Astronomy
NaSc 109 Summer 2019
Exam 3

Name ______________________________

Don't Panic! Take a big deep breath... hold it... holllld it… now let it out. Use your available time on this exam very efficiently; if you don't know an answer right away, move on and go back to the question later (but don't forget to go back). **You may not share calculators.** You have 56 minutes to complete the exam. If you finish early, feel free to turn it in after checking your answers and quietly leave but please come back at 3:40 pm. **Any illegible work will be ignored during grading.**

1. (3 pts.) Upon reflection from a flat mirror,

   ■ the angle of reflection is equal to the angle of incidence.
   ☐ the angle of reflection is equal to two times the angle of incidence.
   ☐ the angle of reflection is one-half the angle of incidence.

2. (3 pts.) Which of the following wavelength ranges of electromagnetic radiation spectrum are not regularly used in astronomy and astrophysics?

   ☐ gamma ray
   ☐ x-ray
   ☐ UV
   ☐ visible light
   ☐ infrared
   ☐ microwave
   ☐ radiowave
   ☐ none of these are used in astronomy
   ■ all of these are used in astronomy

3. (3 pts.) The *energy* of a photon is determined by or describes its (check all that apply)

   ■ color
   ■ frequency
   ■ wavelength
   ☐ speed
   ☐ temperature
   ☐ wave height

4. (3 pts.) We <u>quantitatively</u> determine the temperature of a star by

   ☐ examining its absorption line spectrum.
   ☐ examining its emission line spectrum.
   ■ examining the wavelength at which it emits with the highest intensity; that is, λ_{max}.
   ☐ examining its color.
   ☐ feeling its forehead.

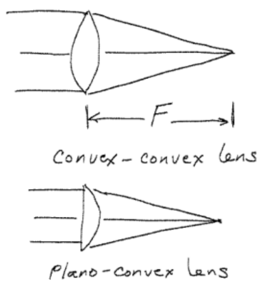
5. (6 pts.) Calculate the frequency (in Hz) and energy (in J) of the 633 nm photon produced by the laser in a grocery store bar code scanner. What color is a beam of 633 nm photons?

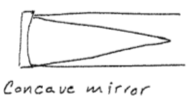
$$\lambda = 633\text{ nm} \times \frac{1\text{m}}{10^9\text{m}} = 6.33\times10^{-7}\text{ m}$$

$$c = \lambda\nu \text{ so } \nu = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{6.33\times10^{-7}\text{ m}} = \boxed{4.74\times10^{14}\text{Hz}}$$

$$E = h\nu = 6.63\times10^{-34}\text{ J}\cdot\text{s}\times4.74\times10^{14}\text{ Hz} = \boxed{3.14\times10^{-19}\text{ J}}$$

6. (3 pts.) Let's try again. Draw 2 optical elements that will bring collimated light to a focus (for example, components of a telescope but not the telescope itself). On one drawing, show what *focal length* is.





7. (3 pts.) What would you suggest to an astronomer, who wants to observe in the infrared region of the electromagnetic radiation spectrum, concerning the best location of their telescope? Why? (Use no more than the space provided.)

Put the observatory high on a mountain or, even better, in space.

8. (5 pts.) List in order the entire electromagnetic radiation spectrum from lowest energy on the left to highest energy on the right. For full credit, include the wavelength range of each region.

γ-ray	x-ray	UV	visible	IR	microwave	radiowave

0.001 nm 0.1 nm 10 nm 400 nm 700 nm 50 μm 10 cm 100 m

HIGH ENERGY **LOW ENERGY**

NOTE: The order is written in reverse of what the question requires

9. (3 pts.) Consider the star giant star Antares (α-Sco in Scorpius) with a surface temperature of 3500 K and Capella (α-Aur in Auriga) with a surface temperature of 5700 K. Which star will appear more red to an observer?

Antares

10. (4 pts.) What characteristic of a star is used to identify the component gases in the star?

Absorption or emission line spectrum

Put your

11. (3 pts.) Given that sound waves cannot travel through a vacuum yet light waves do how, then, do light waves travel through interstellar and intergalactic space?

- ☐ Light waves are very high energy sound waves.
- ☐ Light waves are extra-powerful sound waves.
- ■ Light waves are not sound waves at all so they propagate through space differently than sound.
- ☐ Interstellar space is not a vacuum.

12. (3 pts.) Polaris is almost exactly the same temperature as the Sun but is 94 times bigger. If both were viewed at a distance of, say, 10 pc (32.6 ly), which star would appear to be brighter?

- ☐ Sun
- ■ Polaris
- ☐ Both would appear equally bright at the same distance since they are the same temperature.
- ☐ Can not predict which would appear brighter without additional information.

13. (3 pts.) Studying *globular clusters* is important for understanding or determining

- ☐ stellar mass.
- ☐ stellar temperature.
- ☐ stellar color.
- ■ stellar evolution and age of the universe.
- ☐ Cepheid and RR Lyrae variables.
- ☐ a sugar-coated breakfast cereal.

14. (3 pts.) A larger aperture telescope allows you to… (check all that apply)

- ■ see dimmer stars through the eyepiece.
- ☐ directly observe the red-shift of stars and galaxies.
- ■ observe the separation of close stars better.
- ☐ None of these. The larger telescope only showed that your professor can spend lots of money.

15. (3 pts.) As the chief-financial-officer of an observatory design team, you have been given the job to decide what the single most important feature of the new telescope your team is designing should be. You report back to the design team manager that ________________ is most important and that's where the money should be spent.

- ☐ the number of different eyepieces available
- ☐ open-tube design to permit rapid cooling of all optical systems when the dome is opened
- ☐ locally dark skies
- ☐ focal length
- ■ aperture
- ☐ *f*-ratio
- ☐ adaptive optics
- ☐ the finest CCD camera available to image faint objects
- ☐ brand name manufacturer
- ☐ quality of the glass used in the primary mirror
- ☐ warranty on the main mirror against design defects

initials

16. (3 pts.) Alcor (in Ursa Major) is a binary star system in which the stars are separated by 14" of arc when viewed at 250× with a 12-inch telescope. What is the apparent separation in a 6-inch telescope when viewed at 125×?

☐ 3.74" ☐ 7" ■ 14" ☐ 28" ☐ must be measured

17. (3 pts.) What are the two most abundant elements in the sun? ____**H**____ ____**He**_____

18. (3 pts.) The Doppler Effect causes light from a source moving away from the Earth to be

☐ changed in velocity.
☐ shifted to shorter wavelengths.
■ shifted to longer wavelengths.
☐ All three answers are correct.
☐ None of these are correct. The Doppler Effect only deals with sound waves.

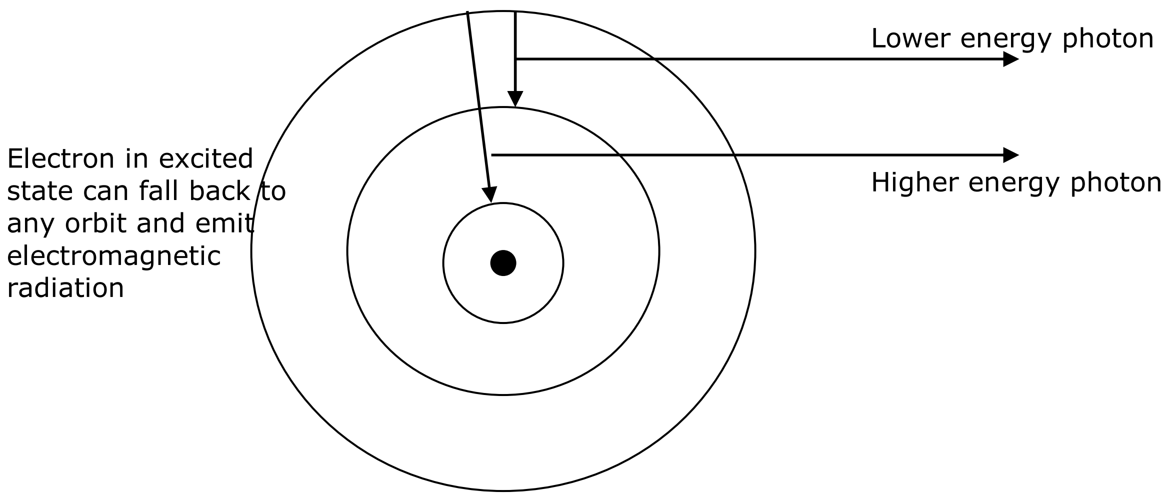
19. (3 pts.) The core stars of spiral galaxy NGC 4321 (M100, in Virgo) have an H_β absorption wavelength of 488.679 nm. Careful measurement of the H_β emission from a gas discharge tube (identical to the one used in class) shows that the wavelength of the emission line is 486.133 nm. What is the velocity of the galaxy relative to the Earth? Is the galaxy approaching or receding away from us?

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c} \quad \text{so....} \quad v = c\frac{\lambda - \lambda_0}{\lambda_0}$$

$$v = 3.00\times10^8 \ \text{m/s} \ \frac{488.679 \text{ nm} - 486.133 \text{ nm}}{486.133 \text{ nm}} = \boxed{1.57\times10^6 \ \text{m/s} = 1570 \ \text{km/s}}$$

in lower right

20. (3 pts.) Show, with a simple diagram of an atom, how specific energies of light are produced when hydrogen gas (1 proton, 1 electron) is electrically excited to glow. Why do excited gases not produce a continuous spectrum (rainbow)?



21. (7 pts.) Match the historical characters to their "claims-to-fame."

__l_ Made the first accurate measurements of the speed of light by observing the time-delay of light as it reflects off of a rotating mirror to a stationary mirror and back to the rotating mirror

__k_ First to characterize light as a wave.

__j_ Observing that Io, a moon of Jupiter, was eclipsed by its host planet later than expected when Jupiter was farthest away from the Earth, deduced that the speed of light was about 125,000 miles per second

__n_ Characterized light as two superimposed waves: an electric wave and a magnetic wave.

____ No, honest, he's just really a nice guy, afterall.

__m_ Using sound, developed a model which allows for the indirect measurement of the velocity of a light source based upon its spectral red- or blueshift.

__o_ Proposed the experimentally-verified particle nature of light.

a. Arisotle
d. William of Occam
g. Johannes Kepler
j. Ole Römer
m. Christian Doppler
p. Niels Bohr
b. Claudius Ptolemy
e. Nicolaus Copernicus
h. Galileo Galilei
k. Christiaan Huygens
n. James Maxwell
q. Albert Einstein
s. None of these
c. Hipparchus
f. Tycho Brahe
i. Isaac Newton
l. Léon Foucault
o. Max Planck
r. Dr. Green

22. (4 pts.) Capella (α-Aurigae) is 3.99 x 10^{17} m (42.2 ly) away from Earth and has a nearly identical surface temperature as the Sun. The photometric brightness of Capella is 2.57 x 10^{-9} W/m^2 (measured electronically).

What is the luminosity (in W) of Capella?

$$L_* = F_* \cdot 4\pi d_*^2$$
$$d_* = 3.993\times10^{17}\,\text{m}$$
$$F_* = 2.57\times10^{-9}\ {}^{\text{W}}\!/\!{}_{\text{m}^2}$$
$$L_* = 4\pi\left(2.57\times10^{-9}\ {}^{\text{W}}\!/\!{}_{\text{m}^2}\right)\left(3.993\times10^{17}\,\text{m}\right)^2$$
$$\boxed{L_* = 5.15\times10^{27}\,\text{W}}$$

23. (3 pts.) Two stars, A and B, appear equally bright when observed by the naked eye. Star A is twice the distance from Earth as star B. Star A has an absolute luminosity which is ____ as bright as star B.

- ☐ one-forth times
- ☐ one-half times
- ☐ equally
- ☐ two times
- ■ four times
- ☐ can not tell from this data

24. (3 pts.) What is the primary advantage of the Hubble Space Telescope? What is(are) its disadvantage(s), if any?

The HST is in space so there is no image degradation due to atmospheric conditions. The telescope has a relatively small mirror. Servicing the observatory is expensive.

25. (2 pts.) The magnification (or power) of a relatively small astronomical telescope purchased from the Celestron Corporation is best changed by

- ☐ changing the objective lens or mirror.
- ☐ putting a shade over a part of the objective lens.
- ■ changing eyepiece focal lengths.
- ☐ using spectroscopy selectively.
- ☐ purchasing a larger telescope

for the free point

26. (3 pts.) A particular Newtonian telescope has a focal length of 1900 mm with an aperture of 125 mm. What is the magnification (or, power) of the telescope when a 15 mm focal length eyepiece is used?

$$magnification = \frac{1900 \text{ mm}}{15 \text{ mm}} = 127\times$$

27. (4 pts.) What are the advantages of a radio telescope? (Check all that apply)

- ■ Reveals radio sources, *i.e.*, objects that shine in the radiowave band of wavelengths
- ■ Shows radio sources behind interstellar dust clouds in parts of the Milky Way Galaxy that are hidden from optical view.
- ■ Works in cloudy weather and in the daytime.
- ■ Shows radio sources in space that are too dim to be seen with an optical telescope.
- ☐ When not performing astronomy, the radio telescope can be used to free HBO.

28. (3 pts.) Long-baseline interferometry (such as is used in the VLA) is primarily used to increase

- ☐ magnification.
- ■ resolution.
- ☐ light gathering power.
- ☐ parallax.
- ☐ none of these.

Pick only one of the two following questions. Correctly solving problem 30 receives extra credit. If you attempt both problems, place an 'X' through the problem you do not want graded. If both problems are attempted and one is not crossed out, problem 29 will be graded.

29. (5 pts.) The binary star system 70-Ophiuchi (a faint star in Ophiuchus) is an extremely well-studied binary system in which the companion star is orbiting the primary star with a period of 87.7 years. The carefully-measured average separation between the stars (the semimajor axis) was determined to be 0.71 ly. What is the combined mass of the two stars?

$$P = 87.7\ \text{y} \times 365.26\,{}^{d}\!/\!_{y} \times 24\,{}^{h}\!/\!_{d} \times 3600\,{}^{s}\!/\!_{h} = 2.768\times10^{9}\,\text{s}$$

$$a = 0.71\ \text{ly} \times 9.461\times10^{15}\,{}^{m}\!/\!_{ly} = 6.717\times10^{15}\,\text{m}$$

$$P^2 = \left[\frac{4\pi^2}{G(m_1+m_2)}\right]a^3$$

$$\left(2.768\times10^{9}\,\text{s}\right)^2 = \left[\frac{4\pi^2}{6.6726\times10^{-11}\,{}^{\text{Nm}^2}\!/\!_{\text{kg}^2}\,(m_1+m_2)}\right]\left(6.717\times10^{15}\,\text{m}\right)^3$$

$$7.6618\times10^{18}\,\text{s}^2 = \frac{5.9165\times10^{11}}{(m_1+m_2)}(3.0306\times10^{47}\,\text{m}^3)$$

$$(m_1+m_2) = \text{combined mass} = 2.34\times10^{40}\ \text{kg}$$

30. (10 pts.) The binary star system Castor (α-Geminorum) has a current separation of 3.9 arcsec and is 51.6 ly away. The period of rotation of the two stars in the binary is 477 years. What is the combined mass of the stars in the binary system?

Small angle formula:

$$D = \frac{\alpha d}{206,265''} = \frac{3.9''\times 51.6\ \text{ly}}{206{,}265''} = 9.756\times10^{-4}\ \text{ly}$$

$$D = 9.756\times10^{-4}\ \text{ly} \times 9.461\times10^{15}\,{}^{\text{m}}\!/\!_{\text{ly}} = 9.231\times10^{12}\,\text{m}$$

$$P = 477\ \text{y} \times 365.26\,{}^{d}\!/\!_{y} \times 24\,{}^{h}\!/\!_{d} \times 3600\,{}^{s}\!/\!_{h} = 1.505\times10^{10}\,\text{s}$$

$$a = 0.71\ \text{ly} \times 9.461\times10^{15}\,{}^{m}\!/\!_{ly} = 6.717\times10^{15}\,\text{m}$$

$$P^2 = \left[\frac{4\pi^2}{G(m_1+m_2)}\right]a^3$$

$$\left(1.505\times10^{10}\,\text{s}\right)^2 = \left[\frac{4\pi^2}{6.6726\times10^{-11}\,{}^{\text{Nm}^2}\!/\!_{\text{kg}^2}\,(m_1+m_2)}\right]\left(9.231\times10^{12}\,\text{m}\right)^3$$

$$2.266\times10^{20}\,\text{s}^2 = \frac{5.9165\times10^{11}}{(m_1+m_2)}(7.8646\times10^{38}\,\text{m}^3)$$

$$(m_1+m_2) = \text{combined mass} = 2.05\times10^{30}\ \text{kg}$$

Extra Credit. (10 pts.) Don’t attempt this problem until you have completed the main portion of the exam. It is not difficult but gets little, if any, partial credit.

During the eclipse on May 20, 2012 it was observed that 3 minutes were required for the Moon to occult (cover up) a large sunspot on the Sun. What was the diameter, in km, of the sunspot? If the diameter of the Earth is 12,756 km, how many "Earths" would have fit, side-by-side, in the sunspot?

Some Important Equations and Constants

Conversions

Time

1 sidereal year = 365.26 day
1 day (mean solar day) = 24 h
1 h = 60 min = 3600 s
1 min = 60 s

Linear Distance

1 AU = 1.496 x 10^8 km
1 ly = 9.461 x 10^{12} km = 9.461 x 10^{15} m
= 63,235 AU
3.26 ly = 1 pc

Angular Distance

1 complete circle = 360°
1° = 60 arcmin = 60'
1 arcmin = 60 arcsec = 60"

Constants

c = 3.00 x 10^8 $^{m}/_{s}$

G = 6.6726 x 10^{-11} $\mathrm{N\,m^2/kg^2}$

π = 3.14159265

σ = 5.67 x 10^{-8} $\mathrm{W/m^2{\cdot}K^4}$

h = 6.63 x 10^{-34} J·s

$M_\odot$ = 1.989 x 10^{30} kg

solar constant = 1370 W/m^2

$L_\odot$ = 3.85 x 10^{26} W

Apparent Magnitude (Sun) = -26.7

Hubble constant, H_0 = 22 $\mathrm{\frac{km/s}{Mly}}$

Equations

$$D = \frac{2\pi \cdot \alpha d}{360°} = \frac{2\pi \cdot \alpha d}{21600'} = \frac{2\pi \cdot \alpha d}{1.296 \times 10^6 ''} = \frac{\alpha d}{206,265''}$$

Distance-Parallax relationship: $d = \dfrac{1}{p}$

Kepler's Third Law: $P^2 = a^3$ Newton's Modification of Kepler's Third Law: $P^2 = \left[\dfrac{4\pi^2}{G(m_1 + m_2)}\right] a^3$

Newton's Law of Gravitation: $F = G\left(\dfrac{m_1 m_2}{r^2}\right)$

$c = \lambda \nu$

Planck's Law: $E = h\nu = \dfrac{hc}{\lambda}$

Wien's Law: $\lambda_{\max} = \dfrac{0.0029}{T}$

Stephan-Boltzmann Law: $F = \sigma T^4$

Doppler Shift: $\dfrac{\Delta\lambda}{\lambda_o} = \dfrac{v}{c}$

Galactic Redshift: $z = \dfrac{\lambda - \lambda_0}{\lambda_0}$

Inverse-Square Law of Light: $F = \dfrac{L}{4\pi d^2}$

Brightness/Magnitude relationship:

$$m_2 - m_1 = 2.512 \log \frac{b_1}{b_2}$$

Einstein's Energy/Mass Relationship:

$$E = mc^2$$

Dawes Limit: $R = 2.5 \times 10^5 \dfrac{\lambda}{D}$

Hubble Law: $v = H_0 \times d$

Schwarzschild Radius: $R = \dfrac{2GM}{c^2}$

Sidereal/Synodic Period Relationship:

$$\frac{1}{P} = \frac{1}{E} - \frac{1}{S}$$

Periodic Table of the Elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA																	VIIIA
1	1 **H** 1.00794	IIA											IIIA	IVA	VA	VIA	VIIA	2 **He** 4.00262
2	3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.179
3	11 **Na** 22.9898	12 **Mg** 24.305	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
6	55 **Cs** 132.9054	56 **Ba** 137.34	57 **La*** 138.91	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.0254	89 **Ac**** 227.0278	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (264)	108 **Hs** (265)	109 **Mt** (266)	110 (270)	111 (272)	112 ***** (277)						

*Lanthanides	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
**Actinides	90 **Th** 232.038	91 **Pa** 231.0659	92 **U** 238.0289	93 **Np** 237.0482	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Mass numbers in parenthesis are the mass numbers of the most stable isotopes. As of 1997 elements 110-112 have not been named.
***Peter Armbruster and Sigurd Hofman synthesized a single atom at the Heavy-Ion Research Center in Darmstadt, Germany in 1996. The atom survived for 280 μs after which it decayed to element 110 by loss of an α-particle