

## **ABSOLUTE AND APPARENT MAGNITUDES** **(© Constantine Thomas, 28th May 2005, updated 15/5/14)**

The ability to determine the brightness of stars as seen from alien worlds could be quite handy when it comes to making a description of a world seem more 'real'.

To do this, you first need to know what magnitudes *are*. The Magnitude scale is basically the way that astronomers quantify the brightness of stars and other objects (including planets, asteroids, spacecraft etc) that they see in the sky.

Magnitudes for stars range in practise from about -10 to +17, but the possible range of values is theoretically unlimited. The lower the number, the brighter the object. So magnitude 17 object is incredibly dim, and a magnitude -10 object is very bright. There are two different quantities used - the **Absolute Magnitude**, and the **Apparent Magnitude**. **Apparent Magnitude** is a more intuitive concept and is more familiar to us - it's simply the brightness of the object as seen by the viewer. **Absolute Magnitude** is a bit more esoteric - it's the brightness that the object **WOULD** have if it was placed at a distance of 10 parsecs from the viewer. Since this distance is standardised, astronomers can use that to figure out the actual luminosity of the object - usually a star - being viewed (but we usually know that already, as world-builders).

The magnitude scale is set up so that a difference in magnitude of 5 between two objects corresponds to an increase in brightness by a *factor* of 100 - i.e. the scale is logarithmic. If the difference in magnitude is 0, then the objects have the same brightness (as seen by the viewer).

magnitude difference	0	1	2	3	4	5	6	7	8	9	10
relative difference	1	2.5	6.3	16	40	100	250	630	1600	4000	10000

The relative brightness difference can be calculated by raising 2.512 to the power of the magnitude difference:  $(2.512)^{\Delta m}$ .

EXAMPLE: If a star has an apparent magnitude of +2 and a planet has an apparent magnitude of -5 (due to light reflected from its surface or cloudtops) as seen from a planet's surface, then the planet appears about 630 times brighter in the sky than the star.

To give you an idea of scale and the numbers used, consult the table below. Planets don't have absolute magnitudes (at least, not in the same sense as stars. I'll get to that in a separate document) - the apparent magnitudes given for planets correspond to when they are brightest as seen from Earth:

<b>Object</b>	<b>Absolute Magnitude</b>	<b>Apparent Magnitude</b>
Sun	4.83	-26.74
Full Moon	-	-12.5
Mercury	-	-1.9
Venus	-	-4.6
Mars	-	-2.91
Jupiter	-	-2.94
Saturn	-	0.43
Uranus	-	5.32
Neptune	-	7.78
Pluto	-	13.56
Alpha Centauri	4.38	0.01
Sirius	1.47	-1.43
Van Maanen's Star	14.21	12.38
Vega	0.58	0.03
Betelgeuse	-5.14	0.45
Antares	-5.28	1.06
Andromeda Galaxy	(-20.64)	3.50
3C 273 (quasar)	(-35.44)	12.8

As a general (not vastly accurate, but close enough) rule of thumb, the highest apparent magnitude that the naked eye can see under ideal viewing conditions is about +6. Objects can cast visible shadows around an apparent magnitude -4 (you'd need a very dark night to see them though - they'd get progressively more noticeable as the object's magnitude decreases). Around an apparent magnitude of between -18 and -21, the object is so bright that its light could scatter in an atmosphere and 'turn night into day' to some extent - at the lower end of this range, the sky would be noticeably "not black" (it would be a very deep blue), especially around the object. Brighter objects would brighten the sky more noticeably and make it a paler blue.

## 1) CALCULATING THE ABSOLUTE MAGNITUDE (M) OF A STAR

Let's say you are describing a scene on a planet, and want to figure out how bright a distant companion star is. You could be doing this for descriptive purposes, but it might be bright enough to cast shadows, or even possibly turn night into day if the world has an atmosphere! Before we can calculate the Apparent Magnitude, we first have to calculate the **Absolute Magnitude** of the star. To do this, we need to know the Luminosity of the star in solar units ( $L$ ), which we should already know as world-builders and GMs. Then plug that into the equation below:

$$M = 4.83 - 2.5 \log_{10} L$$

where:

$M$  = Absolute magnitude of the star (magnitude if viewed from 10 pc)

$L$  = Luminosity of star expressed in solar units.

$M$  is constant for a given luminosity - it only changes if the luminosity of the star itself changes (which would happen if it changes into a red giant or white dwarf, or if it is a variable star).

The mathematical jiggery-pokery required to derive this is rather complex, but trust me - this is correct!

## 2) CALCULATING THE APPARENT MAGNITUDE (m) OF A STAR

Using  $M$  we can now calculate the **APPARENT MAGNITUDE** of the star, which is how bright it is in the sky at its actual distance from the viewer (which is the information we actually are trying to figure out here).

This is much simpler. All we need to do is to take  $M$  calculated above and  $d$  (the distance of the star - the units used can be pc, ly, AU, or km, but see the comments below), and plug them into the equation below:

$$m = M + 5 \log_{10} (d / C)$$

$C$  is a constant that depends on the units that the distance to the star is measured.

if  $d$  is in **parsecs**, then  $C = 10$  (= number of pc in 10 pc)

if  $d$  is in **lightyears**, then  $C = 32.616$  (= number of ly in 10 pc)

if  $d$  is in **AU**, then  $C = 2062641.61$  (= number of AU in 10 pc)

if  $d$  is in **kilometres**, then  $C = 3.08571e14$  (= number of km in 10 pc)

That should cover every practical eventuality for the distance units :).

### 3) EXAMPLES

First, let's test this out on some familiar stars.

a) Procyon is an F5 IV star that is 7.36 times brighter than Sol and 11.4 lightyears from Earth. What are its Absolute (M) and Apparent (m) magnitude?

$$M = 4.83 - 2.5\log(7.36), \text{ so } M = 2.66.$$

$$m = 2.66 + 5\log(11.4/32.616), \text{ so } m = 0.38.$$

These values agree with the real values, so this shows that the equations work!

b) What is the apparent magnitude of Sol as seen from Procyon?

The Absolute Magnitude of the sun is 4.83 (looking at the M equation,  $\log(1) = 0$ , so  $M = 4.83$ ).

$$m = 4.83 + 5\log(11.4/32.616), \text{ so } m = 2.54$$

Sol would appear as a fairly inconspicuous yellow star, visible to the naked eye, in Procyon's sky.

c) What is the apparent magnitude of Sol as seen from Neptune? Neptune is 30 AU from Sol.

We know the Absolute Magnitude of Sol already. Its Apparent Magnitude from Neptune is therefore:

$$m = 4.83 + 5\log(30/2062641.61) = -19.36$$

At magnitude -19.36, Sol would still look brighter than the full moon seen from Earth as seen from Neptune. It would obviously cast shadows, and would scatter light in Neptune's cloudtops so that the sky would probably be a deep blue as seen by a viewer sitting in the planet's upper atmosphere.

Next, let's use a fictional example, taken from Spica Publishing's "System Book 1: Katringa", which I co-authored (it's available at <http://rpg.drivethrustuff.com/product/86279/System-Book-1-Katringa>): The planet Katringa orbits the star Ayo - an A8 IV subgiant - on an eccentric orbit that varies between a perihelion of 9.026 AU and an aphelion of 11.7 AU. The star's luminosity is 46 Sols.

a) How bright is Ayo as seen from Katringa at perihelion (9.026 AU)?

First, we calculate the Absolute Magnitude M:  $4.83 - 2.5\log(46) = 0.67$

Then, we calculate the Apparent Magnitude m, using the appropriate value for C given that we're using distances in AU:  $0.67 + 5\log(9.026/2062641.61) = -26.12$

This very similar in brightness to the apparent magnitude of Sol as seen from Earth, though the light would be whiter and contain a lot more ultraviolet (the star would also cover a third of the area of Sol in Katringa's sky).

b) How bright is Ayo as seen from Katringa at aphelion (11.7 AU)?

After doing the calculations...  $M = 0.67$ , and  $m = -25.56$

The difference in magnitude between perihelion and aphelion is 0.563, which is a factor of  $(2.512^{0.563} =) 1.68$ . So when viewed from Katringa, Ayo is 1.68 times brighter at perihelion than at aphelion (this would probably be noticeable to the human eye).

c) The gas giant Accra orbits Ayo within Katringa's orbit at a distance of 1.9 AU. How bright is Ayo as seen from Accra?

For Accra,  $M = 0.67$  and  $m = -29.51$ .

So from Accra, Ayo would appear 22.6 times brighter than it would from Katringa at perihelion!

(Thanks to Cham, Spaceman Spiff, Selden, and Fridger on the Celestia Boards for helping me figure out the equations!)