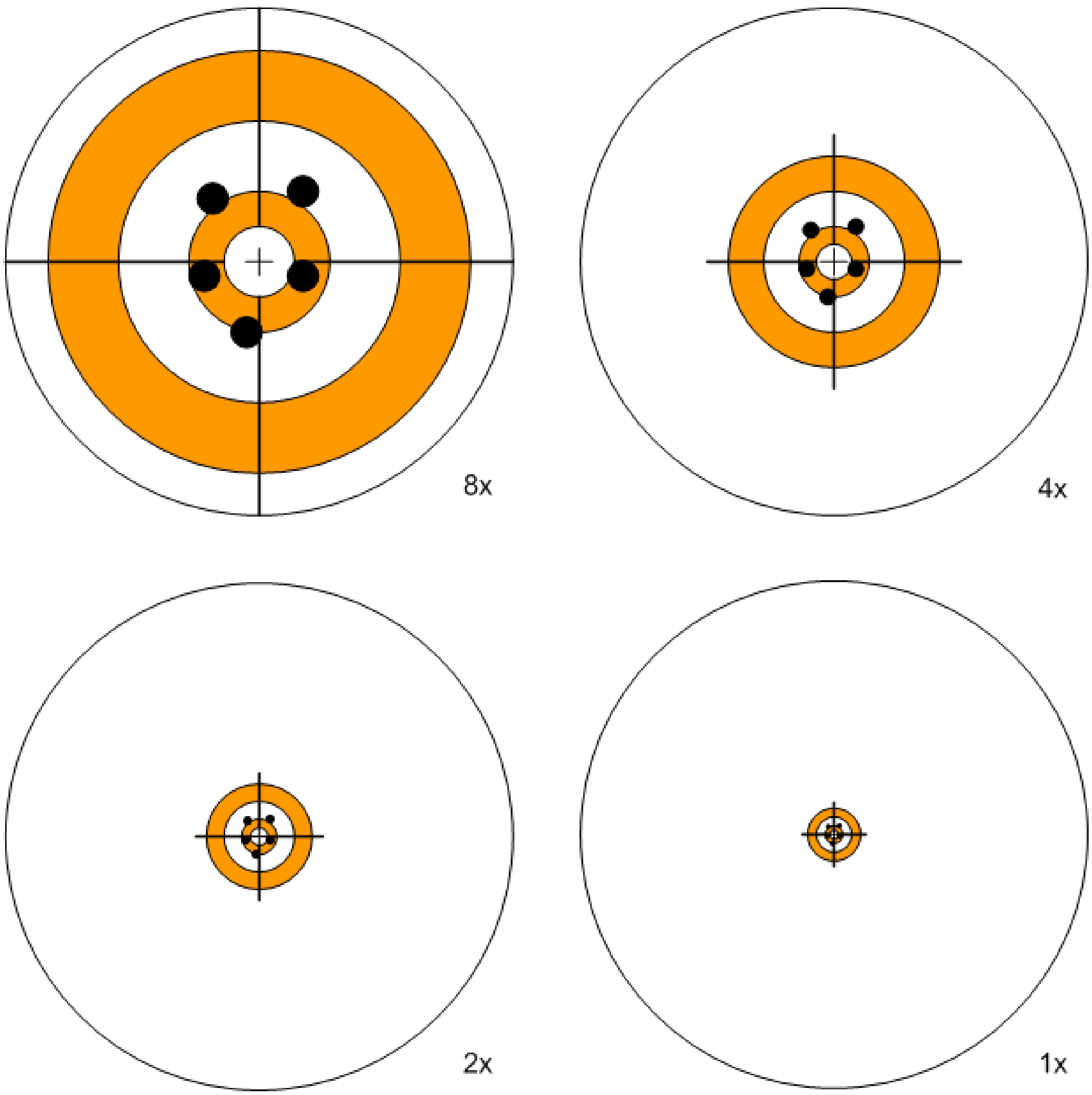
Scope & Spotting Scope Resolution and Magnification

Eyesight Resolution Limits

The normal or median human visual resolution limit is 1 MOA (minute of angle). This is also called normal visual acuity when use by your eye doctor. On the typical Snellen eye chart, the 20/20 line (20 foot line in USA) or 6/6 line (6 meters in the rest of the world) was designed to be readable with a visual resolution or acuity of 1 MOA. The other lines/characters are scaled accordingly.

Telescopes were developed as visual aids to overcome this limited visual resolution or acuity. The principal tool for resolution improvement is magnification. It is obvious that magnification increases the apparent size of objects. However and more importantly magnification increases visual resolution. In the following illustration note how even small (doublings – powers of 2) increases in magnification greatly increase our ability to resolve (distinguish) small but important details by both increasing their apparent size and making better use of the available field of view.



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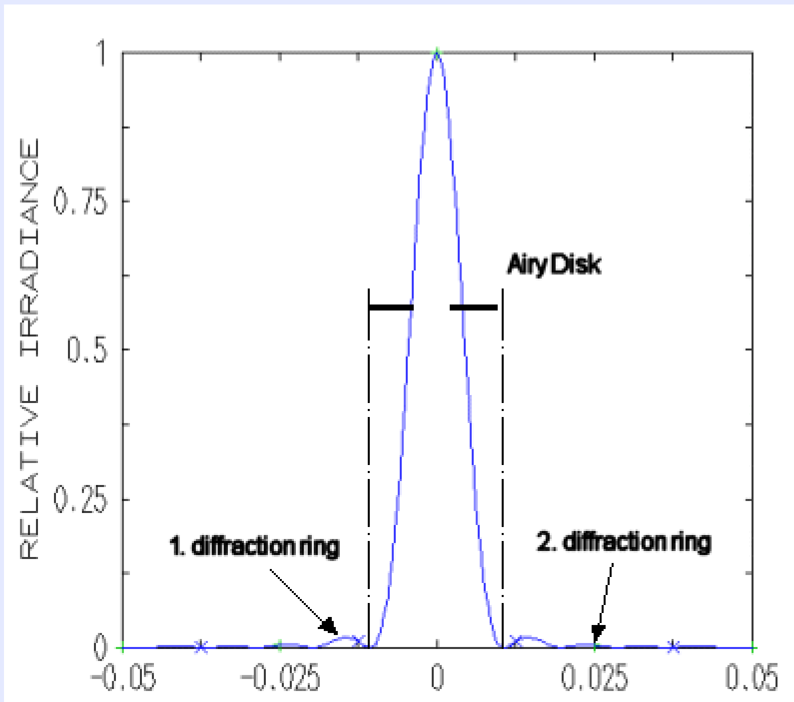
Scope Resolution Limits

Diffraction Limited Optics

A long historical record holds that diffraction defines the ultimate resolution limit of telescopes. Generally we can say that any aperture with a finite size will cause diffraction and hence its resolution will be limited. The finite aperture (front lens, main mirror) must cut off a part of the incoming plane wave front. This missing part is disturbing the otherwise perfect interference of the propagating waves in a certain way. The result is a modulation of the wave front called the Point Spread Function (PSF). Instead of the perfect image of a point this PSF (for an otherwise perfect telescope!) creates something like pictured below (when sliced in the center of this 3-dimensional shape):



PSF of unobstructed, perfect aperture [OSLO light]

The Airy Disk for a perfect and unobstructed telescope is encircling 84% of the energy from the point light source. 16% are spread to the rings with the first ring containing the biggest part. A telescope with such a perfect Airy Disk is also said to have a **Strehl Ratio of 100%**. Because of possible aberrations (i.e. Spherical aberration, Coma, Astigmatism, Chromatic aberration) and other things like wrong focus, central obstruction and spider vanes a real life's telescope has a Strehl Ratio of less than 100%.

Somewhat arbitrarily a telescope with a **Strehl Ratio less than 80%** is said to be **diffraction limited**. This is corresponding to a resulting wave front error of $\lambda/4$.

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Estimating the Resolution Limit: Airy, Rayleigh and Dawes

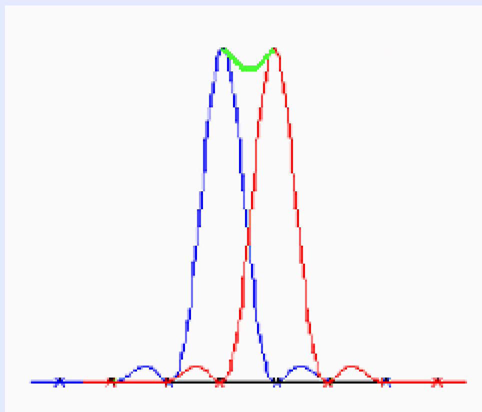
Obviously the resolution limit or resolving power is connected to that Airy Disk, because no detail imaged by the telescope can be smaller than this disk. The radius of the Airy Disk can be estimated with:

$R = 0.2516 * \lambda / D$ (for angular resolving in arc sec)

The Airy Disk is getting smaller when the diameter of the aperture is getting bigger. On the other hand the Airy Disk is shrinking with smaller wavelengths. Blue light is resolving better than red light. Because of the human eye being most sensitive to green light the wavelength of 550 nm is very often picked for the calculations.

Rayleigh's Resolution Limit

Lord Rayleigh said that the ultimate resolution limit of a telescope is reached when the center of one Airy Disk is just one radius away of the other one.



2 PSF separated by one radius

Rayleigh's resolution limit [arc sec] = 138.4 / Aperture Diameter [mm] (for green light)

Dawes Resolution Limit

Dawes found out by his own observations that he could resolve a binary star with both stars having a magnitude of 6 slightly better than Lord Rayleigh claimed. The Dawes limit is hence an empirical one and can be written as:

Dawes's resolution limit [arc sec] = 116 / Aperture Diameter [mm] (for green light)

Or more usefully to rifle scopes and spotting scopes

Dawes's resolution limit [MOA] = 1.933 / Objective Diameter [mm] (for green light)

There have been advances in large astronomic telescope optics, digital imaging and image processing and even adaptive optics (real-time computer assisted mirror shape corrections) to improve the useful resolution of big telescopes. However, for the current available scopes and spotting scopes the Dawes limit currently gives the best (supported by many observations) value for the best resolution that can be reasonably expected in shooting applications.

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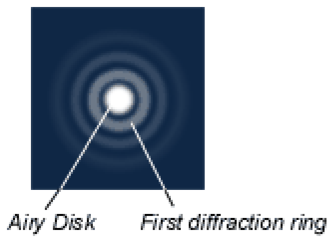
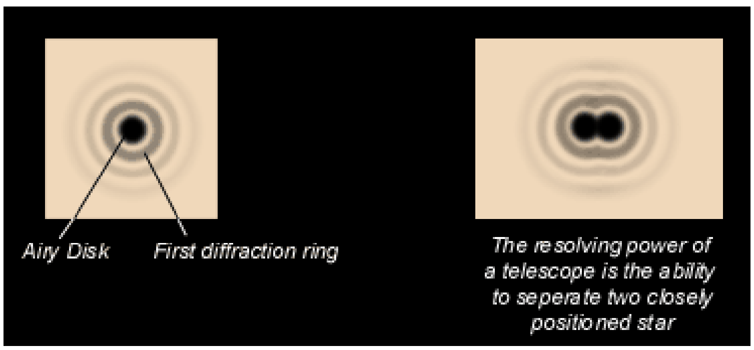
Example Images

The following images show photographs at the diffraction and Dawes Limit for a single point and a limiting close pair of points. The first pair show stars (white on black) and the second are the negative (black on off-white - like common match targets).



The resolving power of a telescope is the ability to seperate two closely positioned star



Data Table

These tables were calculated for popular sizes of objective lens diameters of the respective devices.

Scope Sights

Objective Diameter (mm)	24	32	40	42	45	50	52	56
Dawes Resolution Limit (MOA)	0.081	0.060	0.048	0.046	0.043	0.039	0.037	0.035
Match Magnification (x)	12.4	16.6	20.7	21.7	23.3	25.9	26.9	29.0

Spotting Scopes

Objective Diameter (mm)	60	70	80	85	90	100	125	130
Dawes Resolution Limit (MOA)	0.032	0.028	0.024	0.023	0.021	0.019	0.016	0.015
Match Magnification (x)	31.0	36.2	41.4	44.0	46.6	51.7	64.7	67.2

Match magnification means the Dawes Limit equals the magnified normal visual acuity of the human eye (1MOA). At less magnification the resolution is limited by the user's eye. Above this magnification the resolution is diffraction limited by the objective diameter to the Dawes Resolution Limit (MOA) above.

NOTE: Dawes Resolution Limit (inches) = Dawes Resolution Limit (MOA) x Range (yards) x 0.01047

Also = <u>Smallest separation between features and minimum POA (point of aim) error (confusion circle)!</u>

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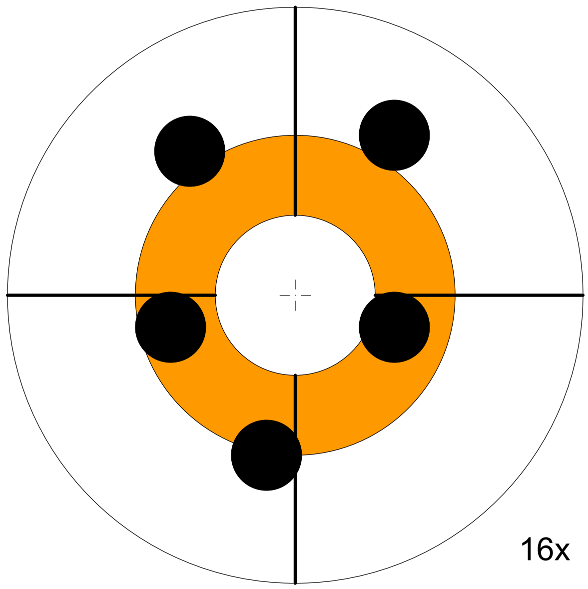
Magnification Limits

Magnifications greater than the match to Dawes Limit do not produce any more real resolution. However such greater magnifications do still help detail perception by reducing useless clutter in the field of view. For example, look at the 8x (top left) illustration on page 1. The magnification could be doubled again then still retain all important information and be easier to decipher do to reduction of irrelevant information in the field of view as shown below.



Note that if viewed through a diffraction limited scope the edges of features of the target image would begin to blur and also show diffraction effects for those features below the Dawes resolution size (diameter or width) at greater than match magnifications. These effects have not been simulated above.

In the best real seeing conditions (clear still air, no mirage) and with no scope motion, maximum useable magnification will be about 400x for spotting scopes. For more typical range and field conditions, maximum useable magnification will be about 250x for spotting scopes.

Scope sights face practical constraints on size and weight such that maximum attainable magnification will be about 60x. Seeing conditions will also degrade the image quality for the scope sight.

Variable Magnification Scope Sights

The principle advantage of a variable versus a fixed magnification scope sight is the ability to set a low magnification to acquire your target then raise the magnification to increase the aiming point resolution. Care must be taken to not to substitute the low magnification scope setting for target searching with binoculars in hunting situations (pointing the scope is also pointing the loaded firearm). Never move the point of aim outside the original field of view (know what your pointing the firearm at – always).

Many prairie dog shooters and even some target shooters use a variable to decrease the power to minimize or at least manage the amount of mirage (optical distortion cause differential heating of the air in the field of view causing apparent motion – often aggravated by wind). What they are doing is reducing the apparent magnitude of this motion by increasing the size of the field of view. The effect is still there but not as easily visible. While in extreme cases this may be necessary, it is being done at the expense of some effective resolution (aiming error increase) by adding clutter to the image field. This must be done with care and is of very dubious value for target shooting (learn to read the mirage as well as the wind).

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Effective Resolution Enhancement

Fortunately we all have a magnificent image enhancement device (our brain) to help us utilize our hardware to its fullest capability. Our brain's ability at pattern recognition (to find a learned pattern within a complex visual field) is awesome. An example is finding a familiar face in a crowd of strangers at an airport or stadium. The target case is much less complex and therefore can be done at much greater distances in a lower resolution data field.

You know what your targets should look like, have looked at them at multiple ranges before, and are expecting to see them. As you bring your cross hairs to bear on your expected target your brain is able to concentrate its vast image processing capability and filter out the noise and clutter in the data stream from your eyes. I firmly believe that you need to practice target acquisition and recognition just as all other aspects of the shooting sequence. Those that do will always be able to demonstrate far better working resolution/acuity on familiar targets than those that don't practice.

You will have much less trouble if you practice using the same optics and targets as you will shoot in matches. It also helps to practice target acquisition and recognition under a wide variety of atmospheric and illumination conditions. These stored images ease the burden on the brain's image analysis system to find your desired POA among the noise and clutter providing for an enhanced "effective resolution ".