Calculating Magnitudes

How scientists determine the brightness of objects in space

In astronomy, the term **apparent magnitude** is used to describe the measurement of an **object's brightness as seen from Earth**.

Today's telescopes have inbuilt charged-coupled devices (CCDs) which record the incoming light from a star. The apparent magnitude of the star can be calculated by measuring the starlight recorded on the CCD and using it in the formula for apparent magnitude (Equation 1).

Apparent Magnitude

We calculate an object's apparent magnitude using Equation 1.

Equation 1 – Apparent Magnitude.

$$\boldsymbol{apparent\ magnitude\ (m) = -2.5\ \log(intensity)}$$

Here, **'intensity'**, also knowns as **'counts'**, refers to the amount of light that is emitted from the object and received by the CCD (see 'Photometry in Astronomy' worksheet).

However, it's a bit of an archaic system in that the **brighter** an object, the **lower** its apparent magnitude value. Objects that appear exceptionally bright have **negative numbers**, the Sun for example has an apparent magnitude of -27. Objects with apparent magnitude values higher than around **6**, are unobservable to us with our naked eye alone.

The very first catalogues of stars were developed by a Greek astronomer, Hipparchus. He used a logarithmic scale when ordering apparent magnitudes of stars he observed. This scale was later formulised by Norman Pogson and it follows that if two stars have a magnitude difference of 1, the difference in **apparent brightness** corresponds to a factor of **2.512**. So a star of first magnitude will appear twice as bright as a star of second magnitude.

This scale is summarised in Table 1.

Table 1 – The Magnitude Scale

Magnitude difference between 2 stars	Calculation of factor difference in apparent brightness	Factor difference in apparent brightness
1	$(2.512)^1$	2.512
2	$(2.512)^2$	6.310
3	$(2.512)^3$	15.85
4	$(2.512)^4$	39.82
5	$(2.512)^5$	100.0

Step 1: Use Table 2 below to see if you can put the list of stars into order of their brightness. Use letters (a) to (e) where (a) is the brightest and (e) is the faintest.

Table 2 – Ordering Stars in terms of the Apparent Magnitude		
Object	**Apparent Magnitude**	**Order of Brightness**
Sirius	-1.46	B
Betelgeuse	0.42	D
Full Moon	-12.5	A
Neptune	7.78	E
Rigel	0.13	C

Now let's take a closer look at the values in Table 2.

Step 2: Do you think that the Moon is truly brighter than a star?

Students should recognise here that in terms of intrinsic brightness, stars are brighter than the Moon. The Moon's light is only what it reflects from the Sun rather than its own emitted radiation.

Imagine looking at a light source of a defined brightness. Think about how bright the light source appears when you are standing close to it compared to when you are standing further away.

Step 3: If you took measurements of the intensity of light you were receiving from a light bulb, would you get the *same values* when you were standing *close* to the light bulb as when you were standing *further away*? Explain your answer.

Students should recognise that when they stand close to a light source they would measure it to be brighter than when they are standing further away. This is because when they are standing further away the light is spread out over a larger area.

Step 4: What factor is therefore *not considered* when we determine an object's apparent magnitude or brightness and why might this be important to consider?

We now know that apparent magnitude tells us an object's brightness as seen from Earth. However, not all objects are the same distance from Earth. As with the light source discussed above, it we are closer to a light source it appears brighter than when we are further away. Apparent magnitude is therefore not an accurate method of determining an object's "true" brightness and cannot be used to compare the inherent properties of objects.

To check your understanding of apparent magnitude, see Quick Quiz 2.

An object's apparent brightness is measured in intensity or counts (depending on the software instruments that are used). In Steps 2 and 3, you should have identified that objects closer to the observer appear brighter and objects further away appear fainter. This is due to the 'inverse square law' that follows in Equation 2.

Equation 2 – Inverse Square Law

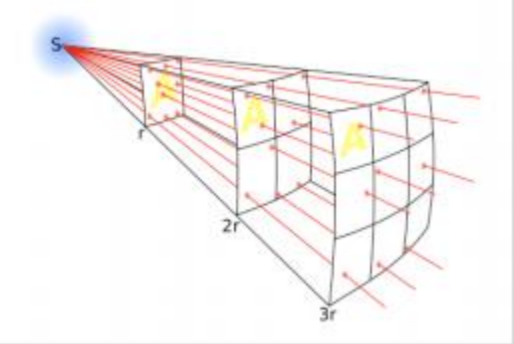
$$b \propto \frac{1}{d^2}$$

Where:

b = apparent brightness (W m^{-2})
d = distance from observer (m)

This relationship means that if you moved a light source to a position **2** times further away than its original distance, its measured brightness would drop by a factor of **4**. If you placed it at **3** times the distance, the brightness would drop by a factor of **9**. This is illustrated in Figure 1.

Figure 1 – An illustration of the inverse square law and how apparent brightness decreases with distance. Image Credit: By Borb, CC BY-SA 3.0



A star radiates its light over a **spherical area**. The red lines we see in Figure 1 represent the intensity of light emitting from a star at point S. As you increase the distance from the star, you increase the radius (r).

Due to Equation 3 below, the surface area of the sphere becomes larger.

Equation 3 – Area of a Sphere

$$A = 4\pi r^2$$

Where:

A = area (m^2)
r = radius of sphere (m)

As the light intensity is per unit area, it appears dimmer.

So the inverse square law explains how an object's apparent brightness is influenced by the distance of the observer. This leads us to question, how do we determine the **true brightness** of an object?

Absolute Magnitude

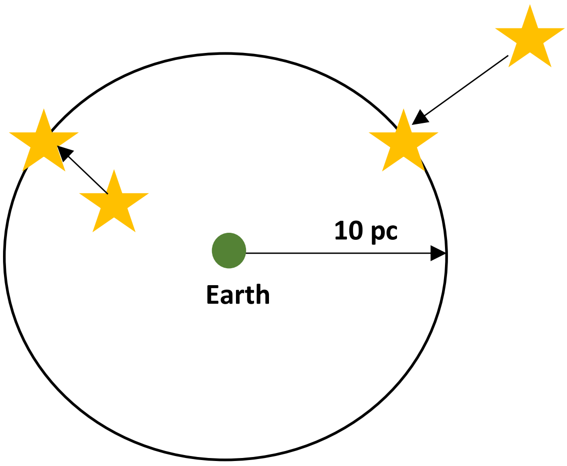
We have seen how apparent magnitude describes how bright an object is to an observer and why the apparent brightness of a star varies in relation to its distance from Earth. However, in order to determine how bright an object is **relative to other objects** in the Universe, we must account for the object's **distance from Earth**.

To do this, astronomers hypothetically place all objects at an **equal distance from Earth** and measure what their brightness would be from this point. This is a distance of **10 parsecs** (pc), where 1 parsec is equal to **3.09×10^{16} m**. You may also be interested to know that 1 parsec is equivalent to 3.26 light years, or the distance that light travels in 3.26 years!

By placing all objects at a defined distance, astronomers are able to compare the "true" brightness of various objects. We call this the **absolute magnitude**

This is illustrated in Figure 2 and calculated through Equation 4.

Figure 2 – A diagram illustrating how astronomers would hypothetically place objects at a distance of 10 pc from Earth to determine their absolute magnitude.



Equation 4 – Absolute Magnitude

$$M = m + 5 - 5\log d$$

Where:

M = absolute magnitude
m = apparent magnitude
d = distance (pc)

If two of the three parameters above are known (m, M or d), we can rearrange Equation 4 in order to calculate the remaining unknown value.

If we know an object's apparent and absolute magnitude we can rearrange Equation 4 to determine the distance to the object, this is shown in Equation 5.

Equation 5 – Distance

$$d = 10^{\left(\frac{m-M+5}{5}\right)}$$

Where:

M = absolute magnitude
m = apparent magnitude
d = distance (pc)

To check you've understood all these different terms, have a go at Quick Quiz 3.