Telescope Terminology

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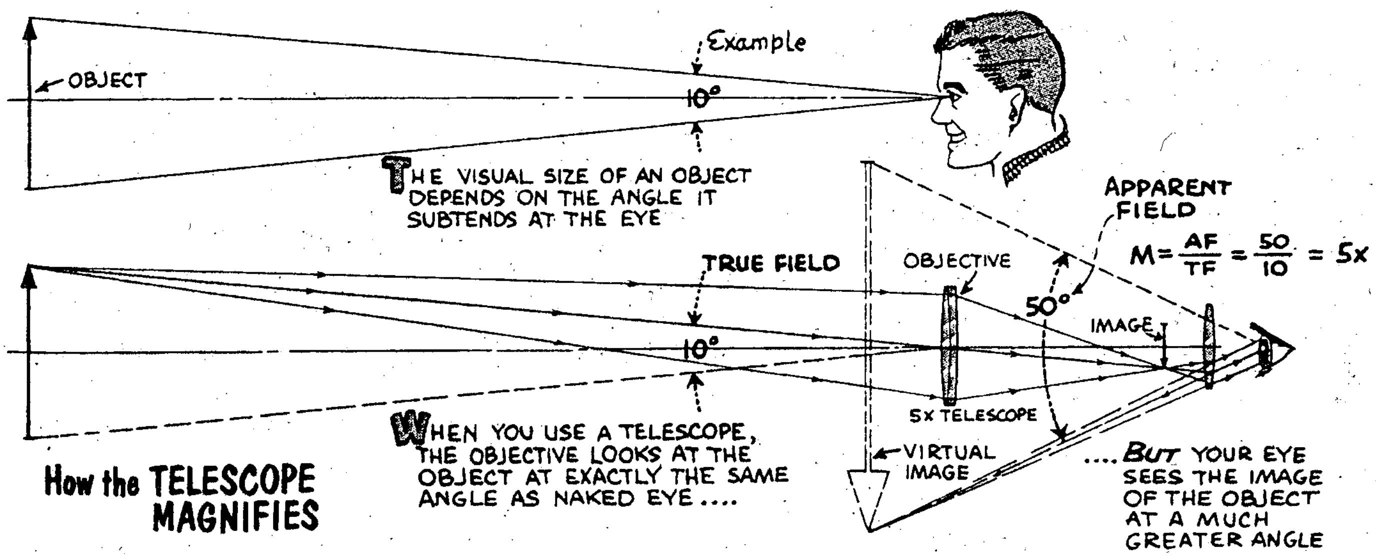
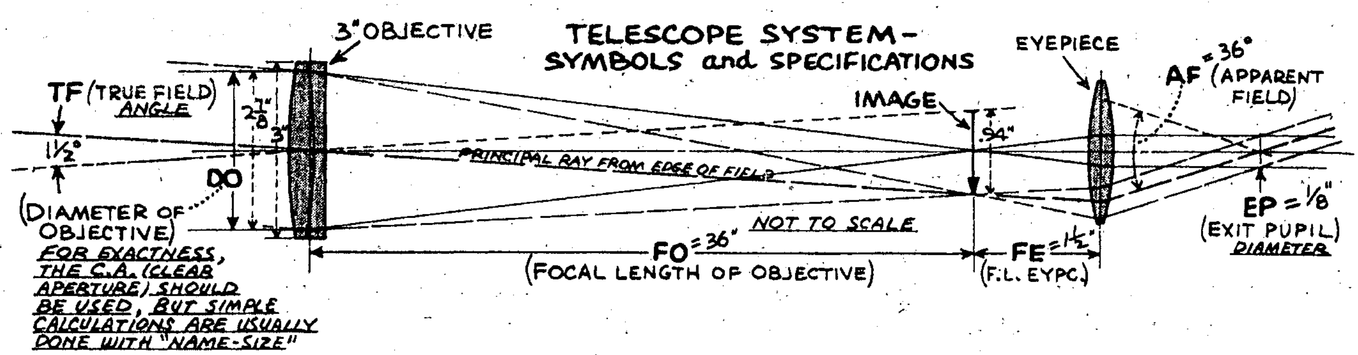




Magnification

Magnification=Focal length of the Telescope Objective/Focal length of the Eyepiece
OR
M = Objective f.l./Eyepiece f.l.
Example: using a 14mm eyepiece in a telescope with a focal length of 812mm results in a magnification of 58x (812 / 14 = 58).

To calculate the magnifying power of any telescope you simply divide the focal length of the objective lens or mirror by the focal length of the eyepiece. Remember to use the same measuring units, eyepieces are generally sold by their focal length in millimeters, telescopes are often sold by their focal lengths in centimeters or inches. Don't forget to convert first! For example, if a telescope's focal length is 50" and the focal length of the eyepiece is ½", then the final magnification will be 100X. Since eyepieces are interchangeable, a telescope can be used at a variety of powers for different applications. The size of an image produced by a telescope is determined by the telescope's focal length and that of the eyepiece used. So an eyepiece that provides a 16X magnifying power on one telescope, may provide a 50X magnifying power on a different telescope; it's all dependent upon the focal length of the given telescope's objective lens or mirror.

Since we can simply use different eyepieces to reach different magnification, the temptation is to "pump-up" the power as high as possible. Telescopes have upper and lower limits of useful magnification. These are determined by the laws of optics and the nature of the human eye. As a rule of thumb, the maximum useful magnification is 60 times the aperture of the telescope in inches, or about 2 times the aperture measured in millimeters. Magnifications higher than this usually result in an image that is too faint. Thus, the maximum useful magnification of a 6" telescope is 360X. Another example: an 80mm refractor is limited to a maximum magnification of about 160x (80 x 2 = 160). Multiply inches by 25.4 to convert to millimeters. Do not believe manufacturers who advertise a 600X power telescope when its aperture is only 60mm. Such advertising is misleading.

Most of your observing will be done at magnifications of 100X and less. This is because there is a lot to see conveniently at these magnifications, and because the Earth's atmosphere often sets an upper limit to the amount of magnification that you can use.

Lowest useful magnification is about 3½ X per inch of telescope aperture. At this limit, the diameter of the telescope's exit pupil has become as large as that of the human pupil. Lower magnifications would not be useful visually and might actually cause a dark spot to appear at the center of the field in Catadioptric or Newtonian telescopes due to the obstruction of the secondary mirror.

Maximum Magnification of a Telescope

f/Ratio

f/ratio = focal length / aperture
Example: an 203mm telescope with an 812mm focal length has a focal ratio of f/4 (812 / 203 = 4 - note that both measurements must use the same unit, in this case mm). ??

The f/ratio of a telescope is determined by dividing the focal length of the primary lens or mirror by the aperture (the diameter of that same lens or mirror). For example, a 6" telescope with a 48" focal length has a focal ratio of 8. This is normally expressed as f/8. This number tells us several important things about a telescope. For example, the lower the f/ratio the faster the telescope is said to be; that basically means that it provides a brighter image than a similar sized telescope with a higher f/ratio. Yet, remember that there is always a tradeoff; by getting brighter images you loose some magnifying power. Telescopes with low f/ratios give wide-field images with bright star fields; they are good for viewing star clusters and faint nebulae. Telescopes with high f/ratios aren't quite as bright, but yield higher magnifications with narrower fields of view. They are ideal for planet viewing and splitting binary stars.

f/6 and lower would be considered fast, ideal for viewing faint nebulosity and wide field objects.

f7 to f/10 would be midrange. The compromise range, telescopes with f/ratios in this range do fairly good at both ends.
f/11 and up would be considered slow, but ideal for planetary work or studying binaries.
When calculating f/ratios you should always remember to use the same units of measure. Don't divide centimeters by inches!
AN IMPORTANT POINT Remember that using f/ratios to compare two telescopes works best when things are equal otherwise. A 10 inch f/11 may very well give you much brighter images than a 4 inch f/6 because it has more light gathering abilities with it's greater aperture. A safer comparison would be comparing two telescopes of the same aperture, but with different f/ratios.
Beginners are often under the false impression that the surface brightness of an extended object image is determined by a telescope's focal ratio. In reality, surface brightness is determined by the telescope's total light grasp and the magnification. Stars differ from extended objects in this respect by actually becoming easier to see at higher magnifications, again, completely regardless of focal ratio.

Field of View

Field of view is the angle of the cone of light that is being seen by the optics. Field of view comes in two varieties: Apparent Field and True Field.

Apparent Field of View

Apparent Field is the field of an eyepiece and is usually 30 to 50 degrees wide. This is a statistic available from the eyepiece manufacturer, but it is useful to note that most Plossls have an AFOV of about 50 degrees.

True Field of View

TFOV = AFOV of eyepiece / magnification given by eyepiece
Example: a 14mm Televue Radian with an AFOV of 60 degrees is used in a telescope of 812mm focal length. The magnification given by this eyepiece is 58x (812 / 14) so the TFOV is about 1 degree (60 / 58 = 1.03).
True Field is a measurement of the actual amount of sky that you see through a telescope using the same eyepiece. It is quite small and may sometimes be only a fraction of a degree wide. A wider true field of view is desirable for extended objects such as large nebula and open clusters.

Exit Pupil

exit pupil = focal length of eyepiece / focal ratio of telescope
Example: using a 14mm eyepiece in a telescope with a focal ratio of f/4 results in an exit pupil of 3.5mm (14 / 4 = 3.5).
The exit pupil of a telescope is the circular beam of light that leaves the eyepiece. Its diameter is a function of telescope aperture and magnification. To determine exit pupil diameter, divide the aperture of the telescope by the magnification of the eyepiece in use. For example, an 8" aperture telescope at 100X will produce an exit pupil 0.080" in diameter. Various focal lengths and magnifications result in differing exit pupils. If the exit pupil is larger than the diameter of the fully opened (dark-adapted) pupil of your eye, some of the light will be wasted. Younger eyes typically have a maximum pupil of about 7mm; older eyes may be limited to 5 or 6mm. In the above example if we substitute a 32mm eyepiece we will end up with an exit pupil of 8.0mm. If this is compared with the maximum of 7mm, this results in a 25% waste of light that is not entering the eye! When exit pupils are small, observers who have astigmatism in their eyes can remove their glasses, since small exit pupils effectively stop down the human pupil, eliminating astigmatism.

Eye Relief

Eye relief is the distance from the final lens surface of an eyepiece to the pupil of the eye that allows access to the optimal field-of-view. Some eyepieces have eye relief so short that your eyelashes will actually brush against the lens. With these eyepieces, eyeglass wearers will see only a small portion of the field. If you are an eyeglass wearer, then you will need to use eyepieces that feature long eye relief.

Airy Disk or Diffraction Disc

The Airy Disc is the result of the diffraction of light, which causes stellar images to appear as diffraction patterns under high magnification. It is the part of a stellar image that is seen and appreciated by the human eye. You will be able to detect the diffraction pattern when you focus on a bright star at a magnification of 30X per inch of telescope aperture. The bright dot at the center of the pattern is the Airy disk. Look closely and you will see the first bright interference ring surrounding it. Since images formed by telescopes are made of diffraction patterns, a telescope's angular resolution will be determined by the angular size of the Airy disk. And since increasing telescope aperture results in less diffraction, large telescopes produce small diffraction patterns. The result is high angular resolution.

Angular Resolution or Resolving Limit

The angular resolution or resolving limit of an instrument is an expression of the smallest detail that can be detected by the instrument. The unit of measure is arcseconds (1/3600th of a degree) and a common test is detecting separation in the components in a very close double star. The greater the aperture of a telescope, the more detail it will reveal. The theoretical angular resolution of a telescope is equal to 4.56 divided by the telescope aperture in inches. Part of the challenge of high-magnification viewing is waiting for wave fronts of high enough quality to arrive at the telescope after passing through the Earth's atmosphere.
There are two commonly used calculations:

Rayleigh Limit = 5.5 / aperture of telescope in inches

Example: the Rayleigh Limit for a telescope with a 8 inch aperture is approximately 0.7 arcseconds (5.5 / 8 = 0.68).

Rayleigh resolution limit of a telescope is reached when the center of one Airy Disk is just one radius away of the other one. Good telescope optics are characterized by converging wave-front path differences that are smooth and do not exceed the Rayleigh Limit. Wave-Front Accuracy (Rayleigh Limit) is ¼ wavelength of light. As wave-front quality approaches 1/10th wavelength, definition becomes essentially perfect.

Dawes Limit = 4.56 / aperture of telescope in inches

Example: the Dawes Limit for a telescope with a 8 inch aperture is approximately 0.57 arcseconds (4.56 / 8 = 0.57).

The Dawes Limit is one-half the angular diameter of the Airy (diffraction) disc, so that the edge of one disc does not extend beyond the center of the other). The working value is two times the Dawes Limit (diameter of the Airy disc), so that the edges of the two stars are just touching. 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 Dawe's limit is hence an empirical one.

Collimation

Collimation is the proper alignment of the optical elements in a telescope. Not only is the alignment of the optical elements important but even more important is the alignment of the optics with the mechanical tube- this is called opto/mechanical alignment. Collimation is critical for achieving optimum results. Poor collimation will result in optical aberrations and distorted images.

Aperture and Performance

The aperture of a telescope objective determines its light grasp and ability to show fine detail. To get much of a start in astronomy, 3" is the minimum acceptable aperture for refracting telescopes, while a slightly larger aperture is required for reflectors and Catadioptrics. When acquiring a telescope, always try to obtain as much aperture as you can, consistent with your budget and portability requirements.

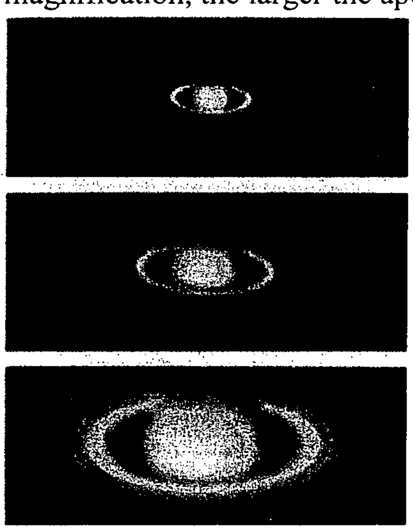
Limiting Visual Magnitude

limiting magnitude = 5 x LOG10(aperture of scope in inches) + 8.8 (at 3.5X per inch of aperture)
limiting magnitude = 5 x LOG10(aperture of scope in inches) + 11.6 (at 40X per inch of aperture)

Field tests have shown that a telescope's limiting visual magnitude for stars depends strongly on both aperture and magnification. The basic limiting magnitude formula is 8.8 + 5LOG D where the constant 8.8 is for telescopes operating at a magnification of 3.5X per inch of aperture. D is expressed in inches. As magnification increases, the constant, known of as Equivalent Magnitude, increases for stars, finally leveling off at 11.6 for telescopes operating at a magnification of 40X per inch of aperture. Thus, the stellar limiting visual magnitude of an 8" telescope is 13.3 at 28X. But at 320X the limiting magnitude is 14.2. To realize your telescope's limit, its optics must be of high quality, the star must be located at the zenith and the air must be transparent and free of light pollution.
Astronomers use a magnitude scale to indicate the brightness of celestial objects. On this scale, which is based on the fifth root of 100, each successive magnitude is 2.512 times fainter than the one below it. For example, a third magnitude star is 2.512 times fainter than a second magnitude star, and 6.310 times fainter than a first magnitude star. The sun, which has a magnitude of -27, is a million times brighter than the full moon, which is of magnitude -12. The faintest star that you can see with your unaided eye is about magnitude 6.

Light gathering power

ratio of light gathering power = square of aperture of larger instrument / square of aperture of smaller instrument
Example: an 8 inch telescope gathers 4 times more light than a 4 inch telescope (64 / 16 = 4 - note that both measurements must use the same unit, in this case inches). Another example: an 80mm scope gathers about 130 times more light than the naked eye (the maximum aperture of the naked eye is about 7mm so 6400 / 49 = 130.6).
This is not really an absolute measurement but rather just a method of comparing two optical instruments. This is the single most important factor in choosing a telescope. The prime function of all telescopes is to collect light, the larger the light gathering power, the fainter the objects that can be detected. At any given magnification, the larger the aperture, the better the image will be. The clear aperture of a telescope is the diameter of the objective lens or primary mirror specified in either inches or millimeters (mm). The larger the aperture, the more light it collects and the brighter (and better) the image will be. Greater detail and image clarity will be apparent as aperture increases. For example, a globular star cluster such as M13 is nearly unresolved through a 4" aperture telescope at 150 power but with an 8" aperture telescope at the same power, the star cluster is 16 times more brilliant, stars are separated into distinct points and the cluster itself is resolved to the core.



The photos to the right demonstrate what increasing aperture will give you -- higher contrast, better resolution and a brighter image. Top to bottom with Celestron telescopes -- C5 (5" aperture), C8 (8" aperture), C14 (14" aperture). All were taken using eyepiece projection photography at a focal ratio of f/90 for comparison. The effects are even more pronounced during visual observation.

The following table shows common scope apertures listed, both in inches and millimeters, with the associated Light Grasp, Magnification limits and Limiting Visual Star Magnitudes.

Aperture in Inches	Aperture in Millimeters	Light Grasp	Lowest Magnification	Highest Magnification	Limiting Visual Magnitude assuming transparent dark skies
0.98	25	13	4	40	9.7
1.26	32	21	5	51	10.2
1.57	40	33	7	63	10.7
1.65	42	36	7	66	10.8
1.97	50	51	8	79	11.2
2.36	60	73	10	95	11.6
2.76	70	100	12	111	11.9
2.99	76	118	13	120	12.1
3.15	80	130	13	126	12.2
3.35	85	147	14	134	12.3
3.5	88.9	161	15	140	12.4
3.54	90	165	15	142	12.5
3.94	100	204	17	158	12.7
3.98	101	208	17	160	12.7
4	101.6	210	17	161	12.7
4.02	102	212	17	161	12.7
4.13	105	225	18	166	12.8
4.33	110	247	18	174	12.9
4.49	114	265	19	180	13.0
4.5	114.3	266	19	181	13.0
4.72	120	294	20	190	13.1
4.92	125	319	21	198	13.2
5	127	329	21	201	13.2
5.12	130	345	22	205	13.3
5.91	150	459	25	237	13.6
6	152.4	474	25	241	13.6
7	177.8	645	30	281	13.9
7.87	200	816	33	316	14.2
8	203.2	842	34	321	14.2
9.25	234.95	1126	39	371	14.6
10	254	1315	42	401	14.7
11	279.4	1592	47	441	14.9
12	304.8	1894	51	482	15.1
12.5	317.5	2055	53	502	15.2
14	355.6	2578	59	562	15.5
16	406.4	3368	68	642	15.7
20	508	5262	85	803	16.2

Eyepiece Magnification And Field Calculation Workbook

Telescope Specifications

Owner:	Scott Kindt
Make and Model:	Meade 8" Schmidt Newtonian
Focal Length (mm):	812
Objective Diameter (mm):	203
Barlow Magnification:	2
Focal Reducer Magnification:	0.5
Limiting Visual Magnitude:	14.2
Min. Resovable Angle ("):	0.59
Lowest Recommend Power:	41
Highest Recommend Power:	406

Eyepiece Specfications			Prime Focus f/ 4			With Barlow f/ 8			With Focal Reducer f/ 2		
Eyepiece Type	Focal Length (mm)	App. Field (deg)	Power	True Field (arc min)	Exit Pupil (mm)	Power	True Field (arc min)	Exit Pupil (mm)	Power	True Field (arc min)	Exit Pupil (mm)
Meade S3000 Plossl 40 mm	40	44	20	130	10.0	41	65	5.0	10	260	20
Meade S3000 Plossl	32	50	25	118	8.0	51	59	4.0	13	236	16
Meade S3000 Plossl	26	50	31	96	6.5	62	48	3.3	16	192	13
Meade S3000 Plossl	20	50	41	74	5.0	81	37	2.5	20	148	10
Meade S3000 Plossl	15	50	54	55	3.8	108	28	1.9	27	111	8
Meade S3000 Plossl	12	50	68	44	3.0	135	22	1.5	34	89	6
Meade S3000 Plossl	9	50	90	33	2.3	180	17	1.1	45	67	5
Meade S3000 Plossl	6	50	135	22	1.5	271	11	0.8	68	44	3
Orion Lanthanum	12	65	68	58	3.0	135	29	1.5	34	115	6
Tele Vue Radian	14	60	58	62	3.5	116	31	1.8	29	124	7

Telescope Formulas

Field of View:

True field of View: angular diameter of view through eyepiece in a telescope

Apparent field of View: Angular diameter of view through ep w/o telescope

Calculated approximate True Field of View in degrees of an ep with a specific telescope

True field of View (TFOV) = Apparent Field of View (AFOV)/Magnification

OR

TFOV = (Field Stop of ep /Focal Length of Telescope) x 57.3, where field stop is usually the smallest diameter circle light passes through between lens and bottom of ep.

Calculated Apparent Field of View

AFOV = Measured TFOV x Magnification

Measuring TFOV:

Center Star in Field of view—move to just outside edge and time its drift through field-note easier with equatorial mount than alt-az

Formula for Converting drift time to field of view:

TFOV = 15.04 x drift time x Cos Dec for star

(if star within 3 degrees Celestial equator (dec = 0) you can omit cosine factor)
(if time measured in minutes, result will be in minutes of arc)
(if time measured in seconds, result will be in seconds of arc)

Alternative method: determine angular separation from chart or planetarium software of particular stars and then compare your actual field of view and estimate

Exit Pupil (Size in mm of image formed by eyepiece in telescope)

Exit Pupil = Focal length of ep / Focal Ratio of Telescope used

OR

Exit Pupil = Diameter of scope in mm / magnification

NOTE: If Exit pupil of ep, is larger than diameter of your own dark adapted pupil, some light will be lost because not seen. This means some of the light is being lost, or that the sky background will be brighter, or, if the exit pupil is a lot larger than your dark adapted pupil, that you might start seeing the shadow of any central obstruction for reflectors, Scts or Mcts. Opinions differ as to whether this is a real problem, so YMMV.

Eye Relief: Distance from lens to plane where image forms, measured in mm-20mm is generous, 6mm or less very awkward, greater than 20 creates blackout problems.