Physics of Stars 2021/2022

Exam (40% of grade)

Monday 20th June, 16-18

Important Notes.

- You are allowed to bring a self-made "cheat sheet" that can cover both sides of one A4.
- No other notes or books, nor any internet connected devices are allowed.
- You can use a calculator.
- Write your name and student number clearly on *all* the pages that you hand in
- Please make sure your handwriting is legible.

The exam consists of 3 questions, and each question is worth 20 points, and the final grade for this exam will be the sum of these points normalised to a mark out of 10.

Tips

- Read all the questions and sub-questions carefully before answering.
- Give concise answers to questions. Answers that look like everything known about a subject has been written down without regard to the actual question risk to be penalised.
- If the result of a calculation yields values that do not make sense to you (the order of magnitude is wrong), but you can't find the error, write a comment indicating the order of magnitude of the value you would have expected and why.
- Note that on the last page there is a list of physical and astronomical constants that may prove useful.

1. **Stellar Evolution** [20 pts]

   (a) Make a sketch of a Hertzsprung-Russell Diagram. *[9 pts]*

   Make sure to include the labels on the axes, and the approximate ranges of values on each axis. Also mark the present position of the Sun, and state what are the X and Y axes values of this position in the units of your sketch. Also carefully identify the following stellar evolution phases:

      i. the main sequence

      ii. the red giant branch

      iii. the horizontal branch

      iv. the asymptotic giant branch

      v. the white dwarf cooling sequence

   (b) For each of the above list of stellar evolution phases explain what is happening in and around the core of a solar mass star. *[5 pts]*

   (c) Using Einstein's mass-energy equation, estimate the amount of energy (in MeV) released during hydrogen burning in stars by the transformation of 4 ^{1}H nuclei into 1 ^{4}He nuclei, and give the fraction of the mass of the fusion material that is converted into energy. *[3 pts]*

   (d) Estimate the time the Sun can spend burning hydrogen in its core, assuming that its luminosity remains constant and that 10% of its mass is in the core. *[3 pts]*

2. **Radiative Transfer** [20 pts]

   (a) With the help of a sketch, explain the radiative transfer equation given below, for radiation passing through a layer (or slab) of plasma. *[7 pts]*

   Make sure to define all the variables and the terms in the equation.

$$\frac{u}{\rho}\frac{dI_\nu(z,u)}{dz} = -k_\nu I_\nu(z,u) + j_\nu$$

   (b) If a single beam of radiation with specific intensity I_ν^0 arrives perpendicular to the surface of a cold cloud of gas with zero emissivity and constant density and opacity, find the intensity of this radiation on the other side of this cloud. *[4 pts]*

   (c) Explain what is meant by the optical depth of a layer (or slab) of plasma, and write down the equation that defines its dependencies. *[2 pts]*

   (d) Show how to rewrite the equation of radiative transfer given above in terms of optical depth instead of z. Explain how this leads to a definition of the source function, and why this is important for stars. *[3 pts]*

   (e) How is the a mean free path of a scattering photon defined? How is the total distance that this photon will travel defined in terms of the number of scattering steps? Thus, estimate how many steps, and thus long it will take for a photon to travel from the core to the surface of the Sun, if you can assume only scattering is important and that the mean free path is always l= 1 mm throughout the whole Sun. *[4 pts]*

3. **Stellar Spectra** [20 pts]

(a) From which part of a star does its optical spectrum originate? *[1 pt]*

(b) How do you determine the type of a star by looking at its optical spectrum? what features do you look for and which physical parameter dominates the differences seen between different spectral types? *[3 pts]*

(c) Explain what is shown in Figure 1. *[6 pts]*

State what are the missing axis labels, who first made this plot and on which 2 well known equations is it based upon. State which aspects of this plot do these 2 well known equations explain.

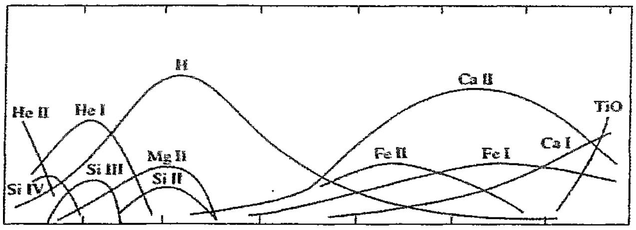

Figure 1: What is shown here?

(d) Why do spectral type K stars have stronger absorption lines of Ca II in their spectra than A-type stars? *[3 pts]*

(e) Why do only the most massive stars have He I absorption lines in their spectra? *[2 pts]*

(f) Describe what is meant by the "metallicity" of a star? *[1 pt]*

(g) What is the main origin of the following chemical elements *[4 pts]*:

i. Carbon (^{6}C)

ii. Iron (^{26}Fe)

iii. An s-process element, like Technetium (^{43}Tc).

iv. An r-process element, like Europium (^{63}Eu)

Physical constants

Be careful that in the study of stellar physics sometimes the same symbol is used with different meanings and thus different definitions or values, so be very careful of the context when looking up symbols here. For example the u used in the equation in question 2 is **not** the same as the u given here.

Constants	Symbol	Value	Units (cgs)
Speed of light	c	$2.99792458 \times 10^{10}$	$\mathrm{cm\,s^{-1}}$
Mass of electron	m_{e}	5.4857990×10^{-4}	u
Mass of proton	m_{p}	1.0072765	u
Mass of ^{4}He atom	m_{He}	4.0026032	u
Atomic mass unit	u	1.660540×10^{-24}	g
		931.5	$\mathrm{MeV/c^2}$

Astrophysical standard values

Constants	Symbol	Value	Units
Solar mass	$M_{\odot}$	1.9891×10^{33}	g
Solar radius	$R_{\odot}$	6.95508×10^{10}	cm
Solar luminosity	$L_{\odot}$	3.8458×10^{33}	$\mathrm{erg\,s^{-1}}$
Sidereal year	yr	3.155815×10^{7}	s