ASTRO PHYSICS

Scope of astronomy and Astrophysics: Light year, Luminosity of stars, magnitude of stars, colour and Surface temperature of stars. Stellar spectra. Classification of stars, HR diagram, Milky way galaxy

Astronomy is the scientific study of celestial objects (such as stars, planets, comets, and galaxies) and phenomena that originate outside the Earth's atmosphere (such as the cosmic background radiation). It is concerned with the evolution, physics, chemistry, meteorology, and motion of celestial objects, as well as the formation and development of the universe.

Astronomy is one of the oldest sciences. Astronomers of early civilizations performed methodical observations of the night sky, and astronomical artifacts have been found from much earlier periods. However, the invention of the telescope was required before astronomy was able to develop into a modern science. Historically, astronomy has included disciplines as diverse as astrometry, celestial navigation, observational astronomy, the making of calendars, and even astrology, but professional astronomy is nowadays often considered to be synonymous with astrophysics.

Generally, either the term "astronomy" or "astrophysics" may be used to refer to this subject. Based on strict dictionary definitions, "astronomy" refers to "the study of objects and matter outside the Earth's atmosphere and of their physical and chemical properties" and "astrophysics" refers to the branch of astronomy dealing with "the behavior, physical properties, and dynamic processes of celestial objects and phenomena"., "astronomy" may be used to describe the qualitative study of the subject, whereas "astrophysics" is used to describe the physics-oriented version of the subject. However, since most modern astronomical research deals with subjects related to physics, modern astronomy could actually be called astrophysics.

Light-year

A **light-year** or **light year** is a unit of length, equal to just under 10 trillion (i.e. 10^{13}) kilometres. As defined by the International Astronomical Union (IAU), a light-year is the distance that light travels in a vacuum in one year. Light moves at a velocity of about 3,00,000Km each second.

One light year = 9,500,000,000,000 km

The light-year is used to measure distances to stars and other distances on a galactic scale. The preferred unit in astronomy is the parsec,

The parsec is defined as the distance at which an object will appear to move one arcsecond of parallax when the observer moves one astronomical unit perpendicular to the line of sight to the observer, and is equal to approximately 3.26 light-years.

Numerical value

1 light-year =
SI units
9.461×10^{12} km 9.461×10^{15} m
Astronomical units
63.24×10^{3} AU 0.3066 pc

A light-year is equal to:

- exactly 9,460,730,472,580.8 km
- about 5,878,630,000,000 miles
- about 63,241.1 astronomical units
- about 0.306601 parsecs

Distances in light-years

List of orders of magnitude for length

Factor (ly)	Value	Item
10^{-6}	15.8 × 10^{-6} ly	One astronomical unit (the distance from the Sun to the Earth). It takes approximately 499 seconds (8.32 minutes) for light to travel this distance.
	4.22 × 10^{0} ly	The nearest known star (other than the Sun), Proxima Centauri, is about 4.22 light-years away.
10^{3}	26 × 10^{3} ly	The center of our galaxy, the Milky Way, is about 26 kilolight-years away.
	100 × 10^{3} ly	The Milky Way is about 100,000 light-years across.

Extensive studies on sun and some of the stars have led to the deduction of some of the important inherent physical properties of the stars: 1) Luminosity 2)brightness 3)distance 4)surface temperature 5) size 6)mass 7)chemical composition

Luminosity: All the stars including sun, in the night sky shine due to thermonuclear fusion. But not all the stars are not identical but are distinguished from one another with their **Luminosities (L). Luminosity is the amount of energy emitted by each star per second.**

The luminosity of stars is measured in terms of the Sun`s luminosity L_O or in terms of watt.

$1L_O = 3.9 \times 10^{26}$ w most of the stars are less luminous than sun. The knowledge of stars luminosity is very important to know the internal structure of the stars and their future evolution.

The luminosity of stars is defined as the amount of energy passing normally through unit area on its surface in unit time. The ratio of luminosity L of stars and surface area of sphere of radius d is apparent brightness (b)

$b = L / 4\pi d^2$ inverse square law

Apparent brightness of Sun $b_O = 3.9 \times 10^{26} / 4\pi(1.5 \times 10^{11})^2 = 1370\ W/m^2$

$d = 1.5 \times 10^{11}$ m(Sun-earth distance)

Luminosty of stars and Sun are respectively $L = 4\pi d^2 b$ and $L_O = 4\pi d_o^2 b_o$

The **apparent magnitude** (***m***) of a celestial body is a measure of its brightness as seen by an observer on Earth, normalized to the value it would have in the absence of the atmosphere. The brighter the object appears, the lower the value of its **magnitude**.

The scale upon which magnitude is now measured has its origin in the Hellenistic practice of dividing those stars visible to the naked eye into six *magnitudes*. The brightest stars were said to be of first magnitude ($m = 1$), while the faintest were of sixth magnitude ($m = 6$), the limit of human visual perception (without the aid of a telescope). Each grade of magnitude was considered to be twice the brightness of the following grade (a logarithmic scale). This somewhat crude method of indicating the brightness of stars was popularized by Ptolemy in his *Almagest*, and is generally believed to have originated with Hipparchus. This original system did not measure the magnitude of the Sun.

In 1856, Norman Robert Pogson formalized the system by defining a typical first magnitude star as a star that is 100 times as bright as a typical sixth magnitude star; thus, a first magnitude star is about 2.512 times as bright as a second magnitude star. The fifth root of 100 is known as *Pogson's Ratio*.[1] Pogson's scale was originally fixed by assigning Polaris a magnitude of 2. Astronomers later discovered that Polaris is slightly variable, so they first switched to Vega as the standard reference star, and then switched to using tabulated zero points[*clarification needed*] for the measured fluxes.[2] The magnitude depends on the wavelength band (see below).

The modern system is no longer limited to 6 magnitudes or only to visible light. Very bright objects have *negative* magnitudes. For example, Sirius, the brightest star of the celestial sphere, has an apparent magnitude of –1.4. The modern scale includes the Moon and the Sun; the full Moon has an apparent magnitude of –12.6 and the Sun has an apparent magnitude of –26.73. The Hubble Space Telescope has located stars with magnitudes of 30 at visible wavelengths and the Keck telescopes have located similarly faint stars in the infrared.

Apparent visual magnitudes of known celestial objects

App. Mag. (V)	Celestial object
–29.30	Sun as seen from Mercury at perihelion
–26.73	Sun (449,000 times brighter than full moon)
–19.3	Sun as seen from Neptune
–12.6	Full Moon
–9.0	Maximum brightness of an Iridium (satellite) flare
–6.0	The Crab Supernova (SN 1054) of AD 1054 (6500 light years away)
–4.6	Maximum brightness of Venus when illuminated as a crescent and the International Space Station (when the ISS is at its perigee and fully lit by the sun)[3]
–4	Faintest objects observable during the day with naked eye when Sun high in the

Absolute magnitude

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In astronomy, **absolute magnitude** (also known as **absolute visual magnitude** when measured in the standard V phometric band) measures a celestial object's intrinsic brightness. To derive absolute magnitude from the observed apparent magnitude of a celestial object its value is corrected from distance to its observer. The absolute magnitude then equals the apparent magnitude an object would have if it were at a standard luminosity distance (10 parsecs, or 1 AU, depending on object type) away from the observer, in the absence of astronomical extinction. It allows the true brightnesses of objects to be compared without regard to distance. **Bolometric magnitude** is luminosity expressed in magnitude units; it takes into account energy radiated at all wavelengths, whether observed or not.

The absolute magnitude uses the same convention as the visual magnitude, with a factor of $100^{(0.2)}$ (≈2.512) difference in brightness between steps in magnitude. The Milky Way, for example, has an absolute magnitude of about −20.5. So a quasar at an absolute magnitude of −25.5 is 100 times brighter than our galaxy (because $(100^{(0.2)})^{(-20.5-(-25.5))} = (100^{(0.2)})^5 = 100$). If this particular quasar and our galaxy could be seen side by side at the same distance, the quasar would be 5 magnitudes (or 100 times) brighter than our galaxy.

History : stellar spectra:

In 1802, William Hyde Wollaston noted that the spectrum of sunlight did not appear to be a continuous band of colors, but rather had a series of dark lines superimposed on it. Wollaston attributed the lines to natural boundaries between colors. Joseph von Fraunhofer made a more careful set of observations of the solar spectrum in 1814 and found some 600 dark lines, and he specifically measured the wavelength of 324 of them. Many of the Fraunhofer lines in the solar spectrum retain the notations he created to designate them. In 1864, Sir William Huggins matched some of these dark lines in spectra from other stars with terrestrial substances, demonstrating that stars are made of the same materials of everyday material rather than exotic substances. This paved the way for modern spectroscopy.

Standard Stellar Types (O, B, A, F, G, K and M)

While the differences in spectra might seem to indicate different chemical compositions, in almost all instances, it actually reflects different surface temperatures. With some exceptions (e.g. the R, N, and S stellar types discussed below), material on the surface of stars is "primitive": there is no significant chemical or nuclear processing of the gaseous outer envelope of a star once it has formed. Fusion at the core of the star results in fundamental compositional changes, but material does not generally mix between the visible surface of the star and its core.

Ordered from highest temperature to lowest, the seven main stellar types are O, B, A, F, G, K, and M. Astronomers use one of several mnemonics to remember the order of the classification scheme. O, B, and A type stars are often referred to as early spectral types, while cool stars (G, K, and M) are known as late type stars. The nomenclature is rooted in long-obsolete ideas about stellar evolution, but the terminology remains. The spectral characteristics of these types are summarized below:

Type	Color	Surf. temp.	Characteristics
O	Blue	> 25,000 K	Singly ionized helium lines either in emission or absorption. Strong ultraviolet continuum.
B	Blue	11,000 - 25,000	Neutral helium lines in absorption
A	Blue	7,500 - 11,000	Hydrogen lines at maximum strength for A0 stars, decreasing thereafter.
F	Blue/White	6,000 - 7,000	Metallic lines become noticeable.
G	White/Yellow	5,000 - 6,000	Solar-type spectra. Absorption lines of neutral metallic atoms and ions grow in strength.
K	Orange/Red	3,500 - 5,000	Metallic lines dominate. Weak blue continuum.
M	Red	< 3,500	Molecular bands of titanium oxide noticeable.

Subtypes

Within each of these seven broad categories, Canon assigned subclasses numbered 0 to 9. A star midway through the range between F0 and G0 would be an F5 type star. The Sun is a G2 type star.

Luminosity classes

The Harvard scheme specifies only the surface temperature and some spectral features of the star. A more precise classification would also include the luminosity of the star. The standard scheme used for this is called the Yerkes classification (or MMK, based on the initials of the authors William W. Morgan, Philip C. Keenan, and Edith Kellman). This scheme measures the shape and nature of certain spectral lines to measure surface gravities of stars. The gravitational acceleration on the surface of a giant star is much lower than for a dwarf star (since $g = G M / R^2$ and the radius of a giant star is much larger than a dwarf). Given the lower gravity, gas pressures and densities are much lower in giant stars than in dwarfs. These differences manifest themselves in different spectral line shapes which can be measured.

The Yerkes scheme uses six luminosity classes:

- Ia - Most luminous supergiants
- Ib - Less luminous supergiants
- II - Luminous giants
- III - Normal giants
- IV - Subgiants
- V - Main sequence stars (dwarfs)

Thus the Sun would be more fully specified as a G2V type star.

R and N type stars

A number of giant stars appear to be K or M type stars, but also show significant excess spectral features of carbon compounds. They are often referred to as "carbon stars" and many astronomers collectively refer to them as C type stars. The most common spectral features are from C_2, CN, and CH. The abundance of carbon to oxygen in these stars is four to five times higher than in normal stars. The presence of these carbon compounds will tend to absorb the blue portion of the spectrum, giving R and N type giants a distinctive red colour. R stars are those with hotter surfaces which otherwise more closely resemble K type stars. S type stars have cooler surfaces and more closely resemble M stars.

S type stars

S type stars have photospheres with enhanced abundances of s-process elements. These are isotopes of elements which have been formed from the capture of a free neutron (changing the isotope of the element) followed by a beta decay (a neutron decays into a proton and an electron, thus changing the element to one with a higher atomic number and an isotope with one less neutron). The s-process is one of the mechanisms by which elements with atomic numbers higher than 56 (Iron) can be made. The s stands for slow. By way of contrast, its partner r-process (for rapid) takes place when there are a sufficient supply of free neutrons for additional neutrons to be acquired in the atomic nucleus before the captured neutron has a chance to beta decay.

Instead of (or in addition to) the usual lines of titanium, scandium, and vanadium oxides characteristic of M type giants, S type stars show heavier elements such as zirconium, yttrium, and barium. A significant fraction of all S type stars are variable.

W type stars

Recently, a new type of star was introduced. See Wolf-Rayet stars for a complete description

Stars and galaxies (*M*)

In stellar and galactic astronomy, the standard distance is 10 parsecs (about 32.616 light years, or 3×10^{14} kilometres). A star at ten pc has a parallax of 0.1" (100 milli arc seconds). For galaxies (which are of course themselves much larger than 10 pc, and whose brightness cannot be sensibly observed from so short a distance) the definition is referred to the apparent brightness of a point-like or star-like source of the same total luminosity as the galaxy, as it would look if observed at the standard 10 pc distance.

In defining absolute magnitude it is necessary to specify the type of electromagnetic radiation being measured. When referring to total energy output, the proper term is bolometric magnitude. The bolometric magnitude can be computed from the visual magnitude plus a bolometric correction, $M_{bol} = M_V + BC$. This correction is needed because very hot stars radiate mostly ultraviolet radiation, while very cool stars radiate mostly infrared radiation (see Planck's law). The dimmer an object (at a distance of 10 parsecs) would appear, the higher its absolute magnitude. The lower an object's absolute magnitude, the higher its luminosity. A mathematical equation relates apparent magnitude with absolute magnitude, via parallax.

Many stars visible to the naked eye have an absolute magnitude which would be capable of casting shadows if they were to lie at 10 parsecs from the Earth: Rigel (−7.0), Deneb (−7.2), Naos (−6.0), and Betelgeuse (−5.6). For comparison, Sirius has an absolute magnitude of 1.4 which is greater than the Sun's absolute visual magnitude of 4.83 (it actually serves as a reference point). The Sun's absolute bolometric magnitude is 4.75.[clarification needed]

Absolute magnitudes for stars generally range from −10 to +17. The absolute magnitude for galaxies can be much lower (brighter). For example, the giant elliptical galaxy M87 has an absolute magnitude of −22.

Computation

One can compute the absolute magnitude of an object given its apparent magnitude and luminosity distance :

where is the star's luminosity distance in parsecs, wherein 1 parsec is approximately 3.2616 light-years.

For nearby astronomical objects (such as stars in our galaxy) the luminosity distance D_L is almost identical to the real distance to the object, because spacetime within our galaxy is almost Euclidean. For much more distant objects the Euclidean approximation is not valid, and General Relativity must be taken into account when calculating the luminosity distance of an object.

In the Euclidean approximation for nearby objects, the absolute magnitude of a star can be calculated from its apparent magnitude and parallax:

where p is the star's parallax in arcseconds.

You can also compute the absolute magnitude of an object given its apparent magnitude and distance modulus :

[edit] Examples

Rigel has a visual magnitude of $m_V = 0.18$ and distance about 773 light-years

Vega has a parallax of 0.129", and an apparent magnitude of +0.03

Alpha Centauri A has a parallax of 0.742" and an apparent magnitude of −0.01

The Black Eye Galaxy has a visual magnitude of m_V=+9.36 and a distance modulus of 31.06.

$$M_V = 9.36 - 31.06 = -21.7$$

[edit] Apparent magnitude

(Main article: apparent magnitude)

Given the absolute magnitude , for objects within our galaxy you can also calculate the apparent magnitude from any distance :

For objects at very great distances (outside our galaxy) the luminosity distance D_L must be used instead of d.

Given the absolute magnitude , you can also compute apparent magnitude from its parallax :

Also calculating absolute magnitude from distance modulus :

[edit] Bolometric magnitude

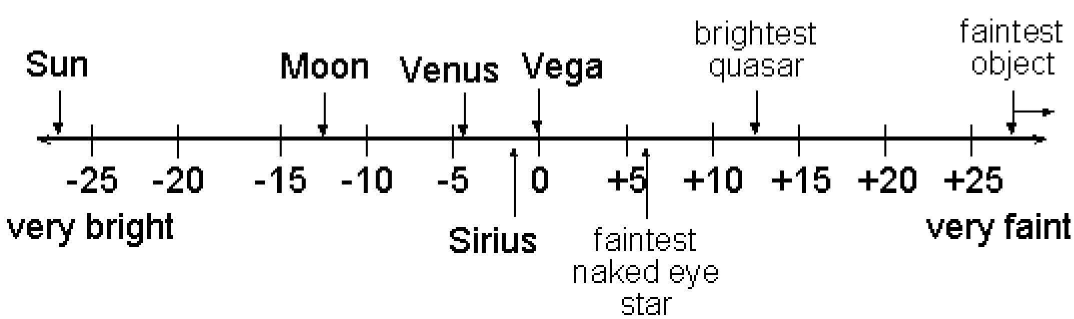
Bolometric magnitude corresponds to luminosity, expressed in magnitude units; that is, after taking into account all electromagnetic wavelengths, including those unobserved due to instrumental pass-band, the Earth's atmospheric absorption, or extinction by interstellar dust. For stars, in the absence of extensive observations at many wavelengths, it usually must be computed assuming an effective temperature.

The brightness of stars are specified with the **magnitude** system. The Greek astronomer Hipparchus devised this system around 150 B.C.E. He put the brightest stars into the first magnitude class, the next brightest stars into second magnitude class, and so on until he had all of the visible stars grouped into six magnitude classes. The dimmest stars were of sixth magnitude. The magnitude system was based on how bright a star appeared to the unaided eye.

By the 19th century astronomers had developed the technology to objectively measure a star's brightness. Instead of abandoning the long-used magnitude system, astronomers refined it and quantified it. They established that a *difference of 5 magnitudes corresponds to a factor of exactly 100 times in intensity*. The other intervals of magnitude were based on the 19th century belief of how the human eye perceives differences in brightnesses. It was thought that the eye sensed differences in brightness on a logarithmic scale so a star's magnitude is not directly proportional to the actual amount of energy you receive. Now it is known that the eye is not quite a logarithmic detector.

Your eyes perceive equal *ratios* of intensity as equal *intervals* of brightness. On the quantified magnitude scale, a magnitude interval of 1 corresponds to a factor of $100^{1/5}$ or approximately 2.512 times the amount in actual intensity. For example, first magnitude stars are about $2.512^{2-1} = 2.512$ *times* brighter than 2nd magnitude stars, $2.512 \times 2.512 = 2.512^{3-1} = 2.512^2$ *times* brighter than 3rd magnitude stars, $2.512 \times 2.512 \times 2.512 = 2.512^{4-1} = 2.512^3$ *times* brighter than 4th magnitude stars, etc. (See the math review appendix for what is meant by the terms ``factor of'' and ``times''.) Notice that you raise the number 2.512 to a power equal to the *difference* in magnitudes.

Also, many objects go beyond Hipparchus' original bounds of magnitude 1 to 6. Some very bright objects can have magnitudes of 0 or even negative numbers and very faint objects have magnitudes greater than +6. The important thing to remember is that brighter objects have *smaller* magnitudes than fainter objects. The magnitude system is screwy, but it's tradition! (Song from *Fiddler on the Roof* could be played here.)



Apparent brightnesses of some objects in the magnitude system.

Apparent Magnitude

The apparent brightness of a star observed from the Earth is called the **apparent magnitude**. The apparent magnitude is a measure of the star's *flux* received by us. Here are some example apparent magnitudes: Sun = -26.7, Moon = -12.6, Venus = -4.4, Sirius = -1.4, Vega = 0.00, faintest naked eye star = +6.5, brightest quasar = +12.8, faintest object = +30 to +31.

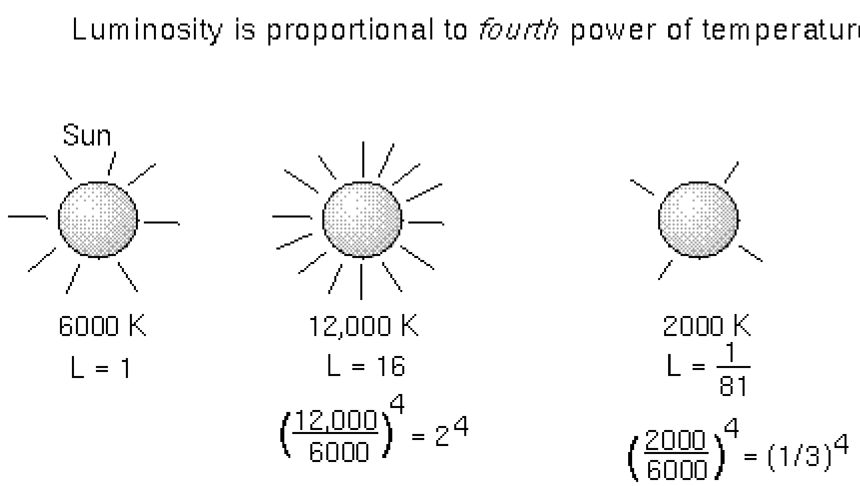
How do you do that?

Star A has an apparent magnitude = 5.4 and star B has an apparent magnitude = 2.4. Which star is brighter and by how many times? Star B is *brighter* than star A because it has a lower apparent magnitude. Star B is brighter by 5.4 - 2.4 = 3 magnitudes. In terms of intensity star B is $2.512^{(5.4-2.4)}$ = $2.512^{3.0}$ = approximately 15.8 times brighter than star A. The amount of energy you receive from star B is almost 16 times greater than what you receive from star A.

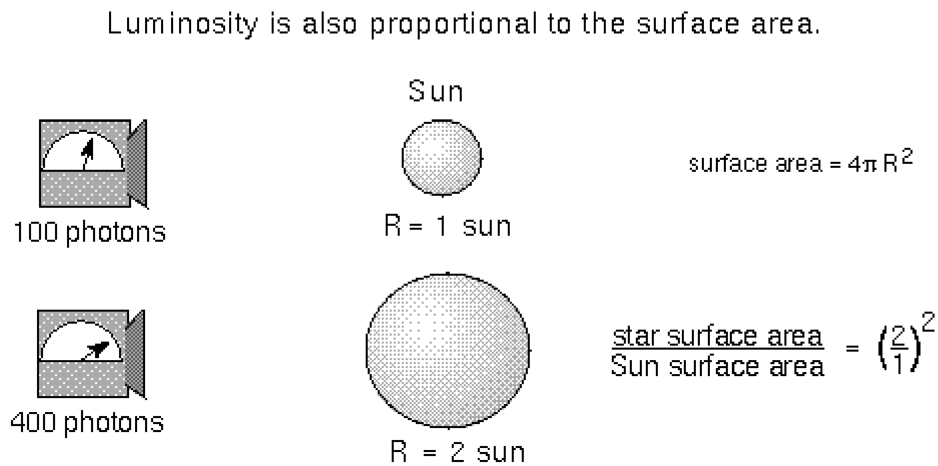
Absolute Magnitude and Luminosity

If the star was at 10 parsecs distance from us, then its apparent magnitude would be equal to its **absolute magnitude**. The absolute magnitude is a measure of the star's **luminosity**---the total amount of energy radiated by the star every second. If you measure a star's apparent magnitude and know its absolute magnitude, you can find the star's distance (using the inverse square law of light brightness). If you know a star's apparent magnitude and distance, you can find the star's luminosity (see the table below). The luminosity is a quantity that depends on the star itself, not on how far away it is (it is an "intrinsic" property). For this reason a star's luminosity tells you about the internal physics of the star and is a more important quantity than the apparent brightness.

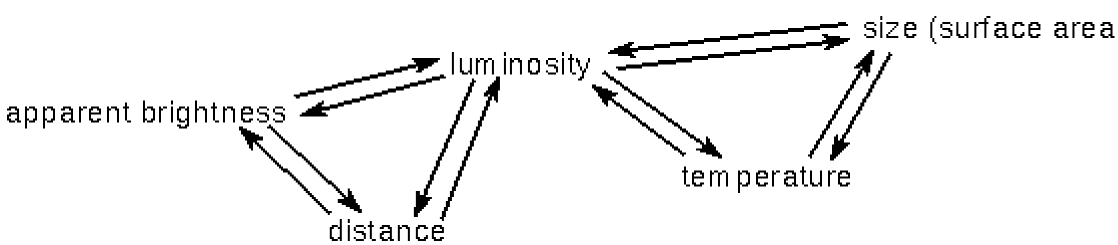
A star can be luminous because it is hot or it is large (or both!). The luminosity of an object = the amount of energy every square meter produces multiplied by its surface area. Recall from the electromagnetic radiation chapter that the amount of energy pouring through every square meter = $\sigma \times$ (object's surface temperature)^4, where σ is the Stefan-Boltzmann constant. Because the temperature is raised to the fourth power, it means that the luminosity of a star increases very quickly with even slight increases in the temperature. The luminosity of a star increases very quickly with even slight increases in the temperature.



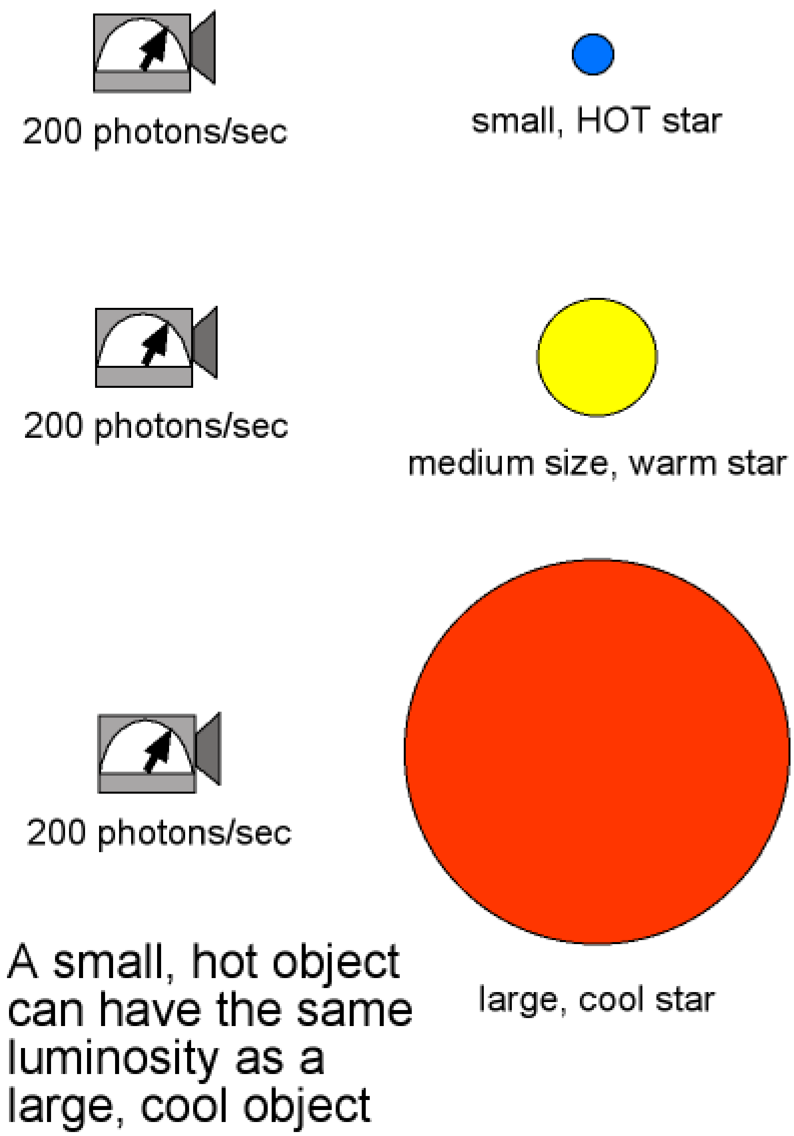
Because the surface area is also in the luminosity relation, the luminosity of a bigger star is larger than a smaller star at the same temperature. You can use the relation to get another important characteristic of a star. If you measure the apparent brightness, temperature, and distance of a star, you can determine its size.



The figure below illustrates the inter-dependence of measurable quantities with the derived values that have been discussed so far. In the left triangular relationship, the apparent brightness, distance, and luminosity are tied together such that if you know any two of the sides, you can derive the third side. For example, if you measure a glowing object's apparent brightness (how bright it appears from your location) and its distance (with trigonometric parallax), then you can derive the glowing object's luminosity. Or if you measure a glowing object's apparent brightness and you know the object's luminosity without knowing its distance, you can derive the distance (using the inverse square law). In the right triangular relationship, the luminosity, temperature, and size of the glowing object are tied together. If you measure the object's temperature and know its luminosity, you can derive the object's size. Or if you measure the glowing object's size and its temperature, you can derive the glowing object's luminosity---its electromagnetic energy output.



Finally, note that a ***small, hot object can have the same luminosity as a large, cool object.*** So if the luminosity remains the *same,* an increase in the size (surface area) of the object must result in a DEcrease in the temperature to compensate.



Most famous apparently bright stars are also intrinsically bright (luminous). They can be seen from great distances away. However, most of the nearby stars are intrinsically faint. If you assume we live in a typical patch of the Milky Way Galaxy (using the Copernican principle), then you deduce that most stars are puny emitters of light. The bright stars you can see in even the city are the odd ones in our galaxy! The least luminous stars have **absolute magnitudes** = +19 and the brightest stars have **absolute magnitudes** = -8. This is a huge range in luminosity! See the ``How do you do that?" box below the following table for examples of using the apparent and absolute magnitudes to determine stellar distances and luminosities of stars.

Even the intrinsically faintest star's luminosity is much, much greater than all of the power we generate here on the Earth so a "watt" or a "megawatt" are too tiny a unit of power to use for the stars. Star luminosities are specified in units of **solar luminosity**---relative to the Sun (so the Sun generates one solar luminosity of power). One solar luminosity is about 4×10^{26} watts.

Magnitudes and Distances for some well-known Stars (from the precise measurements of the Hipparcos mission)

Star	App.Mag.*	Distance(pc)	Abs.Mag.*	Visual Luminosity(rel. to Sun)**
Sun	-26.74	4.84813×10^{-6}	4.83	1
Sirius	-1.44	2.6371	1.45	22.5
Arcturus	-0.05	11.25	-0.31	114
Vega	0.03	7.7561	0.58	50.1
Spica	0.98	80.39	-3.55	2250
Barnard's Star	9.54	1.8215	13.24	1/2310
Proxima Centauri	11.01	1.2948	15.45	1/17700

*magnitudes measured using ``V'' filter, see the next section.

**The visual luminosity is the energy output in the ``V'' filter. A total luminosity (``bolometric luminosity'') would encompass the energy in all parts of the electromagnetic spectrum.

How do you do that?

A quantity that uses the inverse square law and the logarithmic magnitude system is the ``distance modulus''. The distance modulus = the apparent magnitude - absolute magnitude. This is equal to 5 × *log*(distance in parsecs) - 5. The ``*log()*'' term is the ``logarithm base 10'' function (it is the ``log'' key on a scientific calculator). If you measure a star's apparent magnitude and its distance from its trigonometric parallax, the star's absolute magnitude = the apparent magnitude - 5 × *log*(distance + 5. For example, Sirius has an apparent magnitude of -1.44 and Hipparcos measured its distance at 2.6371 parsecs, so it has an an absolute magnitude of -1.44 - 5×*log*(2.6371) + 5 = -1.44 - (5×0.421127) + 5 = 1.45.

If you know a star's absolute magnitude, then when you compare it to calibration stars, you can determine its distance.

$$\text{Its distance} = 10^{(\text{apparent magnitude - absolute magnitude + 5})/5}.$$

For example, Spica has an apparent magnitude of 0.98 and stars of its type have absolute magnitudes of about -3.55, so Spica is at a distance of $10^{[0.98 - (-3.55) + 5]/5} = 10^{1.906} = 80.54$ which is very close to the trig. parallax value measured by Hipparcos (Spica's absolute magnitude of -3.546 was rounded to -3.55 in the table above).

If you know two star's absolute magnitudes, you can directly compare their luminosities. The ratio of the two stars' luminosities is $(Lum._{*1})/(Lum._{*2}) = 10^{-0.4(\text{abs mag*1 - abs mag*2})}$ or in an approximate relation: $Lum._{*1}/Lum._{*2} = 2.512^{(\text{abs mag*2 - abs mag*1})}$. Remember the more luminous star has an absolute magnitude that is *less than* a fainter star's absolute magnitude! Try out this relation on the stars given in the table above.

Stars are dense hot balls of gas so their spectrum is close to that of a perfect thermal radiator, which produces a smooth continuous spectrum. Therefore, the color of stars depends on their temperature---hotter stars are bluer and cooler stars are redder. You can observe the star through different **filters** to get an approximate temperature. A filter allows only a narrow range of wavelengths (colors) through. By sampling the star's spectrum at two different wavelength ranges (``bands"), you can determine if the spectrum is that for a hot, warm, cool, or cold star. Hot stars have temperatures around 60,000 K while cold stars have temperatures around 3,000 K. The filter diagrams are shown below.

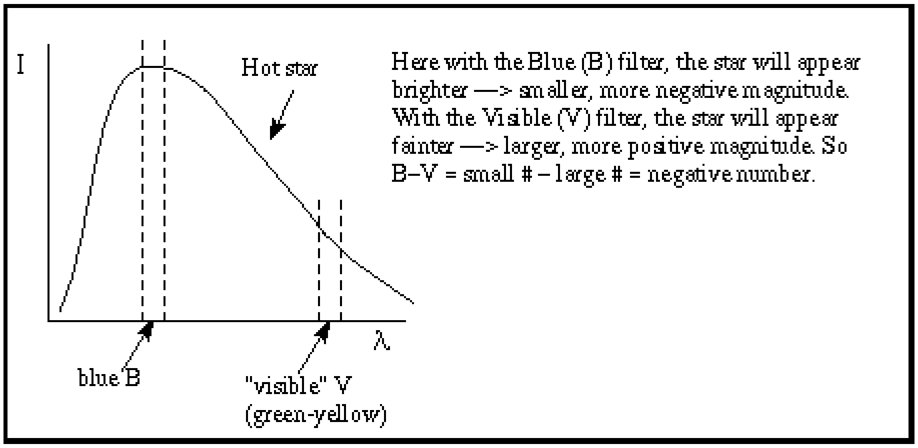
Color Index and Temperature

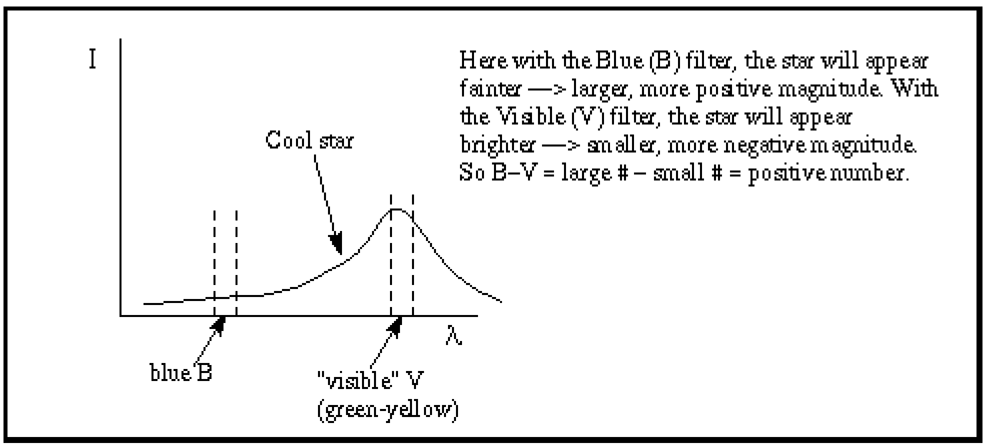
Hot stars appear bluer than cooler stars. Cooler stars are redder than hotter stars. The ``B-V color index'' is a way of quantifying this using two different filters; one a blue (B) filter that only lets a narrow range of colors or wavelengths through centered on the blue colors, and a ``visual'' (V) filter that only lets the wavelengths close to the green-yellow band through.

A hot star has a B-V color index close to 0 or negative, while a cool star has a B-V color index close to 2.0. Other stars are somewhere in between. Here are the steps to determine the B-V color index:

1. Measure the apparent brightness (flux) with two different filters (B, V).
2. The flux of energy passing through the filter tells you the magnitude (brightness) at the wavelength of the filter.

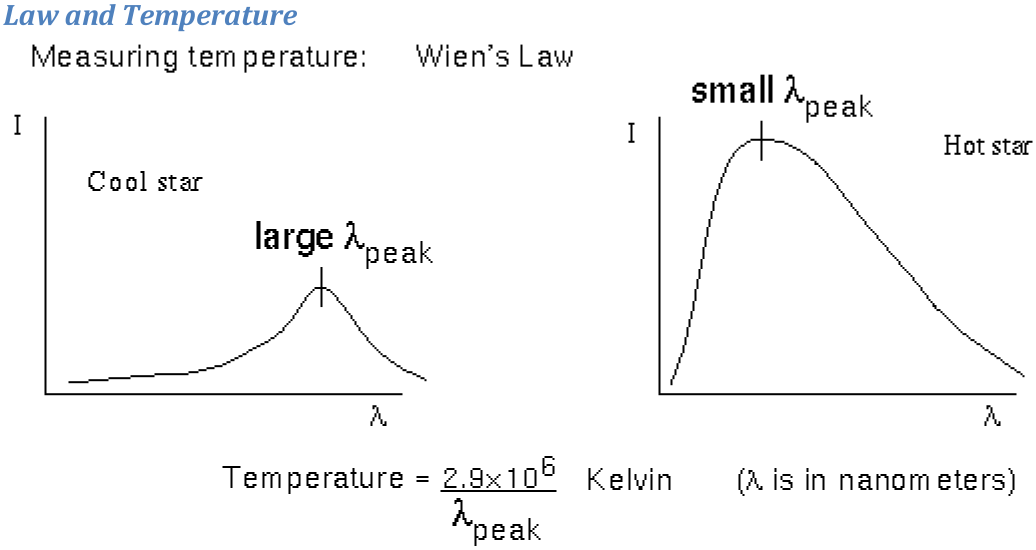
3. Compute the magnitude difference of the two filters, B - V.





The UNL Astronomy Education program's **Blackbody Curves and UBV Filters module** lets you explore the relationship between temperature and the thermal spectrum by manipulating various parameters with a graphical interface (link will appear in a new window). You can also explore temperature-color correlation using various filters.

Wien's Law and Temperature



Another way to measure a star's temperature is to use Wien's law described in the electromagnetic radiation chapter. Cool stars will have the peak of their continuous spectrum at long (redder) wavelengths. As the temperature of a star increases, the peak of its continuous spectrum shifts to shorter (bluer) wavelengths. The final way to measure a star's temperature is more accurate than the previous two methods. It uses the strength of different absorption lines in a star's spectrum. It is described in full a little later in the chapter. The temperatures of different types of stars are summarized in the Main Sequence Star Properties table.

Spectral Types

Stars are divided into groups called **spectral types** (also called *spectral classes*) which are based on the strength of the hydrogen absorption lines. The A-type stars have the strongest (darkest) hydrogen lines, B-type next strongest, F-type next, etc. Originally there was the whole alphabet of types, based on hydrogen line strengths, but then astronomers discovered that the *line strengths depended on the temperature.* Also, the discussion in the previous section and the figure above show that more than just the hydrogen lines must be used because a very hot star and a cool star can have the same hydrogen lines strength. The presence of other atomic or ion lines are used in conjunction with the hydrogen spectrum to determine the particular temperature of the star.

After some rearranging and merging of some classes, the spectral type sequence is now OBAFGKM when ordered by *temperature*. The O-type stars are the hottest stars and the M-type stars are the coolest. Each spectral type is subdivided into 10 intervals, e.g., G2 or F5, with 0 hotter than 1, 1 hotter than 2, etc. About 90% of the stars are called **main sequence** stars. The other 10% are either red giants, supergiants, white dwarfs, proto-stars, neutron stars, or black holes. The characteristics of these types of stars will be explored in the following chapters. The table below gives some basic characteristics of the different spectral classes of *main sequence* stars. Notice the trends in the table: as the temperature of the main sequence star increases, the mass and size increase. Also, because of the relation between luminosity and the size and temperature of a star, hotter main sequence stars are more luminous than cooler main sequence stars. However, there are limits to how hot a star will be, or how massive and large it can be. Understanding why the constraints exist is the key to understanding how stars work.

Main Sequence Star Properties

Color	**Class**	**solar masses**	**solar diameters**	**Temperature**	**Prominent Lines**
bluest	O	20 - 100	12 - 25	40,000	ionized helium
bluish	B	4 - 20	4 - 12	18,000	neutral helium, neutral hydrogen
blue-white	A	2 - 4	1.5 - 4	10,000	neutral hydrogen
white	F	1.05 - 2	1.1 - 1.5	7,000	neutral hydrogen, ionized calcium
yellow-white	G	0.8 - 1.05	0.85 - 1.1	5,500	neutral hydrogen, strongest ionized calcium

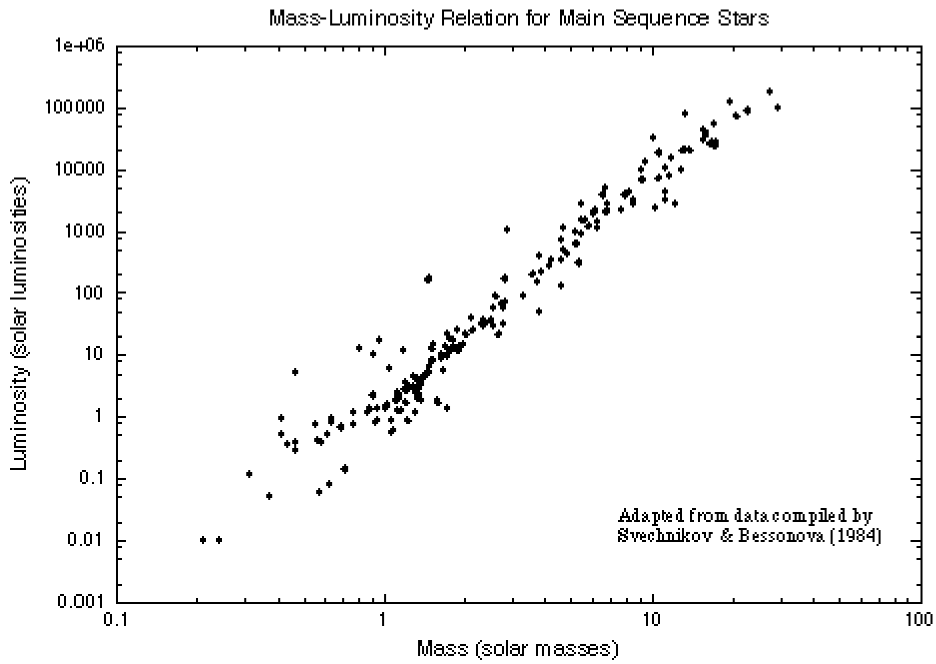
orange	K	0.5 - 0.8	0.6 - 0.85	4,000	neutral metals (calcium, iron), ionized calcium
red	M	0.08 - 0.5	0.1 - 0.6	3,000	molecules and neutral metals

Red giants can get up to about 50 times the size of the Sun. Supergiants are between 20 times the size of the Sun for the BO supergiants and 1000 times the size of the Sun for the M0 supergiants. Despite the tremendous size of some stars, even the largest supergiant is only 1/7000 light years across. Since stars are *several* light years from each other, they do not collide with each other (even the fat ones!).

Vocabulary

In order to better understand how stars are constructed, astronomers look for *correlations* between stellar properties. The easiest way to do this is make a plot of one intrinsic property vs. another intrinsic property. An *intrinsic* property is one that does not depend on the distance the star is from the Earth (e.g., temperature, mass, diameter, composition, and luminosity). By the beginning of the 20th century, astronomers understood how to measure these intrinsic properties. In 1912, two astronomers, *Ejnar Hertzsprung* (lived 1873--1967) and *Henry Norris Russell* (lived 1877--1957), independently found a surprising correlation between temperature (color) and luminosity (absolute magnitude) for 90% of the stars. These stars lie along a narrow diagonal band in the diagram called the **main sequence**. This plot of luminosity vs. temperature is called the **Hertzsprung-Russell diagram** or just **H-R diagram** for short.

Before this discovery astronomers thought that it was just as easy for nature to make a hot dim star as a hot luminous star or a cool luminous one or whatever other combination you want. But nature prefers to make particular kinds of stars. *Understanding why enables you to determine the rules nature follows.* A correlation between mass and luminosity is also seen for main sequence stars: Luminosity = $Mass^{3.5}$ in solar units.

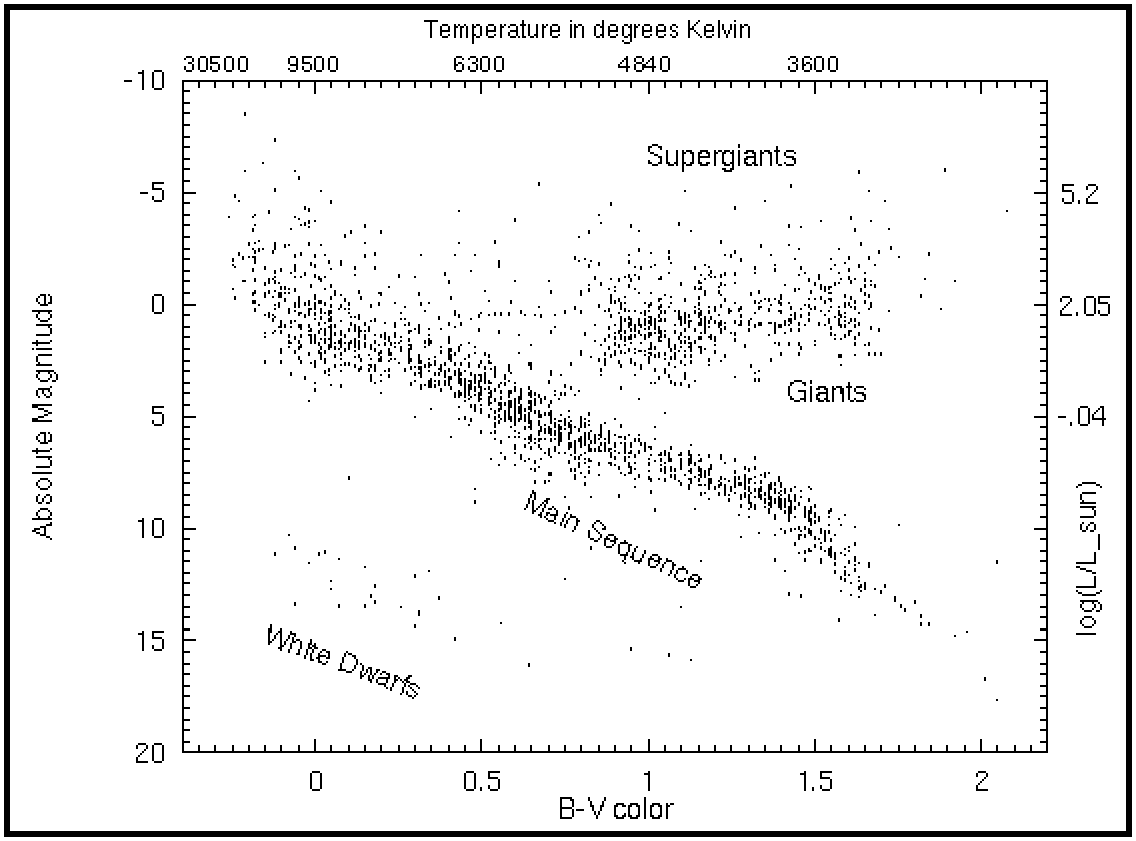


The mass-luminosity relation for 192 stars in double-lined spectroscopic binary systems.

The hot, luminous O-type stars are more massive than the cool, dim M-type stars. The mass-luminosity relationship tells about the structure of stars and how they produce their energy. The cause of the mass-luminosity relation will be explored further in the next chapter.

The other ten percent of the stars in the H-R diagram do not follow the mass-luminosity relationship. The giant and supergiant stars are in the upper right of the diagram. These stars must be large in diameter because they are very luminous even though they are cool. They have a huge surface area over which to radiate their energy. The white dwarfs are at the opposite end in the lower left of the diagram. They must be very small in diameter (only about the diameter of the Earth) because even though they are hot, they are intrinsically dim. They have a small surface area and so the sum of the total radiated energy is small.

The H-R diagram is also called a **color-magnitude diagram** because the absolute magnitude is usually plotted vs. the color. The H-R diagram below is for all stars visible to the naked eye (down to apparent magnitude = +5) plus all stars within 25 parsecs. Luminous stars are easier to observe because they can be seen from great distances away but they are rarer in the galaxy. They tend to reside in the top half of the H-R diagram. Faint stars are harder to see but they are more common in the galaxy. They tend to reside in the bottom half of the H-R diagram.



Use the UNL Astronomy Education program's **Hertzsprung-Russell Diagram module** for another in-depth tutorial on the HR diagram via a graphical interface (link will appear in a new window).

Spectroscopic Parallax

You can use the correlation between luminosity and temperature (spectral type) for *main sequence* stars to get their distances. This method is called **spectroscopic parallax** because a distance is found from knowledge of a star's spectral type. Distances for stars too far away to show a detectable trigonometric parallax are found this way. Here are the steps you use to find a star's distance using the spectroscopic parallax method:

1. Determine the star's spectral type from spectroscopy and measure the star's apparent brightness (flux).
2. Use a calibrated main sequence to get the star's luminosity. The Hyades cluster in the Taurus constellation is the standard calibrator.
3. Use the Inverse Square Law for Brightness to get the distance: unknown distance = calibrator distance × *Sqrt*[calibrator flux/unknown star's flux.]

How do you do that?

A G2 star appears 25 times dimmer than it would if it was at the standard distance of 10 parsecs used for the absolute magnitude. The G2 star is at a distance of = 10 × *Sqrt*[1/(1/25)] = 10 × *Sqrt*[25/1] = 50 parsecs from us.

Distances to red giant and supergiant stars are found in a similar way but you need to investigate their spectra more closely to see if they are the very large stars you think they are. Their position in the calibrated H-R diagram is found and their apparent brightness gives you the distance. Also, this process can be used to find the distance of an entire cluster. The entire color-magnitude diagram for the cluster is compared with a calibration cluster's color-magnitude diagram. The calibration cluster is a known distance away. Some adjustments for the cluster's age and composition differences between the stars in the cluster and the calibration cluster must be made. Such fine-tuning adjustments are called ``main-sequence fitting".