MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Physics Department
Earth, Atmospheric, and Planetary Sciences Department

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Quiz 1

Name ______________________________ **(please print)**
Last **First**

1. Be sure to attempt all problems.
2. The point values of the problems are indicated at the top of each page.
3. Closed book exam; you may use one page of notes.
4. Wherever possible, try to solve the problems using general analytic expressions. Plug in numbers only as a last step.

Problem	Grade	Grader
1		
2		
3		
4		
Total		

APPROXIMATE VALUES OF USEFUL CONSTANTS

Constant	cgs units		mks units	
c (speed of light)	3×10^{10}	cm/sec	3×10^{8}	m/sec
G (gravitation constant)	7×10^{-8}	dyne-cm^2/g^2	7×10^{-11}	N-m^2/kg^2
k (Boltzmann's constant)	1.4×10^{-16}	erg/K	1.4×10^{-23}	J/K
h (Planck's constant)	6.6×10^{-27}	erg-sec	6.6×10^{-34}	J-sec
m_{proton}	1.6×10^{-24}	g	1.6×10^{-27}	kg
eV (electron Volt)	1.6×10^{-12}	erg	1.6×10^{-19}	J
$M_\odot$ (solar mass)	2×10^{33}	g	2×10^{30}	kg
$L_\odot$ (solar luminosity)	4×10^{33}	erg/sec	4×10^{26}	J/sec
$R_\odot$ (solar radius)	7×10^{10}	cm	7×10^{8}	m
σ (Stefan-Boltzmann cons)	6×10^{-5}	erg/cm^2-sec-K^4	6×10^{-8}	J/m^2-sec-K^4
Å(Angstrom)	10^{-8}	cm	10^{-10}	m
km (kilometer)	10^{5}	cm	10^{3}	m
pc (parsec)	3×10^{18}	cm	3×10^{16}	m
kpc (kiloparsec)	3×10^{21}	cm	3×10^{19}	m
Mpc (megaparsec)	3×10^{24}	cm	3×10^{22}	m
year	3×10^{7}	sec	3×10^{7}	sec
day	86400	sec	86400	sec
AU	1.5×10^{13}	cm	1.5×10^{11}	m
$1'$ (arc minute)	1/3400	rad	1/3400	rad
$1''$ (arc second)	$1/200,000$	rad	$1/200,000$	rad

Problem 1 (25 points)

Orbital Dynamics

A binary system consists of two stars in circular orbit about a common center of mass, with an orbital period, $P_{\text{orb}} = 10$ days. Star 1 is observed in the visible band, and Doppler measurements show that its orbital speed is $v_1 = 20$ km s^{-1}. Star 2 is an X-ray pulsar and its orbital *radius* about the center of mass is $r_2 = 3 \times 10^{12}$ cm $= 3 \times 10^{10}$ m.

(a) Find the orbital radius, r_1, of the optical star (Star 1) about the center of mass.

(b) What is the total orbital separation between the two stars, $r = r_1 + r_2$?

(c) Compute the total mass of the system, $M_1 + M_2 = M_{\text{tot}}$.

(d) Compute the individual masses of Star 1 and of Star 2.

Problem 2 (25 points)

Geometric and Physical Optics

(a) Compare the angular resolution of the The Very Large Array (VLA), the Hubble Space Telescope, and the Spitzer Space Telescope. The effective diameters of the three instruments are 36 km, 2.5 m, and 85 cm, respectively, while typical wavelengths used for observation might be 6 cm, 0.6 μm, and 5 μm, respectively.

(b) Each of the two Magellan telescopes has a diameter of 6.5 m. In one configuration the effective focal length is 72 m. Find the diameter of the image of a planet (in cm) at this focus if the angular diameter of the planet at the time of the observation is $45''$.

(c) A prism is constructed from glass and has sides that form a right triangle with the other two angles equal to $45°$. The sides are L, L, and H, where L is a leg and H is the hypotenuse. A parallel light beam enters side L normal to the surface, passes into the glass, and then strikes H internally. The index of refraction of the glass is $n = 1.5$. Compute the critical angle for the light to be internally reflected at H. Does it do so in the geometry described here?

Problem 3 (25 points)

Doppler Effect and Bohr Atom

(a) A binary system with circular orbit is viewed edge on (i.e., in the plane of the orbit), and the spectrum of one of the stars is recorded on a regular basis (the other star is undetectable). The orbital speed of the visible star is 300 km s^{-1}, and the orbital period is $P_{\rm orb}$. The center of mass of the binary system is moving *toward* the Solar System at 300 km s^{-1}. Compute an expression for the Doppler shift of the Hα line (at 6563 Å) as a function of time, and sketch $\Delta\lambda$ as a function of orbital cycle. You may ignore the orbital speed of the Earth around the Sun.

(b) If the Bohr energy levels scale as Z^2, where Z is the atomic number of the atom (i.e., the charge on the nucleus), estimate the energy or wavelength of a photon that results from a transition from $n = 3$ to $n = 2$ in Fe, which has $Z = 26$. Assume that the Fe atom is completely stripped of all its electrons except for one.

Problem 4 (25 points)

Luminosity and Magnitudes

(a) A white dwarf star has an effective temperature, $T_e = 50,000$ degrees Kelvin, but its radius, R_{WD}, is comparable to that of the Earth. Take $R_{\mathrm{WD}} = 10^4$ km (10^7 m or 10^9 cm). Compute the luminosity (power output) of the white dwarf. Treat the white dwarf as a blackbody radiator.

(b) An extrasolar planet has been observed which passes in front of (i.e., transits) its parent star. If the planet is dark (i.e., contributes essentially no light of its own) and has a surface area that is 2% of that of its parent star, find the decrease in magnitude of the system during transits.

(c) If a star cluster is made up of 10^4 stars, each of whose absolute magnitude is -5, compute the combined *apparent* magnitude of the cluster if it is located at a distance of 1 Mpc.