Rowan Introduction to Astronomy

Lab 5 / Properties of Telescopes: Light-Gathering Power, Magnification, Resolution

Name: ____ **Score:** ______________________

Summary: The student will learn about the relationship between objective size, resolution, focal length, and magnification..

Light-Gathering Power [33 pts]

Light-gathering power of a telescope is directly proportional to the area of its primary lens or mirror. All lenses and mirrors have a circular circumference. The area of a circle is given by the formula: $A = \pi r^2$. Because π is a constant, the radius, *r*, of the mirror or lens is the most important factor in determining the light-gathering power of a telescope. Note that area of a circle varies by the square of the radius. Thus, a lens or mirror that is twice the radius (or diameter) of another telescope objective has 2^2 or 4 times the light-gathering power.

1. A typical pair of binoculars has an objective lens of 50-mm diameter. A typical amateur telescope is an 8-inch reflector that has a mirror diameter of 203 mm. (Give answers in *a* and *b* as a number; that is, when multiplying, use π as 3.14159.)

(a) What is the light-collecting area of the 50-mm objective? _________________________ mm^2 [Round to **1** decimal place]

(b) What is the light-collecting area of the 203-mm objective? _________________________ mm^2 [Round to **1** decimal place]

(c) The 203-mm objective collects _______________ times the light of a 50-mm objective. [Round to **nearest** whole number]

(d) The brightness of celestial objects usually is expressed in terms of magnitude. A 1st magnitude star is defined as being 100 times brighter than a 6th magnitude star (5 magnitude steps). A single magnitude jump equals a brightness change of about 2.512 (given that $2.512^5 = 100$). Using the factor of 2.512 for a single magnitude jump, about how many magnitudes fainter can the 203-mm objective "see" than the smaller 50-mm objective? **[Round to nearest whole number]**

__________ magnitudes [Hint: $2.512^1 = 2.512$; $2.512^2 = ?$; $2.512^3 = ?$; $2.512^4 = ?$; $2.512^5 = 100$]

2. Compare an amateur telescope of 100 mm (a typical "4-inch" telescope, usually a refractor) with that of the Keck telescope, which is 10 meters across. [Hint: Work in powers of ten; "2 decimals" means after the decimal point in powers of ten notation.]

(a) Area of 100-mm objective in mm^2: _______________ mm^2 [Write in scientific notation and round to **2** decimals; same for part *b*]

(b) Area of 100-mm objective in m^2: _______________ m^2 (Careful! Note the conversion from millimeters^2 to meters^2. Working with powers of ten can make this step easier. Hint: How many mm in 1 meter? How many mm^2 in 1 m^2?) [Round to **2** decimals]

(c) Area of 10-m Keck objective: ____________________ m^2 [Write answer in scientific notation and round to **2** decimals]

(d) 10-m objective collects _______________ times the light of a 100-mm objective [Round to **nearest** whole number]

(e) The answer to (d) represents how many magnitudes? _______________
(**Hint**: Look for the x^y function on a scientific calculator. If $(2.512)^5 = 100$ and represents 5 magnitude steps, then how many steps does the answer to *d* represent? If $100 = 10 \times 10$ or 10^2, then how many powers of ten is the answer to *d*?)

3. A quicker way to calculate light-gathering power is to use the formula:

$$\frac{LGP_A}{LGP_B} = \left(\frac{D_A}{D_B}\right)^2$$

[Hint: Don't forget that on the right side the values are squared after being divided.]

where LGP_A and LGP_B are the light-gathering powers of A and B, respectively, and D_A and D_B are the diameters of objectives A and B, respectively. If the human eye has a diameter of 8 mm (actually the pupil of the eye), and we have both a 50-mm telescope and a 203-mm telescope, how much more light will the telescopes gather than our eye? [Round answers to **nearest** whole number]

(a) LGP_{50mm}/LGP_{eye} = _______________ times more light

(b) LGP_{203mm}/LGP_{eye} = _______________ times more light

◢Magnification [37 pts: 36 pts + 1 "free" pt]

Magnification is the ability of an optical instrument such as a telescope to enlarge an image. Though usually the most well-known, magnifying power is the least important function of a telescope because it enlarges any distortions due to the telescope and particularly the atmosphere. Magnification does not work on stars because they are points of light. (The disk of a star image under magnification is just the light from the star smeared out.). However, extended objects such as planets or clusters can benefit from some magnification under good seeing conditions. Because they are relatively close to Earth, the planets in our solar system show as a disk rather than as a point of light. We can magnify that disk to see more detail.

Under the best sky conditions possible, the top useful power is about 60X per inch of objective aperture. Thus, a 4-inch (102-mm) telescope can handle at best 240X. An 8-inch (254-mm) can handle 480X. Thus, the claim that a cheap 60-mm (2.4-inch) refractor can provide "600X" is false. At best, a 60-mm objective can handle 144X. For practical usage under typical skies, most telescopes work best at magnifications in the range of 10X –30X per inch of aperture.

The magnification a telescope can provide is dependent on two factors: the focal length of the telescope—the objective lens or mirror— and the focal length of the eyepiece used to complete the telescope optical system. The formula for calculating magnification is given below:

$$\text{magnification} = f_{obj}/f_{eye}$$

where f_{obj} is the focal length of the objective and f_{eye} is the focal length of the eyepiece. (Eyepiece focal lengths always appear on the barrel of the eyepiece.)

The "speed" (or "f" number) of a telescope is determined by dividing the focal length of the objective by the diameter of the objective (usually in millimeters). For example, a refractor with a 150-mm (6-inch) diameter objective and a 1200-mm focal length has a speed of f/8. A reflector with a 256-mm (10-inch) diameter and a 1200-mm focal length has a speed of f/4.7. The reflector is said to be "faster" than the refractor. Fast focal length telescopes are good for observing galaxies and other faint deep space objects. Telescopes with slower focal lengths are good for observing planets. [Round focal lengths below to **nearest** whole number.]

$$f/obj = f_{obj}/d_{obj}$$

Telescope 1: William Optics 105-mm (4.1-inch) f/7 refractor. The focal length of this telescope is: _______________ mm

Telescope 2: Orion Telescopes 203-mm (8-inch) f/5.91 reflector. The focal length of this telescope is: _______________ mm

Telescope 3: Celestron 279-mm (11-inch) f/10 Schmidt-Cassegrain. The focal length of this telescope is: _______________ mm

[Caution: Round focal length answers to **nearest** whole number.] **[Each answer above is worth 2 pts for a total of 6 pts.]**

Given the eyepiece in column 1, fill in the magnification for each telescope with that eyepiece. [**Round to nearest whole number.**]
[Each correctly filled-in blank in the table is worth 0.75 pt for a total of 21 pts.]

Eyepiece *f.l.*	Telescope 1	Telescope 2	Telescope 3
3 mm			
4 mm			
6 mm			
9 mm	82		
12 mm			
15 mm			
18 mm			
20 mm			
25 mm			
32 mm			87

Magnification is usually denoted as "power," which is symbolized with an "X," as in 30X or 30 power. Using the rule of **60X per inch** (or 25.4 mm) of aperture yields the maximum useful magnification for that lens or mirror, calculate the maximum magnification for each telescope described on page 2 and listed below. **[Each answer is worth 3 pts for a total of 9 pts.]**

MAXIMUM MAGNIFICATION EYEPIECES THAT SHOULD NOT BE USED

Telescope 1: _______________X Can all the eyepieces be used with Scope 1? ❒ Yes ❒ No ____________________________

Telescope 2: _______________X Can all the eyepieces be used with Scope 2? ❒ Yes ❒ No ____________________________

Telescope 3: _______________X Can all the eyepieces be used with Scope 3? ❒ Yes ❒ No ____________________________

◢Resolving Power [30 pts]

Resolving power is the ability to see small details and sharp images. It is also the ability to separate or "split" two objects—such as stars—that are close together. (Catalogs of double stars always list the angular separation between such stars.) The resolving power or resolution of a telescope is the absolute smallest angle that can be detected. This angle is expressed in arcseconds, and the resolution of a telescope is denoted by a particular number of arcseconds for a particular diameter of the objective. Technically, the wavelength of the electromagnetic radiation (light) that is either reflected or refracted by the mirror or lens is also a factor. For visible light, which is what most optical telescopes will "see," we can assume that the wavelength of light is about 500 nm. Also, note that resolving power is a theoretical limit for most telescopes because the instability of our atmosphere blurs visible-light images of distant objects.

1. For optical telescopes, a simple formula describes the resolving power of that telescope. This formula is known as **Dawes' limit**.

$$\theta = \frac{11.58}{D}$$

where θ is the resolution in arcseconds and D is the diameter of the objective in centimeters (cm). The practical limit for resolution on Earth is approximately 0.5 arcseconds.

Below is a table that gives the resolution of popular amateur telescopes. Using the Dawes' limit formula, calculate the resolution of the telescope objectives. [**Note**: Express each answer to **3** decimal places.] **[Each answer in the table is worth 3 pts.]**

Telescope Objective	Published Resolution	Calculated Resolution
102 mm	1.14″	
127 mm	0.91″	
150 mm	0.77″	
203 mm	0.57″	
254 mm	0.46″	

2. A telescope with a 115.8-cm (45.6-inch) objective will have a theoretical resolution of 0.1 arcsecond. We calculate resolution using a formula that takes into account the wavelength of light (or electromagnetic radiation) being imaged.

$$\theta = 252{,}000 \times \frac{(\text{observation wavelength})}{(\text{objective diameter})}$$

For the 102-mm objective, we have θ = 252,000 × (500 nm)/(102 mm) = 252,000 × (5×10^{-7} m)/(1.02×10^{-1} m) = ?

Using this equation, calculate the resolution for the 5 telescopes. [**Note**: Express each answer to **3** decimal places.]

[Each answer in the table is worth 3 pts.]

Telescope Objective	Published Resolution	Calculated Resolution
102 mm	1.14″	
127 mm	0.91″	
150 mm	0.77″	
203 mm	0.57″	
254 mm	0.46″	