Homework 2

AST 301, Section 47791, Spring 2017

NAME Student EID Score is on last page.

Due Tuesday, February 28, 2017 Help Session: February 27, 4–6 PM in Welch 3.502

Questions A – C should help you to understand the properties of light. **Show your work. If you don't show your work, we will reluctantly have to give you only 1/2 of the full points even if you get the correct answer.**

A. How many wavelengths of blue light would fit across the **thickness** of a sheet of paper? The easiest way to find the thickness of a sheet of paper is to take a stack of xerox pages that is (for example) 1 cm thick (use a ruler to measure it), count the number of pages in the stack, and then divide 1 cm by this number. (5 points)

B. How long does it take for red photons from the Sun to reach the Earth? (2 points) How about blue photons? (2 points) Why? (1 point)

C. The energy of one photon is equal to Planck's constant times the speed of light divided by the wavelength of the photon. Planck's constant is 6.63×10^{-34} Joule sec. The speed of light is 3.0×10^8 m/s. How many photons are emitted per second by a 100 Watt lightbulb? Notes: 1 Watt = 1 Joule per second. You can get the wavelength by assuming that the color is yellow. (8 points) Why can you not see individual photons? (2 points)

D. This is a calculation to show you how inadequate chemical reactions are for powering the Sun. According to the 76^{th} Edition of the *Handook of Chemistry and Physics*, burning one gram of benzene (a simple form of gasoline) produces 4.18×10^4 Joule of energy. The Sun's mass is 2×10^{30} kg and its luminosity is 3.8×10^{26} Joule/s. If the Sun were made of benzene and you burned it fast enough to produce the solar luminosity, how many years would it last? (Ignore the fact that you need oxygen to burn something.) Other chemical reactions would be similar. Note that the Earth's age is about 4.5 billion years. (15 points)

E. In class, we found out that matter and energy are equivalent and that the energy "frozen" inside a given mass is the mass times the square of the speed of light ($E = mc^2$). This question gives you a feeling for how much energy there is in even a small amount of mass. If you could totally annihilate a 1 kg potato (that is, if you could completely convert it to energy), how many joules of energy would you get? The total electric power consumption of greater Austin averages about 1.1×10^9 watt (1 Watt = 1 joule/s; 1 joule = 1 kg m^2/s^2). How long could you satisfy Austin's electricity needs if you could harness all the energy from your potato? (10 marks)

F. Plot a Hertzsprung-Russell diagram on the graph paper provided at the end of this homework (“HW”). First plot absolute magnitude M_V against spectral type for the stars nearest to the Sun; they are listed in the Appendices of the textbook, but since different students have different editions, I provide tables at the end of this HW. Plot white dwarf stars at spectral type A0. Ignore stars of types Y and T. Then use a different color pen to plot the brightest stars in the sky (table at the end of this HW). Finally, in a still different color, add the main-sequence stars (table at the end of this HW). Plot points clearly and accurately. (15 points)

Label the following key regions on your diagram:

The main sequence (3 points)

The giant branch (3 points)

The supergiants (3 points)

The white dwarfs (1 point)

Here are some interesting things you can note from the plot and the tables:

(a) Compare your plot with p. 153 (Edition 8) or p. 167 (Edition 9) or p. 165 (Edition 10) or p. 155 (Edition 11) or p. 165 (Editions 12, 13) in the textbook. They show the brightest and nearest stars in separate Hertzsprung-Russell diagrams. Note that the nearest and the apparently brightest stars are very different. The nearest stars are mostly faint, low-mass dwarfs. The apparently brightest stars really are intrinsically bright and mostly far away. That is, no extreme dwarf star is so near the Sun that it looks very bright.

(b) The plot should convince you that the Sun in a very average star.

(c) Rigel and Betelgeuse are two of the brightest stars in Orion: Rigel is the right foot and Beteguese is the left shoulder (there is a map of Orion in Chapter 2). They are very different: Betelgeuse is a cool star with a temperature of 2900 K; when you look at it in the sky, you can see that it looks reddish. Rigel is extremely blue and bright; it’s surface temperature is 36,000 K. That’s why Betelguese is an M2 star and Rigel is B8. You can see the different colors of these stars when you look at the constellation in the sky.

(d) Sirius and Canopus are the brightest stars in the sky (after the Sun, of course). They are only a factor of two different in apparent brightness, but in reality, Canopus is 4.5 magnitudes or 63 times more luminous than Sirius. Why do they look almost equally bright? Because Canopus is 11 times farther away. (The distances are given in the table.)

(e) In fact, Deneb, at apparent magnitude 1.26, is still one of the brightest stars in the sky, but is much farther away (1600 ly, compared to 98 ly for Canopus and only 8.7 ly for Sirius). It is a supergiant star, 60,000 times more luminous than the Sun. You really can’t tell a star’s distance or true luminosity just by looking at it.

(f) Alpha Centauri A, α Centauri B, and Proxima Centauri form a triple system and are the closest stars to the Sun. Proxima Centauri is the closest of the three. It's name comes from the Latin word for "close". Note where Proxima is on your Hertzsprung-Russell diagram. You will see that it is one of the least luminous dwarfs known.

(g) Sirius A and B and Procyon A and B are both binary stars, i. e., a pair of stars that orbit around each other. Note how different they are. The A stars are normal main-sequence stars; the companions are already white dwarfs. We will see that white dwarfs are essentially dead stars – they have virtually finished their evolution. We will also see that more massive stars die more quickly. The fact that the fainter member of each pair has already evolved to a white dwarf means that it started out more massive than it's brighter companion. When both stars were young, the star that is now the white dwarf would have been much the brighter of the two.

(h) Arcturus is an orange giant 27 times the size of the Sun and the fourth brightest star in the sky. Our Sun is expected to become very much like Arcturus in its old age (about 5000 million years from now).

(i) If you enjoyed the Star Trek TV series and movies, you may be interested to note that the fictional planet Vulcan which is the homeworld of Mr. Spock is said to revolve around the star ϵ Eridani (see the table of nearest stars). It is a K2 star rather cooler and therefore redder than the Sun. That's why the "sunlight" on the planet is always shown as red. "Live long and prosper."

G. Multiple-choice questions: for each question, circle the correct answer. (5 points each)

1. If the core of a main sequence star gets too hot,

   (A) the star explodes.

   (B) the star expands, engulfing its planets.

   (C) the core expands, cools, and thereby reduces its energy output.

   (D) the star contracts.

   (E) nuclear reactions produce Helium more quickly, and the star lives less long.

2. Which event marks the end of a star's life on the main sequence?

   (A) Core collapse

   (B) Helium ignition

   (C) Carbon deflagration

   (D) Hydrogen in the core is used up

   (E) Supernova explosion

3. Energy produced in the core of the Sun escapes

   (A) by conduction

   (B) by convection

   (C) by radiation

   (D) near the center, by convection; then, near the surface, by radiation

   (E) near the center, by radiation; then, near the surface, by convection

4. Which of the following are affected by the Sun's 11-year cycle?

   (A) Sunspots

   (B) Prominences

   (C) Flares

   (D) The Earth's climate

   (E) All of the above

5. Globular clusters are about 13 billion years old. What type of stars do they **not** contain?

   (A) red giant stars

   (B) 10 $M_\odot$ main sequence stars

   (C) 3 $M_\odot$ neutron stars

   (D) 0.6 $M_\odot$ main sequence stars

   (E) 0.6 $M_\odot$ white dwarfs

The Brightest Stars

Star	Name	Apparent Visual Magnitude (m_V)	Distance[3] (pc)	Absolute Visual Magnitude[4] (M_V)	Spectral Type
	(Sun)	−26.74		4.8	G2 V
α CMa	Sirius	−1.47	2.6	1.5	A1 V
α Car	Canopus	−0.72	95	−5.6	F0 II
α Boo	Arcturus	−0.04	11	−0.2	K1.5 III
α Cen A	Rigil Kentaurus	−0.01	1.3	4.4	G2 V
α Lyr	Vega	0.03	7.7	0.6	A0 V
β Ori	Rigel	0.12	260	−7.0	B8 Iab
α CMi	Procyon	0.34	3.5	2.6	F5 IV-V
α Ori	Betelgeuse	0.42	150	−5.5	M2 Iab
α Eri	Achernar	0.50	43	−2.7	B3 Vpe
β Cen	Hadar	0.60	120	−4.8	B1 III
α1 Aur	Capella A	0.71	13	0.1	G8 III
α Aql	Altair	0.77	5.1	2.2	A7 V
α2 Aur	Capella B	0.96	13	0.4	G0 III
α Tau	Aldebaran	0.98	20	−0.5	K5 III
α Vir	Spica	1.04	77	−3.4	B1 III-IV
α Sco	Antares	1.09	170	−5.1	M1.5 Iab-b
β Gem	Pollux	1.15	10	1.2	K0 IIIb
α PsA	Fomalhaut	1.16	7.7	1.7	A4 V
α Cyg	Deneb	1.25	430	−6.9	A2 Iae
β Cru	Mimosa	1.30	85	−3.3	B0.5 IV
α Cen B	Rigil Kentaurus	1.33	1.3	5.8	K1 V
α Leo	Regulus	1.40	24	−0.5	B8 IV
α Cru A	Acrux	1.40	99	−3.6	B0.5 IV
ε CMa	Adara	1.51	120	−3.9	B2 Iab
λ Sco	Shaula	1.62	180	−4.7	B2 IV
γ Cru	Gacrux	1.63	27	−0.5	M3.5III
γ Ori	Bellatrix	1.64	77	−2.8	B2 III
β Tau	El Nath	1.68	41	−1.4	B7 III
β Car	Miaplacidus	1.70	35	−1.0	A2 IV
ε Ori	Alnilam	1.70	610	−7.2	B0 Iab
α Gru	Alnair	1.74	31	−0.7	B6 V
ε UMa	Alioth	1.76	25	−0.2	A0pCr
ζ Ori A	Alnitak	1.77	230	−5.0	O9 Iab
α UMa A	Dubhe	1.79	38	−1.1	K0 Iab
ε Sgr	Kaus Australis	1.80	44	−1.4	B9.5 III
γ2 Vel	Suhail	1.81	340	−5.8	O7.5e
α Per	Mirfak	1.82	160	−4.2	F5 Iab
δ CMa	Wezen	1.84	150	−4.0	F8 Iab
η UMa	Alkaid	1.85	32	−0.7	B3 V
θ Sco	Sargas	1.86	92	−3.0	F1 II
γ Gem	Alhena	1.90	34	−0.8	A0 IV
α Pav	Peacock	1.91	55	−1.8	B2 IV
α TrA	Atria	1.92	120	−3.5	K2 IIb-IIIa
α Gem A	Castor A	1.93	15	1.0	A1 V
δ Vel A	Koo She	1.95	25	0.0	A1 V

Star	Name	Apparent Visual Magnitude (m_v)	Distance[3] (pc)	Absolute Visual Magnitude[4] (M_v)	Spectral Type
α Ari	Hamal	2.00	20	0.5	K2III
β CMa	Mirzam	2.00	150	−3.9	B1 II-III
α Hya	Alphard	2.00	55	−1.7	K3 II-III
α UMi	Polaris	2.00	130	−3.6	F7 Ib-II
β Cet	Deneb Kaitos	2.04	29	−0.3	K0 III

[1]Data from the SIMBAD database, operated at CDS, Strasbourg, France.
[2]For multiple star systems, the magnitude given is the combined light of all components; the spectral type is for the primary component.
[3]Rounded to two significant figures.
[4]Computed from m_v and distance.

Table A-9 | The Nearest Stars[1]

Name	Distance (pc)	Apparent Visual Magnitude (m_v)	Absolute Visual Magnitude (M_v)	Spectral Type
Sun		−26.7	4.85	G2V
Proxima Centauri	1.30	11.1	15.5	M6Ve
α Centauri A	1.33	0.01	4.40	G2V
α Centauri B	1.33	1.34	5.70	K1V
Barnard's Star	1.83	9.51	13.2	M4.0Ve
Wolf 359	2.39	13.44	16.6	M6.0V
Lalande 21185	2.54	7.47	10.4	M2.0V
Sirius A	2.63	−1.46	1.42	A1V
Sirius B	2.63	8.44	11.3	WD
Luyten 726-8	2.68	12.54	15.4	M5.5Ve
WISE 1541-2250	2.85	21.20	23.9	Y
Ross 154	2.97	10.43	13.1	M3Ve
Ross 248	3.16	12.29	14.8	M6.0Ve
Epsilon Eridan	3.22	3.73	6.20	K2V
Lacaille 9352	3.27	7.34	9.80	M2Ve
Ross 128	3.35	11.10	13.5	M4.5Vn
EZ Aquarii A	3.45	13.33	15.6	M5.0Ve
EZ Aquarii B	3.45	13.27	15.6	M?
EZ Aquarii C	3.45	14.03	16.3	M?
Procyon A	3.50	0.34	2.70	F5IV-V
Procyon B	3.50	10.70	13.0	WD
61 Cygni A	3.50	5.21	7.50	K5.0V
61 Cygni B	3.50	6.03	8.30	K7.0V
Struve 2398 A	3.57	8.90	11.2	M3.0V
Struve 2398 B	3.57	9.69	12.0	M3.5V
Groombridge 34 A	3.56	8.08	10.3	M2.0V
Groombridge 34 B	3.56	11.06	13.3	M6.0V
Epsilon Indi A	3.63	4.69	6.90	K5Ve
Epsilon Indi Ba	3.63	24.12	26.3	T1.0V
Epsilon Indi Bb	3.63	>23	>25	T6.0V
DX Cancri	3.63	14.78	17.0	M6.5Ve
Tau Ceti	3.64	3.49	5.70	G8.5Vp
GJ 1061	3.68	13.09	15.3	M5.5V

The Nearest Stars (Continued)

Name	Distance (pc)	Apparent Visual Magnitude (m_v)	Absolute Visual Magnitude (M_v)	Spectral Type
YZ Ceti	3.72	12.02	14.2	M4V
Luyten's Star	3.79	9.86	12.0	M3.5V
Teegarden's star	3.84	15.40	17.2	M7V
SCR 1845-6357 A	3.85	17.39	19.4	M8.5V
SCR 1845-6357 B	3.85	?	?	T6
Kapteyn's Star	3.92	8.84	10.9	M1.0V
Lacaille 8760	3.95	6.67	8.70	M0V
UGPS 0722-05	4.07	16.52	18.5	T9
Kruger 60 A	4.03	9.79	11.8	M3.0V
Kruger 60 B	4.03	11.41	13.4	M4.0V
DEN 1048-3956	4.04	17.39	19.4	M9V
Ross 614 A	4.09	11.07	13.1	M4.5V
Ross 614 B	4.09	14.23	16.2	M8V
Wolf 1061	4.24	10.07	11.9	M3.5V
Van Maanen's star	4.31	12.38	14.2	WD
Gliese 1	4.36	8.55	10.4	M1.5V
Wolf 424 A	4.39	13.18	15.0	M4Ve

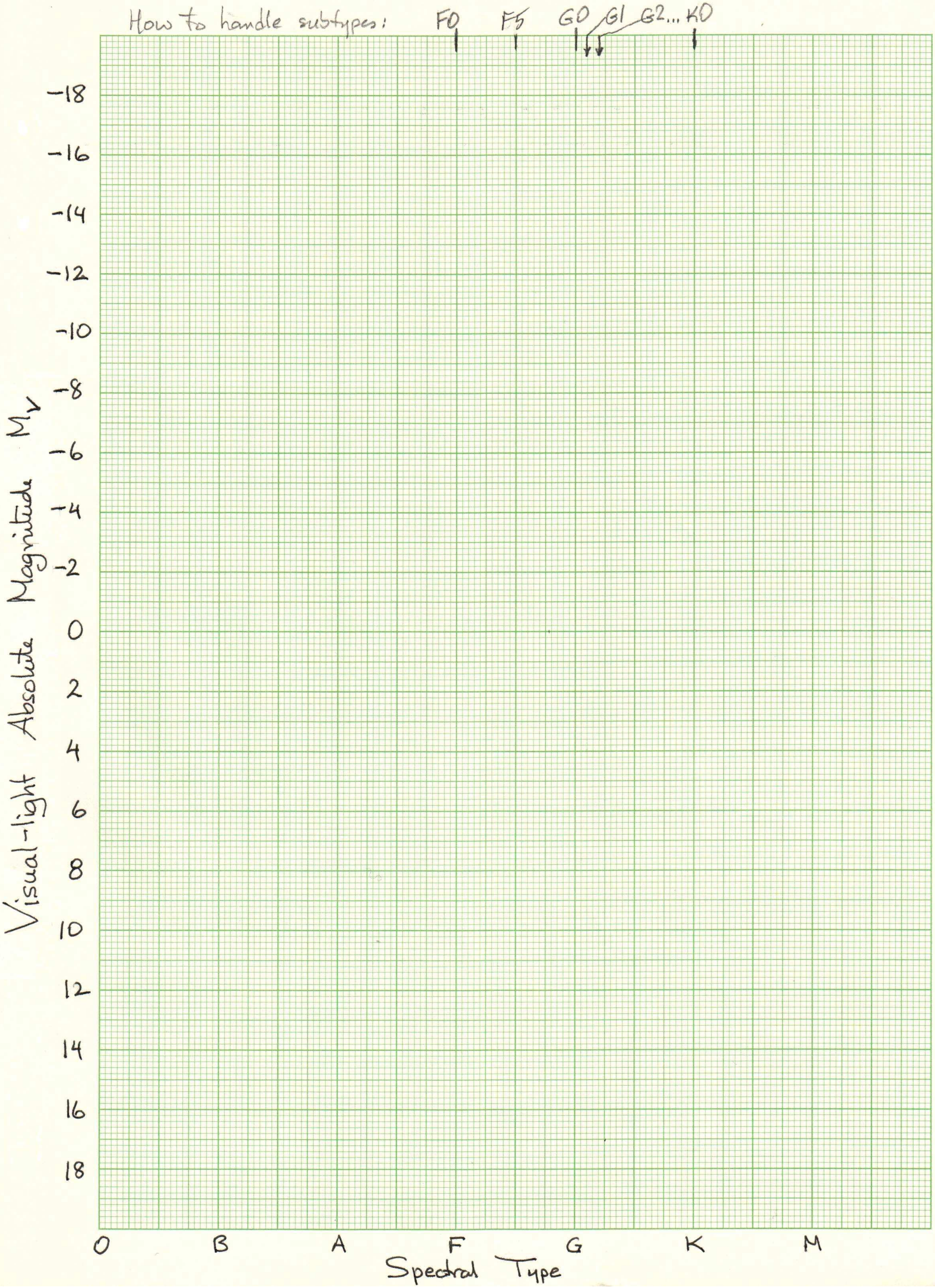
[1]Data from the SIMBAD database, operated at CDS, Strasbourg, Franc.

■ Table A-7 Properties of Main-Sequence Stars

Spectral Type	Absolute Visual Magnitude (M_v)	L[1,2]	Temp. (K)	λ_{max} (nm)	Mass[1]	Radius[1]	Average Density (g/cm^3)
O5	−5.7	620,000	42,000	69	60	12	0.03
B0	−4.0	61,000	30,000	97	18	7.4	0.04
B5	−1.2	1,100	15,000	191	5.9	3.9	0.1
A0	0.7	73	9800	296	2.9	2.4	0.2
A5	2.0	18	8200	354	2.0	1.7	0.4
F0	2.7	8.8	7300	397	1.6	1.5	0.5
F5	3.5	4.6	6600	436	1.4	1.3	0.6
G0	4.4	2.1	5900	488	1.05	1.1	0.8
G2	4.7	1.0	5200	558	1.0	1.0	0.1
G5	5.1	0.7	5600	521	0.9	0.9	0.8
K0	5.9	0.6	5200	563	0.8	0.8	1.2
K5	7.4	0.3	4400	657	0.7	0.7	1.8
M0	8.8	0.1	3800	755	0.5	0.6	2.2
M5	12.3	0.01	3200	914	0.2	0.3	10

[1]Luminosity, mass, and radius are given in terms of the sun's luminosity, mass, and radius.

[2]Luminosity is computed from radius and temperature.


How to handle subtypes:
F0
F5
G0
G1
G2... K0
Visual-light Absolute Magnitude M_V
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
O
B
A
F
G
K
M
Spectral Type