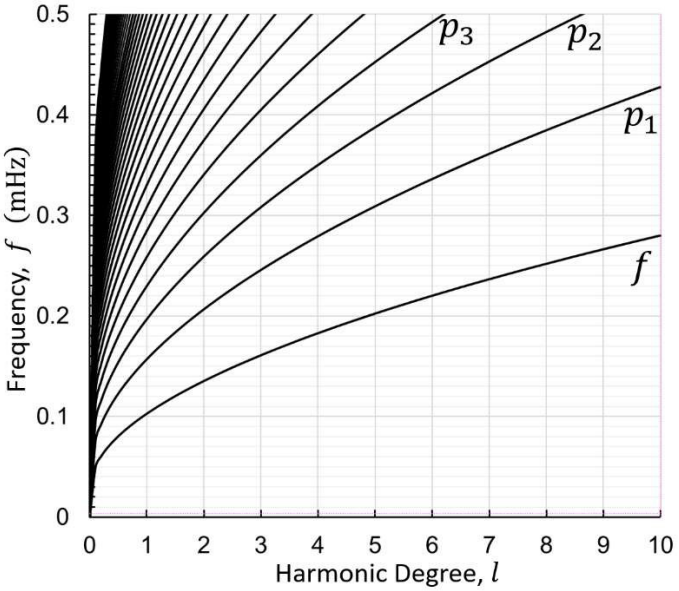


[4]

b) Make a sketch of a sectoral mode with an eigenvalue less than that of the p_2 mode above. Give both the harmonic degree and azimuthal order of this sound wave mode in the solar interior.

[3]

c) Name the plot below and work out the oscillation period of the p_2 mode described in question (a).



[5]

d) Using plane-wave approximation, show that the propagation speed, v, of the p_2 mode, introduced in question (a), is proportional to the distance, r_{tp}, of the turning point from the solar centre, and also give the propagation direction of the wave at that point.

[3]

e) In a layer at depths $d = 580 - 610\ \mathrm{Mm}$ in the solar core, where the turning point of the p_2 mode is, the radial profile of the plasma temperature, T, and sound speed, v, can be approximated as:

$$T = Ar \quad \text{and} \quad v = B\sqrt{T}$$

where: $A = 5 \times 10^{-3}\ \mathrm{K\,m^{-1}}$ and $B = 70\ \mathrm{m\,s^{-1}\,K^{-\frac{1}{2}}}$.

Find the depth, $d_{\mathrm{tp}} \equiv R_{\mathrm{sun}} - r_{\mathrm{tp}}$, of the turning point of the p_2 mode.

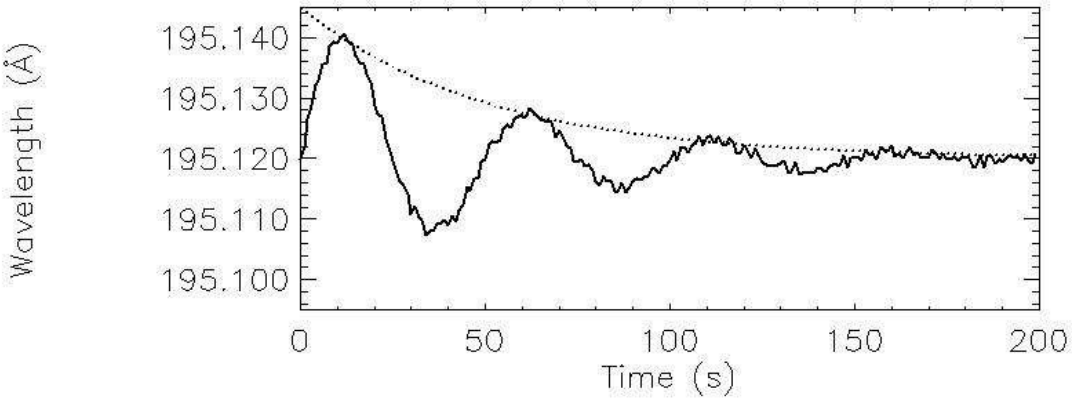
The plane-wave approximation formula is:

$$k_{\tan} = \frac{L}{r} = \frac{\sqrt{l(l+1)}}{r}$$

The dispersion relation for sound waves is $\omega = kv$, and the solar radius is $R_{\mathrm{sun}} \approx 700\ \mathrm{Mm}$

[5]

10 Satellite data were used to study oscillations of a solar coronal loop that has a length of 50 Mm. A time series in the 195.12 Å spectral line (solid curve in the figure) was obtained and the time series was identified as a damped fast kink oscillation. Answer the following questions about these data:



a) Briefly explain the importance of MHD waves in the solar atmosphere.

[3]

b) List 3 characteristic features of fast kink oscillations.

[3]

c) Find the period of the observed oscillations and provide support to the argument that the observed time series represents a magnetically driven fast kink oscillation rather than a slow magnetoacoustic oscillation.

[4]

d) Determine the maximum amplitude $\frac{\Delta\lambda}{\lambda}c$ of the observed oscillations in $\mathrm{km\ s^{-1}}$.

[3]

e) Determine the damping time of the oscillations, τ, by approximating the damping with a decaying function $D(t) = A\exp\left(-\frac{t}{\tau}\right) + W$ (dotted curve in the figure), where A is an unknown and W is the rest wavelength of 195.12 Å.

You may use the following values for the decaying function: $D(10) = 195.14$ Å and $D(45) = 195.13$ Å

[7]

11 A fast magnetohydrodynamic wave is propagating along the x-axis while the background magnetic field $\mathbf{B}_0$ is along the z- axis. The phase speed of the wave can be written as

$$\frac{\omega}{k} = \sqrt{v_A^2 + v_S^2},$$

where v_A is the Alfvén speed and v_S is the proton sound speed. The wave produces a fluid velocity perturbation which only has an x-component.

a) Given Ohm's law, $\mathbf{E} + \mathbf{u} \times \mathbf{B} = 0$, determine which component of the wave's electric field is non-zero.

[5]

b) Given Faraday's law in the usual notation:

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

determine the non-zero component (or components) of the perturbed magnetic field.

[5]

c) Is the wave compressive? Give your reasoning.

[5]

d) The Poynting vector can be written as $\mathbf{E} \times \frac{\mathbf{B}}{\mu_0}$. Discuss the physical meaning of the wave in terms of energy transport due to the wave.

[5]

END OF PAPER