

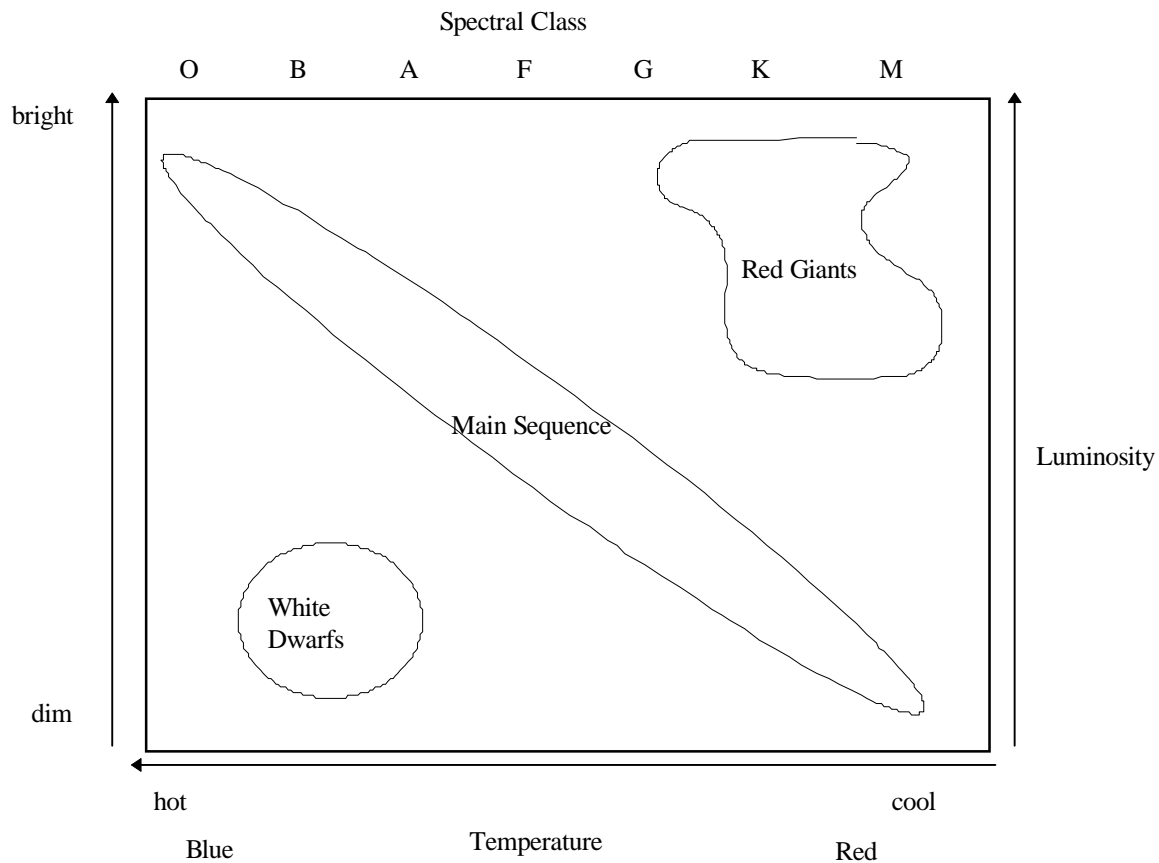
# Hertzsprung-Russell Diagram

**Objectives:** To learn what a Hertzsprung-Russell Diagram is, what its major regions represent, and how to construct such a diagram. To study the evolution of star clusters.

**Equipment:** Scaling transparency, photographs of the Trapezium and Pleiades star clusters, PC, Excel spreadsheet.

**Discussion:** The first Hertzsprung-Russell (H-R) diagrams were plots of *luminosity* (intrinsic brightness) of stars versus their *spectral class* (color). The same distribution may be achieved by plotting *luminosity* or *absolute magnitude* versus *spectral class* or *color index* or *surface temperature*. An H-R diagram of a homogeneous sample of stars shows several basic groupings: super giant/giant stars, main sequence stars, and white dwarf stars. Figure 1 shows an H-R diagram.

The largest group of stars in Figure 1 is that labeled Main Sequence. The main sequence is common to all H-R diagrams and is the longest stage of evolution for any star. A star on the main sequence derives its energy almost entirely from a nuclear reaction involving the



**Figure 1.** A Hertzsprung-Russell diagram.

conversion of hydrogen to helium via fusion. A star spends most of its life on the main sequence. From the diagram we see that the brighter a main sequence star is, the hotter it is. The hotter main sequence stars are also bluer and more massive. The cooler, dimmer main sequence stars are redder and less massive. Although it is not obvious, the hotter, brighter, more massive, and bluer a star is, the less time it spends on the main sequence. It is important to note that *stars do not move up and down the main sequence*. The position of a star on the main sequence is uniquely determined by its mass.

The next region of interest in Figure 1 is the group of stars labeled Red Giants.<sup>1</sup> The red giant phase of stellar evolution follows the main sequence phase. When the hydrogen is nearly exhausted in the central core of a star, the star begins to undergo a cataclysmic set of convulsions. During this process core temperature, pressure and density increases within the star. Energy released during this process causes the outer parts of the star to swell to enormous proportions. The star, as a whole, becomes less dense since all but the central core is expanding. This expansion of the outer regions of the star results in surface cooling and results in their red appearance. The energy being released by the core heats up the hydrogen in the areas surrounding it to extremely high temperatures. This accelerates hydrogen fusion and the production of helium, causing the star to increase in luminosity. After leaving the main sequence these stars move to the upper right side of the H-R diagram (low temperature, high luminosity). Red giants are, therefore, characterized by very large diameters and relatively low surface temperatures. Their large diameters, and consequently their large surface areas, make them relatively bright.

The final group of stars in Figure 1 are White Dwarfs. These stars are at the end of the line in terms of stellar evolution. Near the end of a star's life, as it begins to exhaust its supply of energy, it begins to shrink. During this process the star may ultimately attain an enormous density. White dwarfs are compact objects about the size of Moon but containing about mass of the sun. Although white dwarf stars are extremely hot, they are not very bright because of their compact size. White dwarf stars have very high densities (roughly that of the nucleus of an atom). This is possible because the constituent atoms of the gases residing in the interior of these stars are completely *ionized*, i.e., stripped of all electrons. Most of the mass of an atom (~99.975%) is concentrated in the nucleus, but most of the volume is occupied by orbiting electrons. With the electrons stripped away, it is possible to pack nuclei very close together resulting in a substance of extremely high density. The density of a typical white dwarf star is, for example, over a million times that of water.

There are two other possible end states in stellar evolution: neutron stars and black holes. Neither of these are luminous enough to appear in the H-R diagram.

To summarize, there are three main classes of stars on the H-R diagram. A star begins its evolution at a point on the main sequence determined by its mass, matures into a red giant stage, and can end its life as a white dwarf.

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<sup>1</sup> The Red Giant group is actually composed of two subgroups: Red Giants and Red supergiants.

## Procedure

In this exercise you will construct two separate H-R diagrams, one of the Pleiades Cluster and one of the Trapezium Cluster. To construct a H-R diagram you will need to determine the *absolute magnitude* and *color index* of a representative sample of stars in the cluster. By assuming that all of the stars in the cluster are at about the same distance from us (a good assumption), the photographic magnitude may be used as a measure of the absolute magnitude, i.e., the size of a star in the photograph may be related to its intrinsic brightness. The bigger the star in the photograph, the greater its brightness. If the same cluster is photographed with film having a different color sensitivity, one may find the color index by comparing the sizes of the images on the two photographs. Therefore all that is needed to construct your H-R diagram are two black and white photographs of each star cluster.

Once you have constructed your H-R diagrams you can estimate the age of the clusters by noting how many of the stars have left the main sequence and become red giants and white dwarfs. The absence of any stars on the upper left of the main sequence, for example, and the presence of a large number of red giants indicates a highly evolved, older cluster.

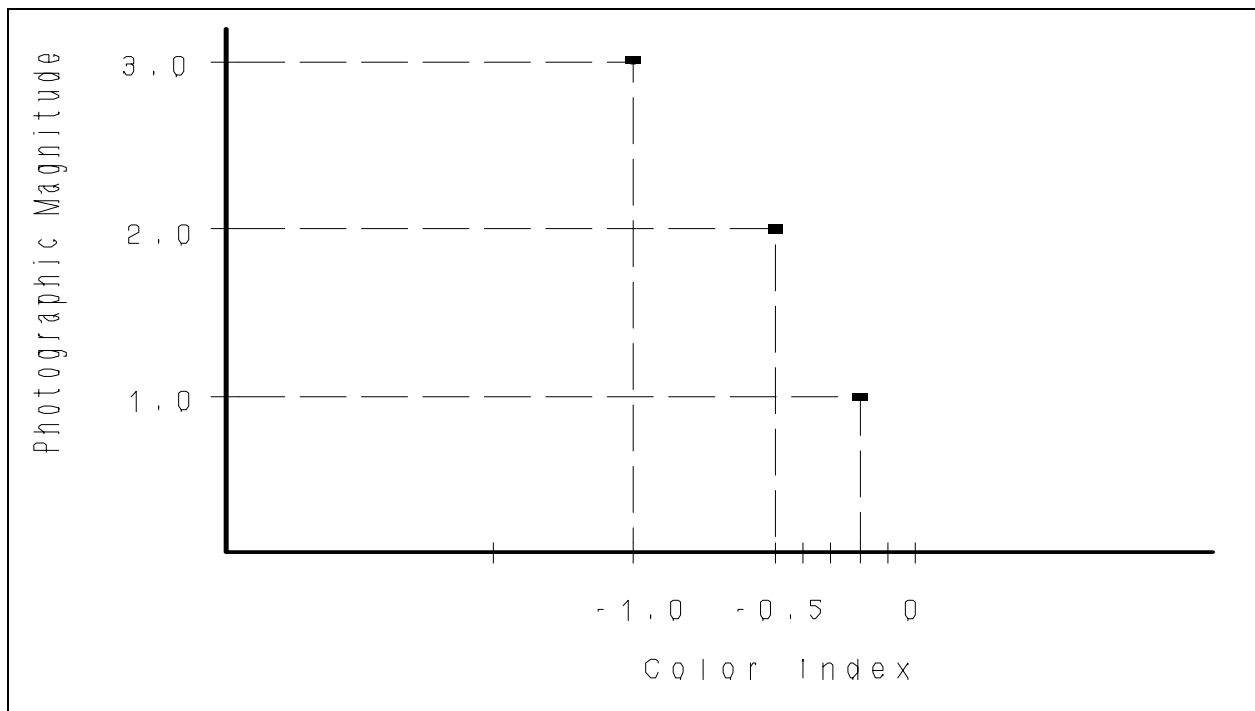
### Pleiades Cluster

Two different positive prints (black sky, white stars) of the Pleiades Cluster have been provided for you. One print is from a photographic negative made without a filter and the other from a photograph negative made with an amber filter. The unfiltered photograph has slightly larger star images. Do not mark these prints!

The measurements that you need are the sizes of individual stars on each photograph. Recall that these measurements represent the magnitudes of the stars. You should, therefore, get two measurements for each star: one from the filtered and one from the unfiltered photograph. By subtracting the photographic magnitude (unfiltered) from the filtered magnitude one may compute the color index of the star, e.g.,  $\text{Color Index} = M_f - M_p$ . Record your data in a table with the column headings: **photographic magnitude, filtered magnitude, color index**. Pick stars that you are sure are members of the cluster, i.e., stars close to the center of the print. Be sure to eliminate as candidates for measurement any stars that appear single on one print but can be resolved as close binaries on the other. Take measurements using the scale on the transparency that has been supplied to you. The scale on this transparency is graduated so that the largest measurement is 1 centimeter. Record your data in your notebook in units of centimeters. Once you have collected data *on at least twelve stars*, enter your data into the spreadsheet (PLIEADES.XLS) that has been prepared for you on the computer (your lab instructor will show you how to do this). The computer will construct a Hertzsprung-Russell diagram for you based on the data you enter. Copy this diagram into your lab notebook.

Photographic Magnitude	Filtered Magnitude	Color Index
1.0	0.8	-0.2
2.0	1.5	-0.5
3.0	2.0	-1.0

**Figure 2.** Example Data Table.



**Figure 3.** Example plot for H-R diagram based on data from Fig 2.

### Trapezium Open Cluster

The photographs of this cluster, from the Palomar Sky Survey, are negative prints (white sky, black stars). The plate numbers are in the upper left hand corner of each print. The plates provided are E1477 and O1477. The E plate is red sensitive and the O plate is blue sensitive.

The Trapezium cluster (located in the constellation Orion) appears around the gas cloud on the right of each print. In these photographs the Trapezium cluster appears to be more spread

out than did the Pleiades Cluster in the photographs you previously examined. But since the scale of the photographs is different, this comparison is invalid. You should choose for measurement foreground stars around the dark cloud on the right of the print and proceed as before. This time, construct a data table with the column headings: blue magnitude, red magnitude and color index. In this case the color index is the difference between the red and blue magnitudes, or: **Color Index** =  $M_r - M_b$ . For this cluster, construct an H-R diagram from a plot of blue magnitude vs color index. Again, a spreadsheet (TRAPEZ.XLS) has been prepared for your use that will aid you in this process.

Estimate the *relative* age of each cluster by comparing your H-R diagrams. Both of the clusters you studied in this exercise are open clusters. What generalizations can you make about the age of open clusters?

## Exercises

1. What determines the position of a star on the Main Sequence?
2. What type of nuclear reaction drives the evolution of a star?
3. According to your H-R diagrams, Open Clusters are composed primarily of what type of stars?
4. What type of star is located on the lower left of a H-R diagram?
5. Why do the same stars appear to have different sizes in the contrasting photographs in this exercise?
6. Where are the hottest stars on a H-R diagram? The brightest?
7. What is the eventual fate of our own sun?