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.

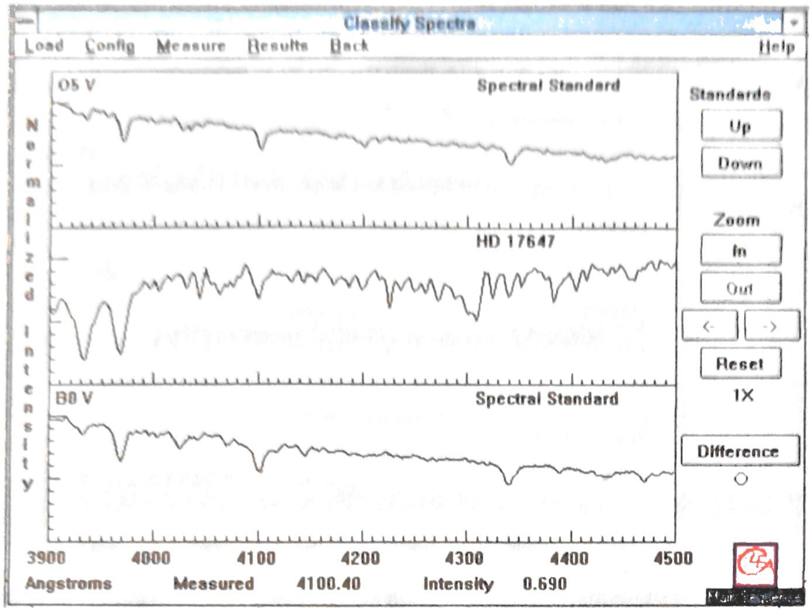

Figure 2
The Classification Window

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

Wavelength 4338.00 **Intensity** 0.640

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

Wavelength 3970.00 **Intensity** 0.460

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? violet

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 selecting the **File...Atlas of Standard Spectra** option. A window will open up displaying numerous choices. Click on **Main Sequence**, the atlas at the top of the list, to select it. 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 moving the scrollbar at the right of the Atlas window, up and down. 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 in the space provided on the following page, include 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.

A5V

Spectral types in the atlas

O5V, B0V, B6V, A1V, A5V, F0V, F0V, F5V, G0V, G6V, K0V, K5V, M0V, M5V

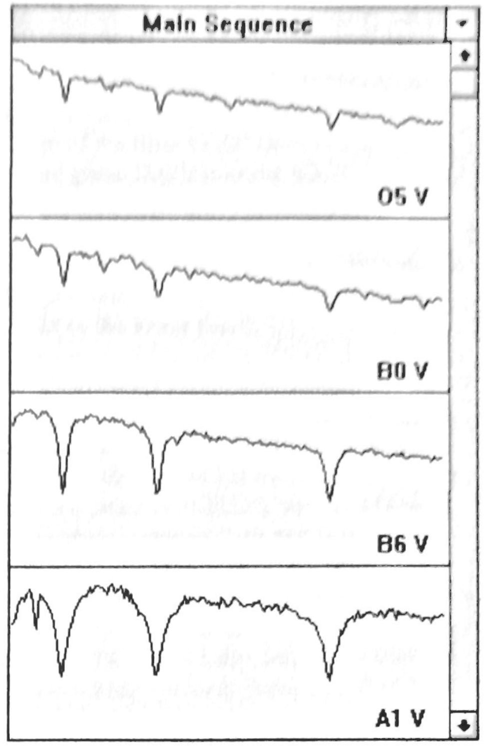

Figure 3
The Spectral Window

5. Because the spectral types represent a sequence of stars of different surface temperatures two things are notable:

• the different spectral types show different absorption lines, and

• 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:

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

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? O5V.

Explain your answer. (Remember that, on all these graphs, 3900 Å is at the left, and 4500 Å is at the right). O5V starts at the highest intensity at 3700, greater than any other form at that wavelength.

b. At about what spectral type is the peak continuum intensity at 4200 Å ? (4200 Å is about the middle along the x axis). F5V

$$T = \frac{2.9 \times 10^7}{\lambda_{max}} = \frac{2.9 \times 10^7}{0.890} = \frac{2.9}{\frac{89}{100}} \times 10^7 = \frac{2.9}{89} \times 100 \times 10^7 = 0.034 \times 10^9$$

c. What would be the temperature of this star? 3.4 x 10^7 K.

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 minimizing the Atlas window. 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** located at the upper right of the spectrum display. Continue this until you get a close match. You should find that the best match is made 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 A1 ✓ **.**

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.). The 'difference' window had the lowest Δ.

8. Record your choice for HD 124320 and your reasons in the computer by selecting **Classification...Record**. This opens up a dialog box where you can record your assigned spectral type and a brief note for your choice. 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 **Review** 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 **File...Spectral Line Table**. You will see a window containing a list of spectral lines. (See FIGURE 4) Adjust the position of the list by pointing the cursor to the blue region of the list window and dragging it in order to view the Classification Window simultaneously. Using the mouse, point the cursor at the center of any absorption line in the spectrum (try the wavelength 4341) and double click the left-hand mouse button. A red line should appear across the screen in the classification window and, if you've centered the crosshairs correctly, a double dashed line on the spectral line list will identify the absorption line at that wavelength.

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

Now identify the line at 3933 Å Ca II (K line)

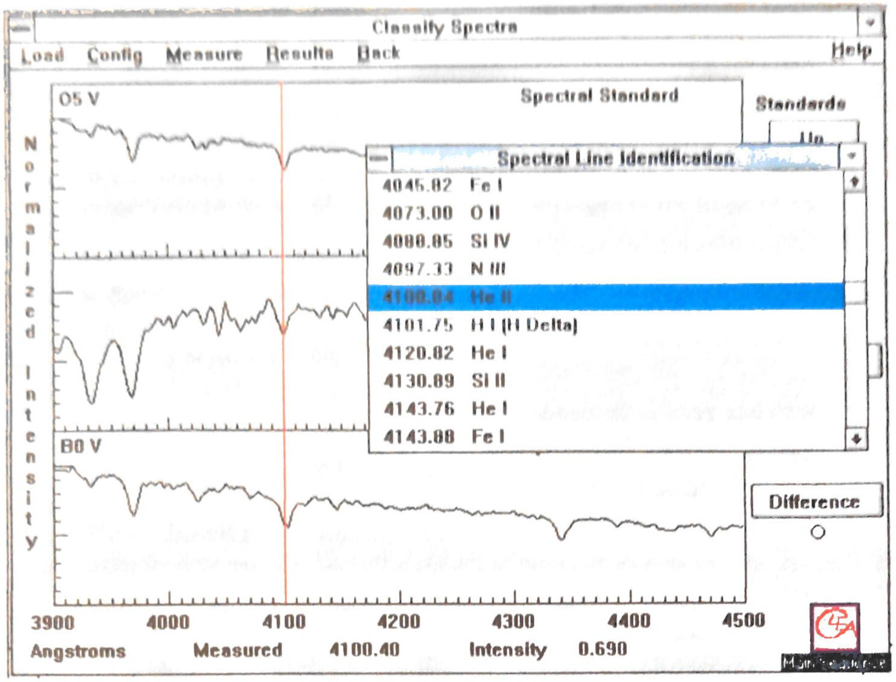

Figure 4
The Spectral Line Table

Note: You can minimize the Line Table window until you need it again.

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 **File...Preferences...Display...Grayscale Photo**. You are now looking at a representation of what the spectrum might look like if you photographed it. To see the relation between the graphical trace and the photographic representation, select **File...Preferences...Display...Comb. (Photo&Trace)**. The center panel will show the photographic representation of HD124320, and the bottom panel a graph.

Give a physical description of the absorption lines in the photographic spectrum?
They are darker areas.

In the graphical trace? they are dips in the graph.

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 to this choice by selecting the **File...Preferences...Display...Intensity Trace** menu.

11. You have now classified one spectrum. Call up the next unknown spectrum by pulling down the **File...Unknown Spectra...Next in List**. 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 use **Classification Results...Save to File** to 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 **Classification Results...Print**.

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	B4	He I lines consistent
HD 35619	B Ø	Fe I + wavelengths consistent
HD 23733	F Ø	H I – Si III very consistent
O1015	B5	Large difference in He I
HD 24189	F5	Not a good fit, but best (F7)
HD 107399	G1	Ca II lines between G2-G3
HD 240344	B3	Looks like avg between B0 - B6
HD 17647	G5	Very close to G6, largest diff in He I
BD +63 137	M2V	–
HD 66171	G4	Strong in He I
HZ 948	F4	Strong in HI
HD 35215	B2	Weak in HI (HE)
Feige 40	B1	Weak in Ca II
Feige 41	A2	Ca II line strong
HD 6111	G3	Strong in He I
HD 23863	A2	Weak in Ca II
HD 221741	A3	N III lines weak
HD 242936	B Ø	Strong in O III
HD 5351	K4	Weak in Ca I
SAO 81292	M4	Strong in He I
HD 27685	G5	–
HD 21619	A4	Strong in O III
HD 23511	F5	–
HD 158659	B Ø	–

Now, before you have gone any further, record the coordinates of the star below so that you and your instructor can identify which one you are viewing. The coordinates appear on the telescope control panel to the left of the view monitor.

Right Ascension: 11:00:50.3

Declination: +39:12:45

Apparent Magnitude: 5.08

5. If you have positioned the telescope, you are ready to take a spectrum. Click on the **Take Reading** button to the right of the view screen. The spectrometer window now opens. (See FIGURE 7) Note that the spectrometer is set up to collect a spectrum ranging from 3900 Å to 4500 Å, the same range you have been using to classify stars. The graph is a plot of wavelength (the x axis) versus intensity (the y axis).

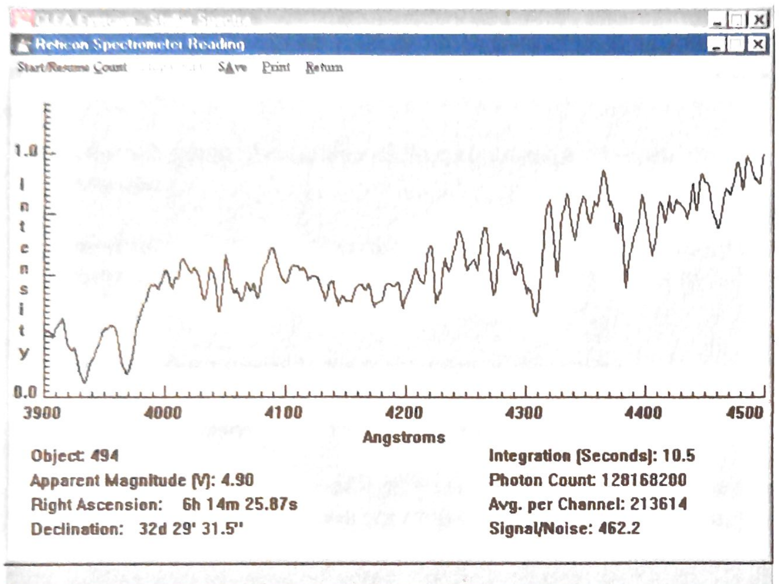

Figure 7
The Spectrometer Reading

To begin taking a spectrum, click the **Start/Resume count** choice on the menu bar. The spectrometer will begin to collect photons from the star, (and a few from the background sky) one by one. It is a random process, and you will see photons coming in at all wave-lengths like drops of rain spattering randomly over a pavement. For a few seconds the pattern may look entirely random, or **noisy**, especially if the star is very faint. (See Appendix III, page 24, for additional information on background noise.) But after a while the overall shape of the spectrum begins to take form. The more photons you collect, the less noisy and more well-defined the spectrum will appear. Because the computer automatically adjusts the spectrum so that the most intense points have a value of 1.0 on the graph, you won't see the spectrum growing in height, but you will see it get more sharply defined as more photons are collected.

To stop the data taking and check on the progress of the spectrum, click the **Stop Count** button. The computer will connect the dots representing the intensity at each wavelength to give you a trace of the spectrum.

6. Look at the spectrum you have just taken. You can measure intensities and wavelengths on the spectrum, just as you did in the classification tool, by moving the arrow to the desired point, and then clicking the left mouse button. Notice that the arrow changes to a crosshair, and that displays labeled **WaveLength** and **Intensity** now appear at the top of the display. If you hold the left mouse button and move the crosshair along the spectrum, you will note that you are able to measure intensity and wavelength at the any position.

The Spectrometer Reading Window contains the following information:

Information that appears in the lower left hand portion of the window

Object: the name of the object being studied

Apparent magnitude: the visual magnitude of the object

Right Ascension: Displays the celestial coordinates of the center of the field of view. Right Ascension is displayed in hours, minutes and seconds.

Declination: Declination is displayed in degrees, minutes and seconds.

Information that appears in the lower right hand portion of the window

Integration (seconds): The number of seconds it took to collect data

Photon count: The total number of photons collected so far, and the average number per pixel

Avg. per Channel: The number of photons averaged from the total number of the channels of the spectrometer.

Signal-to-noise Ratio: A measurement of the quality of the data taken to distinguish the H and K lines of calcium from the noise. Try to get a signal-to-noise ratio of 10 to 1. For faint galaxies, this may take some time.

Information that appears in the top portion of the window

Wavelength (angstroms): Wavelength as read by the cursor in the measurement mode

Intensity: Relative intensity of light from the galaxy at the position marked by the cursor in the measurement mode If you have not achieved a S/N of 100 or better, you should click on the **Start/Resume count** to continue taking data until your spectrum is of suitable quality for classification purposes. When the suitable data has been collected, stop and examine the results. (See Appendix III, page 24)

7. You now want to save the spectrum so that you can classify it using the classification tool. Click on the **Save** option on the menu bar. A window will open asking you to assign a number to the star (it is set for number 0). Enter the object number located in the lower left hand corner of the spectrometer window, and click **OK**. The computer will now assign a name to the spectrum file based on the first letters of the name you logged in with and the number you just gave. Write the file name of the file below, just for your records, and click **OK** to save the file.

File name for first star spectrum: N 373ø-ø2498 . SSP

8. You can return to the telescope by choosing the **Return** option on the spectrometer menu bar. You now have seen how to take spectra and save them. Choose another star (you will have to return to the finder field to do so), this time a rather faint one, and obtain and record its spectrum as star number 2. Remember to collect enough light to get a sufficiently high signal-to-noise ration. Keep a log of your data in the space provided on the following page.

Star 2:

Coordinates:

Right Ascension 11:00:39.5

Declination +38:59:56

Spectrum stored in file named N3730-00707.SSP

9. When you are done taking and storing the spectra, you can call up the classification tool once again by selecting the **File...Run...Classify Spectra** option from the telescope menu bar. The classification window will open, just as before. If the spectral atlas has not already been loaded, you can reload it using the **File...Atlas of Standard Spectra** command.

To see the spectra you have just taken, choose the **File...Unknown Spectra...Saved Spectra** menu item. A list of the saved spectrum files should appear. Click and choose the file for the first star you obtained. From here, all procedures are the same as those you used in the first part of the lab. Classify both stars you observed. (Remember to print the spectrum for each star before moving to the classification window.) For the two stars you have observed, record your results on the computer using the **Classification Results...Record** menu choice. Calling up this choice for each star will also display its Object Name (from a catalog of stars stored in the computer), and its apparent magnitude (determined from the number of photons that entered the spectrometer which you will also want for the record), the spectral type that you have determined and any notes you want to record on the selection of the spectral type of your unknown. Your instructor may want you to print out your results using the **Classification Results...Print** option. You will also want to record your data below for the record.

Spectral Type of Two Unknown Stars

Star #	Object Name	Spectral Type	Reasons
1	N3730-02498	F0V	Matches exactly
2	N3730-00707	G3V	weak in

OIII ? HEI

10. Check to make sure you have completed all the parts of the exercise requested by your instructor. All data tables should be complete, and all printouts from the computer should be stapled to this worksheet.