

Exploring the H-R diagram

Activity:

Early this century, two researchers, Enjar Hertzsprung and Henry Norris Russell independently developed what has come to be known as the Hertzsprung-Russell (HR) diagram. The HR diagram is a plot of absolute magnitude/luminosity on the vertical axis versus spectral class/temperature/color on the horizontal axis. In this activity, you will create your own H-R diagram as well as explore its properties.

Part 1: Building the HR Diagram

In this portion of the activity, your group will create an HR diagram from the data in Tables I and II.

- 1) For each star, indicate its position on the graph below with a small "x." The Sun (G2, 4.8) has been plotted for you. Plot the bright stars (Table I) and near stars (Table II) in different colors by using, for instance, pencil for the bright ones and blue ink for the near ones. Each member of your group should plot about the same number of stars so that everyone gets some practice.

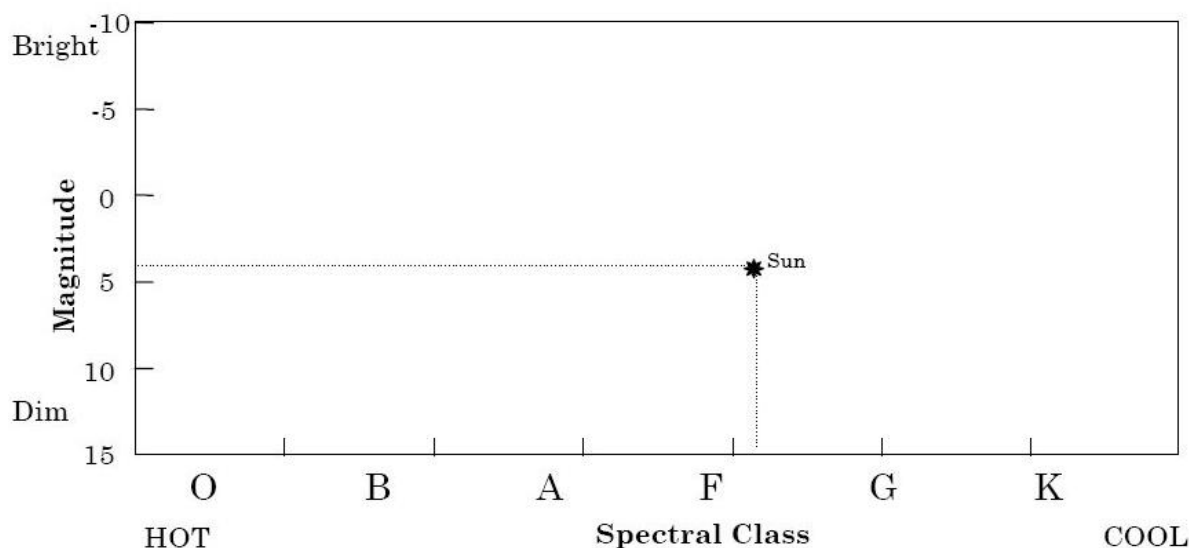


Table I: Bright Stars (as they appear from Earth)

Name	Spectral Class	Absolute Magnitude	Name	Spectral Class	Absolute Magnitude
Sirius B	B8	11.6	Betelgeuse	M2	-5.5
Canopus	F0	-3.1	Antares	M2	-4.5
Arcturus	K2	-0.3	Spica	B1	-3.6
Capella	G3	-0.7	Deneb	A2	-6.9
Rigel	B8	-6.8	Procyon A	F5	2.6

Table II: Near Stars

Name	Spectral Class	Absolute Magnitude	Name	Spectral Class	Absolute Magnitude
Sun	G2	4.8	Luyten 789-6 A	M6	14.6
Alpha Centauri A	G2	4.4	Ross 128	M5	13.5
Sirius A	A1	1.4	61 Cygnus A	K5	7.6
Ross 154	M5	13.3	61 Cygnus B	K7	8.4
Ross 248	M6	14.8	Procyon A	A0	13.0

- 2) In general (i.e., you may have to ignore some of the data points), is there a correlation between spectral class and absolute magnitude? What is it?

- 3) Can you make any generalizations about stars that are close to Earth?

- 4) Identify the Main Sequence, White Dwarfs and Red Giants on your H-R diagram.

Part 2: Stellar Sizes

Once we know a star's temperature and its total luminosity we can also deduce its size. The reason is that there is a connection between temperature and total energy output, which is described by the Stefan-Boltzmann law. There are two important aspects to remember:

- The total amount of light energy that a star emits — called the luminosity (L), and measured by the absolute magnitude (M) — increases with temperature (T).

$$L \propto T^4$$

In fact, it increases as the fourth power of the temperature so that a star the same size as our Sun but twice the temperature would emit 16 times the energy!

- The amount of energy that a star emits per area of surface depends only on the star's temperature. Therefore, the total luminosity of a star increases with the surface area. A star at the same temperature as our Sun but four times the surface area emits four times the energy.

To estimate the size of a star we first determine its temperature from either its color or spectral class. This tells us how much energy each area of the surface is emitting. The total luminosity is just a measure of the total energy, which allows the surface area to be determined, which is a measure of the star's size. Consider the stars in Table I to answer the following questions.

- 5) Does Sirius B have a higher, equal, or lower surface temperature than Rigel? Explain your reasoning. (hint: compare their spectral classes)

- 6) Which of these two stars has greater luminosity? Explain your reasoning.

- 7) Which is the larger of the two stars? Explain your reasoning.

Part 3: Classifications on the HR Diagram

- 8) How does the size of stars near the top left of the HR diagram compare with stars of the same luminosity near the top right of the HR diagram? Explain your reasoning.

- 9) How does the size of stars in the top left of the HR diagram compare with stars at the same temperature near the bottom left of the HR diagram? Explain your reasoning.

- 10) Classify the following newly discovered stars as main sequence, dwarfs, or giants.
 - a. Hermanson A (G4 +5.2):

 - b. α Slataurus (K8 -4.0):

 - c. β Adamisus (A3 +10.4):

 - d. Franciscus G (F2 +3.1):

Part 4: Estimating Relative Distances

Betelgeuse has an apparent magnitude (m) of +0.4, which tells us how bright it appears at its true location. Betelgeuse has an absolute magnitude (M) of -5.5 , which tells us how bright it would appear if we could move it to a distance of 10 parsecs (about 33 light-years).

- 11) Where would Betelgeuse appear brighter, in its true location or if it were at a distance of 10 parsecs? Explain your reasoning.
- 12) So, is its true location closer or farther than 10 parsecs? Explain your reasoning.
- 13) Below is a list of five stars and their apparent and absolute magnitudes. Your task is to classify each star as being located either closer or farther than 10 parsecs.

Star Name	Apparent Magnitude	Absolute Magnitude	Distance (Closer or farther)
Sirius	-1.5	+1.4	
Rigel	+0.14	-6.8	
Procyon	+0.37	+2.6	
Betelgeuse	+0.41	-5.5	
α Centauri	-0.01	+4.4	

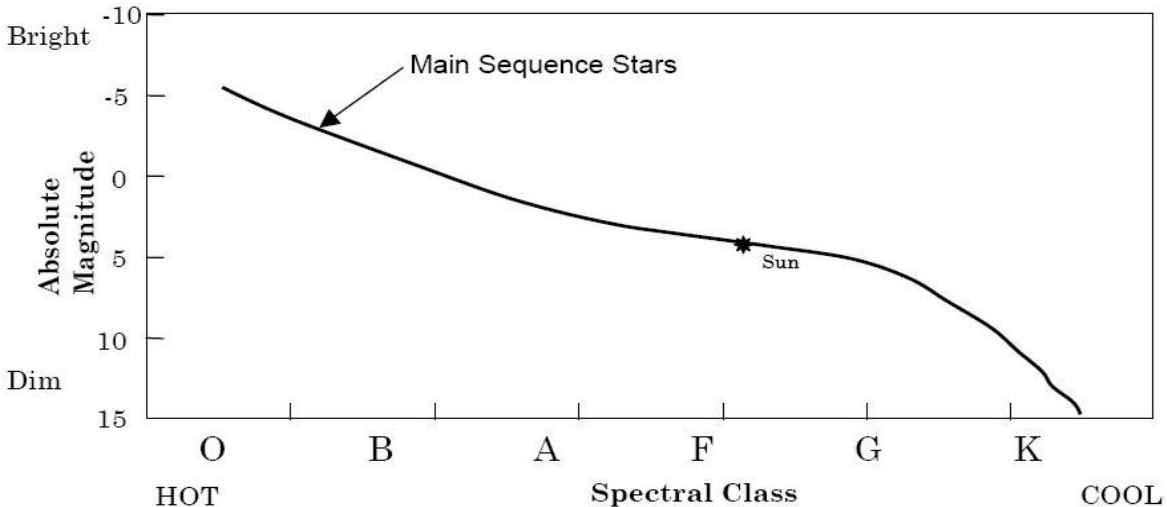
Part 5: Spectroscopic Parallax

The table on the following page gives both the apparent magnitude and spectral class for five main sequence stars. For each star, do the following:

- 14) Using the HR diagram on the next page, estimate the absolute magnitude for each star.
- 15) Complete the table by classifying each star as being less than, slightly more than, or much more than 10 parsecs away.
- 16) Use the following equation to calculate the actual distance to the stars in parsecs. Each group member should do at least one star. Recall that apparent magnitude = (m); absolute magnitude = (M); parsec = (pc); distance = (d).

$$d = 10^{(m-M+5)/5} \text{ pc}$$

Star	Apparent Magnitude	Spectral Class	Absolute Magnitude	Distance Estimate	Actual Distance
Rigel Kentaurus	0.0	G2			
Vega	+0.04	A0			
Rigel B	+6.6	B9			
Canopus	-0.72	F0			
Deneb	+1.26	A2			



More on stellar luminosity, the Stefan-Boltzmann Law, and black body radiation:

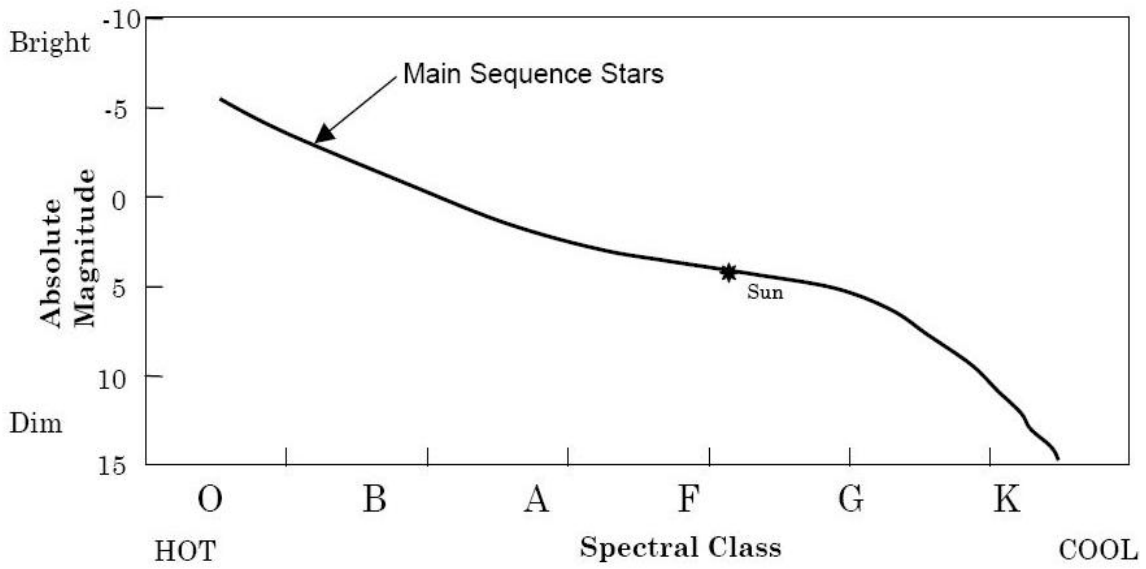
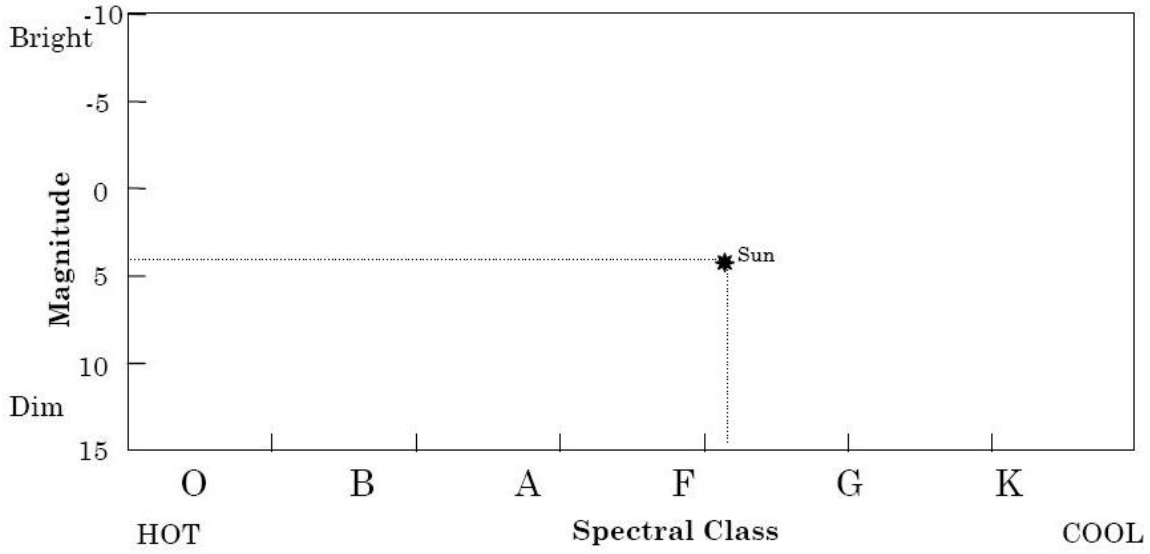
http://outreach.atnf.csiro.au/education/senior/astrophysics/photometry_luminosity.html

<http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/stefan.html>

Part 6: Classifying Stars

Using the Brightest Stars Cards and Nearest Stars Cards, have teams of students classify the stars in their stack.

- 1) Print Brightest Stars Cards and Nearest Stars Cards onto stiff paper. Cut them out.
- 2) Divide students into teams of 2 or 3 each.
- 3) Give each team some star cards from each pile, being sure to include several spectral classes.
- 4) Students classify their cards according to however the team wants.
- 5) Then have teams re-classify the cards and place them onto the blank HR diagram below. They can use colored pencils if desired.



The Brightest Stars:

Common Name	Distance (light years)	Absolute Magnitude	Spectral Type	Mass (compared to Sun)	Color	Radius (compared to Sun)
Sun	8 light minutes	4.8	G2V	1	yellow	1
Sirius A	8.6	1.4	A1Vm	2.43	blue	2.3
Canopus	74	-2.5	A9II	8.5	Blue- white	65
Rigel Kentaurus	4.3	4.4	G2V + K1V	1.1	yellow	1.22
Arcturus	34	0.2	K1.5IIIp	3.5	orange	25.7
Vega	25	0.6	A0Va	3.25	blue	2.9
Capella	41	0.4	G6III + G2III	2.69/2.56	Yellow-white	12.2/9.2
Rigel	~1400	-8.1	B81ae	17	blue	62
Procyon	11.4	2.6	F5IV-V	1.68	Blue-white	1.7
Achernar	69	-1.3	B3Vnp	6–8	blue	~10
Betelgeuse	~1400	-7.2	M2Iab	20	red	950-1000
Hadar	320	-4.4	B1III	10.7 /10.3	blue	8
Acrux	510	-4.6	B0.5Iv +B1Vn	14 / 10	blue	?
Altair	16	2.3	A7Vn	1.79	Blue-white	1.63 to 2.0
Aldebaran	60	-0.3	K5III	2.5 / 0.15	Orange-red	44.2 / 0.04
Antares	~520	-5.2	M1.5Iab	15.5	Orange red	700
Spica	220	-3.2	B1V	11/7	blue	7.8/4.0
Pollux	40	0.7	K0IIIb	1.86	Yellow-white	8.0
Fomalhaut	22	2.0	A3Va	1.9	blue	1.9
Becrux	460	-4.7	B0.5III	14	Blue-white	8
Deneb	1500	-7.2	A2Ia		Blue-white	
Regulus	69	-0.3	B7Vn	4.4	Blue-white	3.6
Adhara	570	-4.8	B2II	10	blue	11.4
Castor	49	0.5	A1V + A2V	2.15 / 1.7	Blue-white	2.3 / 1.6
Gacrux	120	-1.2	M3.5III	3	red	113
Shaula	330	-3.5	B1.5IV	10.4, 1.8, 8.1	blue	

The Nearest Stars

Common Name	Distance (light years)	Absolute Magnitude	Spectral Type	Mass (compared to Sun)	Color	Radius (compared to Sun)
Sun	-	4.8	G2V	1	yellow	1
Proxima Centauri	4.2	15.5	M5.5Vc	.38	orange	0.145
Rigil Kentaurus	4.3	4.4	G2V	1.1	yellow	1.22
Alpha Cen B	4.3	5.7	K1V	0.907	Yellow-white	0.865
Barnard's Star	6.0	13.2	M3.8V	.22	Red-orange	0.15 - 0.20
Wolf 359	7.7	16.7	M5.8Vc	.10	Red-orange	0.16
BD +36 2147 (Lalande 21185)	8.2	10.5	M2.1Vc	.43	red	.48
Luyten 726-8A	8.4	15.5	M5.6Vc	.10	red	.14
Luyten 726-8B	8.4	16.0	M5.6Vc	.10	red	.14
Sirius A	8.6	1.4	A1Vm	2.02	Blue-white	1.711
Sirius B	8.6	11.2	DA	0.978	White dwarf	0.0084
Ross 154	9.4	13.1	M3.6Vc	0.17	Red-orange	.24
Ross 248	10.4	14.8	M4.9Vc	.4	Red-orange	.5
Epsilon Eri	10.8	6.1	K2Vc	0.85	Yellow-white	.84
Ross 128	10.9	13.5	M4.1V	.156	orange	.21
61 Cyg A	11.1	7.6	K3.5Vc	0.70	orange	0.72
61 Cyg B	11.1	8.4	K4.7Vc	0.63	orange	.67
Epsilon Ind	11.2	7.0	K3Vc	.77	orange	.76
BD +43 44 A (And)	11.2	10.4	M1.3Vc	.404	red	.379
BD +43 44 B (And)	11.2	13.4	M3.8Vc	.163	red	.19
Luyten 789-6	11.2	14.5	M5V	.11	Red	.5
Procyon A	11.4	2.6	F5IV-V	1.50	Blue-white	1.86
Procyon B	11.4	13.0	DF	.6	White dwarf	.01234
BD +59 1915 A	11.6	11.2	M3.0V	0.36	red	.55
BD +59 1915 B	11.6	11.9	M3.5V	0.3	red	.54
CoD -36 15693 (Lacaille 9352)	11.7	9.6	M1.3Vc	.47	red	.47-.57

