When you have had a look at the Help function, close all the help windows and proceed to log in to the program as described on the following page.

Part II Entering Student Accounting Information

Position the cursor over the **LOG IN...** on the menu bar at the top of the logo screen and click the mouse button **once** to activate the Student Accounting screen.

Enter your name (first and last), and those of your lab partners. Do not use punctuation marks. Press **tab** after each name is entered, or **click** in each student block to enter the next name. Enter the Laboratory Table Number or Letter you are seated at for this experiment if it is not already filled in for you. You can change and edit your entries by clicking in the appropriate field and making your changes. When all the information has been entered to your satisfaction, click **OK** to continue, and click **yes** when you are asked if you are finished logging in. The opening screen of the **Spectral Classification** lab will then appear.

Part III Spectral Classification Of Main-Sequence Stars

Purpose

To become familiar with the appearance of the spectra of main sequence stars. To learn how to classify the spectra of main sequence stars by comparing a spectrum with an atlas of spectra of selected standard stars.

Method

You will examine the digital spectra of 25 unknown stars, determine the spectral type of each star, and record your results along with the reason for making each classification. The spectra can be compared visually and digitally (point by point) with an representative atlas of 13 standard spectra, and by looking at the relative strengths of characteristic absorption lines, you will be able to estimate the spectral type of unknown stars to about a tenth of a spectral class, even if they lie between spectral types of these stars given in the atlas.

Procedure

1. Select the **CLASSIFY SPECTRA** function from the **RUN** pull-down menu by clicking on the **RUN** option and dragging down to the **CLASSIFY SPECTRA** choice (this is a procedure you will use frequently to access items and make menu choices). Answer **no** to any questions the computer may ask at this time about stored spectra (later you may want to examine these spectra, but not now).

   You are now in the classification tool. (See **FIGURE 2** on the following page.) The screen that you see shows three panels, one above another with some control buttons at the right and a menu bar at the top. The center panel will be used to display the spectrum of an unknown star, and the top and bottom panels will show you spectra of standard stars which can be compared with the unknown. Let us now run through the features of the classification tool by classifying the first of the 25 unknown spectra provided for practice.

2. Call up the spectra of a practice *unknown* star by dragging down the **LOAD** pull-down menu. You will see 3 choices: **Unknown Spectrum**, **Atlas of Standard Spectra**, and **Spectral Line Table**. Choose **Unknown Spectrum** by dragging the mouse cursor to the right as indicated by the arrow on that choice, and then selecting **Program List**. A window will appear displaying a list of practice stars by name. Highlight the first star on the list — **HD124320** — by dragging the mouse (it should be highlighted already) and then click on the **OK** button. You will see the spectrum of HD 124320 displayed in the center panel of the classification screen.

   Look at the spectrum carefully. Note that what you are seeing is a graph of intensity versus wavelength. The spectrum spans a range from 3900 Å to 4500 Å, and the intensity can range from 0 (no light) to 1.0 (maximum light).

The highest points in the spectrum, called the **continuum**, are the overall light from the incandescent surface of the star, while the dips are **absorption lines** produced by atoms and ions further out in the photosphere of the star. You can measure both the wavelength and the intensity of any point in the spectrum by pointing the cursor at it and clicking the left mouse button. The cursor changes from an arrow to a cross, making it easier to center the cursor on the point desired.

a. Choose any point on the continuum of HD 124320 and record its wavelength and intensity below.

Wavelength _____ Intensity _____

b. Measure the wavelength and intensity of the deepest point of the deepest absorption line in the spectrum of HD 124320.

Wavelength _____ Intensity _____

Note that the spectrum you see here, which is typical of those used for spectral classification, does not cover the entire range of visible wavelengths, but only a limited portion.

c. Question: If you were to look at this range of wavelengths with your eyes, what color would they appear?

_____

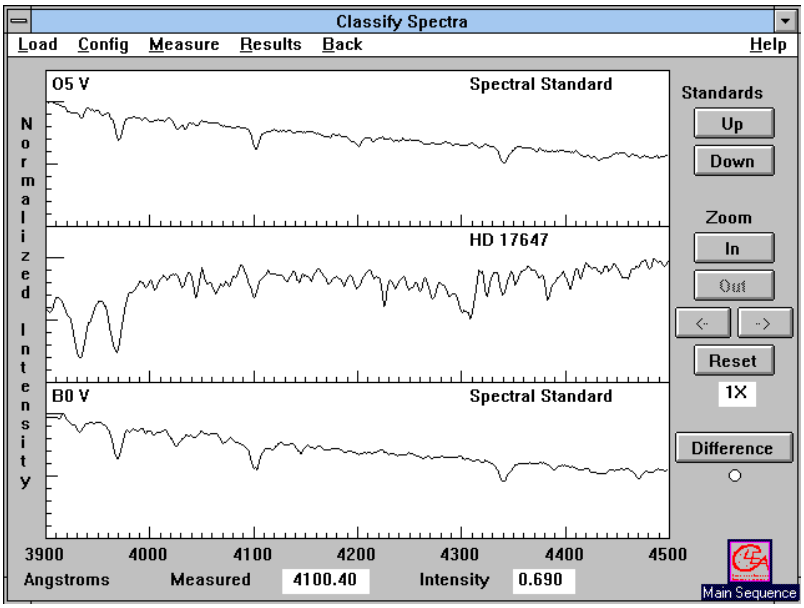

Figure 2
The Classification Window

3. Now you want to find the spectral type of HD 124320 by comparing its spectrum with spectra of known type. Call up the comparison star atlas by dragging the **LOAD** pull down menu to the **Atlas of Standard Spectra** option. A window will open up on which you will see numerous choices, but the atlas you want is the one at the top of the list, **Main Sequence**. Select it and click on **OK** to load the atlas.

4. The 13 spectra in the Atlas will come up in a separate window (see FIGURE 3), but only 4 can be seen at one time. You can look at the entire set by dragging up and down on the scrollbar at the right of the Atlas window. Do this, and note that a sequence of representative types, spanning the range from the hottest to the coolest are shown. List the different spectral types that are included in the Atlas on the line below, including both the letter of the class and the number of the decimal tenth of a class (e.g. G2, ...). You can ignore the Roman numeral "V" at the end of the spectral type—this just indicates that the standard stars are main sequence stars.

Spectral types in the atlas

_____

_____

_____.

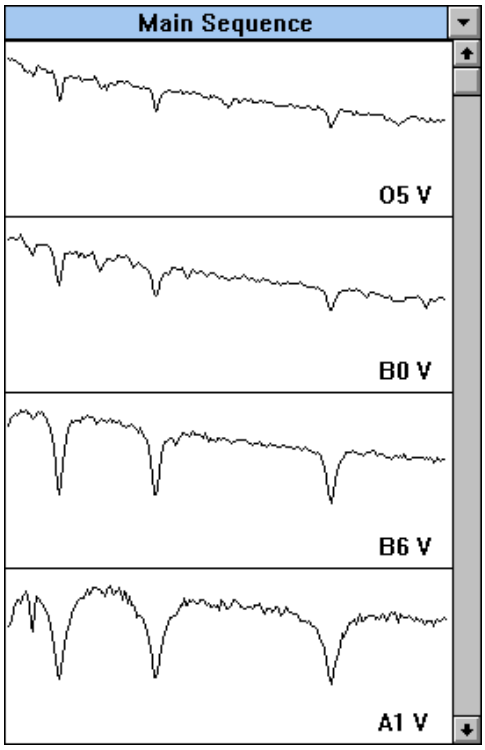

Figure 3
The Spectral Window

5. Because the spectral types represent a sequence of stars of different surface temperatures two things are notable: (1) The different spectral types show different absorption lines, and (2) The overall shape of the continuum changes. The absorption lines are determined by the presence or absence of particular ions at different temperatures. The shape of the continuum is determined by the blackbody radiation laws. One of these laws, Wein's Law, states that the wavelength of maximum intensity is shorter when the temperature of the object is hotter. This is described mathematically in the equation below:

$$\lambda_{max} = 2.9 \times 10^{7} / T$$

where λ_{max} = the wavelength of maximum intensity in Angstroms (Å)

T = temperature in degrees Kelvin (°K).

a. As you look through the stars in the Atlas, can you tell from the continuum which spectral type is hottest? Identify the hottest spectral type? _____.

Explain your answer. (Remember that, on all these graphs, 3900 Å is at the left, and 4500 Å is at the right).

_____

b. At about what spectral type is the peak continuum intensity at 4200 Å ? (4200 Å is about the middle along the x axis).

_____

c. What would be the temperature of this star?

_____.

6. Now use the comparison spectra to classify the star. If you look at the panels behind the Atlas window, you will see that two of the comparison star spectra have already been placed in the two panels above and below the spectrum of your unknown star. You can see the three panels more clearly by reducing the Atlas window to an icon (click on the little arrow button at the upper right of the Atlas window to iconize it; if you want the Atlas window back, you can double click on the icon again.) You should see the spectrum of an O5 star is in the top panel, and the spectrum of the next star in the atlas, a B0, in the bottom panel.

If neither of these looks quite like a match to your unknown star, you can move through the Atlas by clicking on the button labeled **down** to the upper right of the spectrum display. Continue this until you get a pretty good match. You should find that the best match is with spectral types that have very strong hydrogen lines (more about how to identify these later), and not many other features. The stars with the strongest hydrogen lines are around spectral type A1.

Because not all spectral types are represented in the Atlas, and because you want to get the classification precise to the nearest 1/10 of a spectral type (i.e. G2, not just G), you may have to do some interpolation. Look at the relative strengths of the absorption lines to do this. For your unknown star, for instance, you should note that it looks most like an A0 type star, but not quite. When the top panel shows an A1 comparison star, the bottom panel will show a A5 star. The strength of the lines in HD124320 lies somewhere between these two. You can therefore make an educated guess that it is about A3.

7. If you want to do this in a more quantitative fashion, click on the button labeled **difference** to the right of the spectrum display. The bottom panel graph will now change, showing the digital difference between the intensity of the comparison spectrum at the top and the unknown spectrum in the center, with zero difference being a straight horizontal line running across the middle of the lower panel.

   Look at the dips and valleys on this bottom panel and think about them for a minute. If an absorption line in the comparison star is shallower than the line at the same wavelength in the unknown star, then intensity at those wavelengths in the comparison star will be greater than those in the unknown. So the difference between the two intensities will be greater than zero, and the difference display will show an upward *bump*. If the top panel is showing an A0 spectra, for instance, and the middle panel HD124320, you should see a small bump at 3933 Å, indicating that the absorption line in the unknown is deeper than that in the A0.

   By the same reasoning, if an absorption line in the comparison spectrum is deeper than one in the unknown star, then the difference display will show a downward *dip*. Click on the Standards **down** button to display an A5 comparison spectrum. Note that the 3933 Å difference display now shows a dip, indicating that the absorption line in the unknown is shallower than that of an A5. So it is somewhere in between A0 and A5.

   To use the difference display, page through the comparison spectra (using the Up and Down buttons) until the difference between the comparison and unknown star is as close to zero at all wavelengths as possible. To estimate intermediate spectral types, watch to see when the display changes from bumps for some lines, to dips (Since some lines get stronger with temperature, and others get weaker, you will see some lines go from bumps to dips, and some from dips to bumps, as you change comparison spectra). Try to estimate whether the amount of change places the unknown halfway between those two comparison types, or if it seems closer in strength to one of the two comparison types that it lies between.

   Your estimate of the spectral type of HD124320_____.

   Give reasons for your answer. (For this example: The strength of lines at 4340.4 Å and 4104 Å are almost exactly those of type A1 or A5, and the strength of the 3933 Å line lies somewhere between them.).

8. Record your choice for HD 124320 and your reasons in the computer by dragging the menu **RESULTS** to the choice **RECORD**. This opens up a window on which you can record your assigned spectral type and a brief note on your reasons. As in the **Login** form, you can enter data by Tabbing to the proper box, or clicking the mouse to position the cursor in a box. When you are done recording the classification, click **OK**. You can choose **RE-VIEW** in this menu if you later want to edit or revise your entry.

9. You have used one or two spectral lines for making a refined classification. But what elements produced them? For reference, you will want to identify the source of the line you are looking at. Select the **SPECTRAL LINE TABLE** from the **LOAD** pull-down menu. You will see a window containing a list of spectral lines. (see FIGURE 4) You can move this list over to either side of the display by pointing the cursor to the blue region of the list window and dragging it over . Try moving it to the upper left. Now, using the mouse, point the cursor at the center of any line in the spectrum (say the one at 4341) and double click the left-hand button. A red line should appear across the screen and, if you've centered correctly, a double dashed line on the line list to show you what the line is.

For instance, the line at 4341 Å is a line from Hydrogen, HI Verify this.

Now identify the line at 3933 Å _____.

You can iconize the Line Table window by clicking on the little arrow on top of the Line Table window, just to the right of the title *Spectral Line Identification*. That will get it out of the way until you need it again.

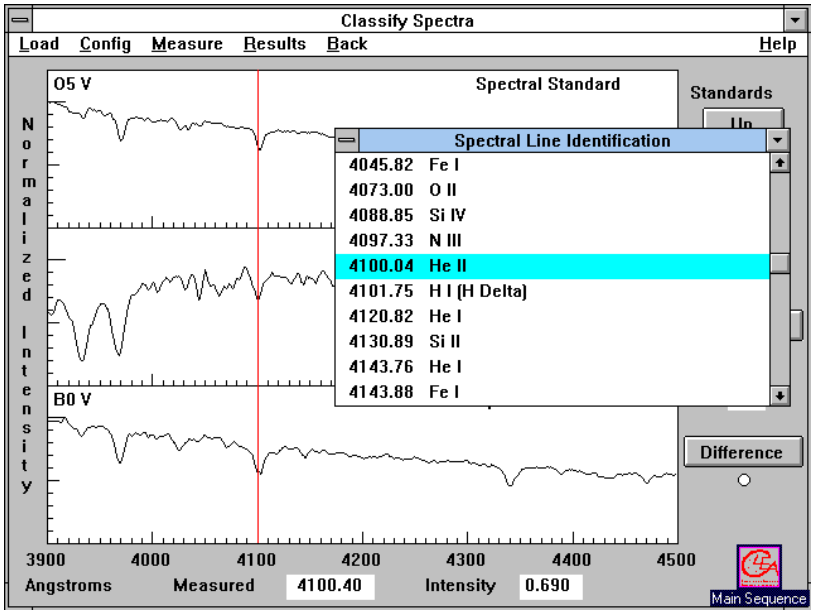

Figure 4
The Spectral Line Table

10. Spectra are often displayed as black and white pictures showing the starlight spread out as a rainbow by a diffraction grating or prism. You can view spectra this way using the classification tool. Pull down the menu **CONFIGURATION**, drag down to the **DISPLAY** option and then drag right to choose "**GRAYSCALE PHOTO**". You are now looking at representation of what the spectrum might look like if you photographed it. To see the relation between the graphical trace and the photographic representation, pull down the **CONFIGURATION** menu and choose the **COMBINATION** option. The center panel will show the photographic representation of HD124320, and the bottom panel a graph.

    How can you tell absorption lines in the photographic spectrum?
    _____

    In the graphical trace? _____.

    It is possible to classify stars by looking only at the photographs of the spectra (in fact that is the way it used to be done before computers and digital cameras came along). But you will want to use the trace display for most of your work. Return this choice by picking **DISPLAY**, **INTENSITY TRACE** in the **CONFIGURATION** menu.

11. You have now classified one spectrum Call up the next unknown spectrum by pulling down the **LOAD**, **SPECTRA** choices, and choosing the next Program star. You do not have to reload the spectral atlas. Use the methods you have practiced above, along with the descriptions of spectral types given in **Appendix I** on page 22 to classify the remaining 24 stars on the list. Use the computer to record your results and your reasons and save the results. You may also use the data table on the following page to record your results (and to provide hard-copy backup should the computer fail), and your instructor may request you to print out the record of results from the computer by choosing the **RESULTS**, **PRINT** menu.

12. Additional Hints

One quick way to go through the spectral atlas, rather than using the **up** and **down** buttons is to open up the Atlas window and double click on a graph panel of the atlas representing the spectrum you want to insert in the upper comparison panel of the Classification window. The atlas panel selected will be tinted blue to indicate that it is the one selected. You can then iconize the atlas again to see the Classification window more clearly.

You can get close-up views of the spectra by clicking on the **Zoom In** button to the right of the Classification window. In zoom mode, the right and left arrows under the **Zoom** buttons can be used to pan along the spectrum to see wavelengths that are off the edges of the range of view. The **Reset** button returns to full view of the spectrum.

When the Spectral Line List is visible, you can find a particular spectral line on a spectrum by pointing the cursor at an entry on the list and double clicking the *left* mouse button. A red line will appear on the spectrum display at the wavelength of the line.

When the Spectral Line List is visible, pointing the cursor at an entry and double clicking the *right* mouse button will bring up a window with further information on the spectral line in question. In many cases several ions produce spectral lines at about the same wavelength, so it will not be immediately clear what ion is producing a particular absorption line. For instance both CaII and HI produce lines at a wavelength of about 3970 Å . But HI lines are strongest in A stars, while CaII lines are strongest in G and K stars. The notes provided in the spectral line information screens can thus be used to decide what ions are producing what absorption lines if you have a rough idea of the spectral type you are looking at.

Data Table: Practice Spectral Classification

STAR	SP TYPE	REASONS
HD124320	A3	HI lines very strong, CaII line betw. A0 and A5
HD 37767		
HD 35619		
HD 23733		
O1015		
HD 24189		
HD 107399		
HD 240344		
HD 17647		
BD +63 137		
HD 66171		
HZ 948		
HD 35215		
Feige 40		
Feige 41		
HD 6111		
HD 23863		
HD 221741		
HD 242936		
HD 5351		
SAO 81292		
HD 27685		
HD 21619		
HD 23511		
HD 158659		