NAME:________________________________

Astronomy 350 **Fall 2011**

HOUR EXAM 1

September 23, 2011

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1. DO NOT OPEN THIS EXAM UNTIL INSTRUCTED TO DO SO.
2. Write you name and all answers in your test booklet. Turn in your booklet and this sheet.
3. Show all of your work in the test booklet, and indicate clearly your final answer! A correct final answer may not receive credit if no work is shown.
4. Budget your time! Don't get stalled on any one question.
5. Short answer questions can be answered in 1-2 sentences, unless indicated otherwise. If you are writing paragraphs, you may have misread or misunderstood the question.
6. For your reference there are constants listed below.
7. The total number of points on the exam is 100, and there are 5 additional bonus points available.

Possibly Useful Information

Note that a symbol may take different meanings in different equations.

$d = vt$	$\Delta v = a \times \Delta t$
$a_{\rm AU}^3 = P_{\rm yr}^2$	$a^3 = GMP^2/4\pi^2$
$F = ma$	$F = Gm_1m_2/R^2$
$KE = \frac{1}{2}mv^2$	$PE = -Gm_1m_2/R$
$T = 3000\ \mathrm{K}\ \times\ (10^{-6}\ \mathrm{m}/\lambda_{\rm peak})$	$v/c = \Delta\lambda/\lambda_{\rm em} = (\lambda_{\rm obs} - \lambda_{\rm em})/\lambda_{\rm em}$
$F = L/4\pi R^2$	$d = 1\ \mathrm{pc}/p_{\rm arcsec}$
$L \propto M^4$	$\tau = 10^{10}\ \mathrm{yr}\ (M/M_\odot)^{-3}$
$G = 6.7 \times 10^{11}\ \mathrm{m^3/kg\ s^2}$	$c = 3.0 \times 10^8\ \mathrm{m/s}$
$1\ \mathrm{AU} = 1.5 \times 10^{11}\ \mathrm{m}$	$1\ \mathrm{pc} = 3.1 \times 10^{16}\ \mathrm{m} = 3.3\ \mathrm{lyr}$
$1\ \mathrm{kpc} = 10^3\ \mathrm{pc} = \mathrm{c} \times (3300\ \mathrm{yr})$	
$M_\odot = 2.0 \times 10^{30}\ \mathrm{kg}$	$M_{\rm Earth} = 6.0 \times 10^{24}\ \mathrm{kg}$
$L_\odot = 3.8 \times 10^{26}$ Watts	$\tau_\odot = 10^{10}\ \mathrm{yr} = 10$ billion yrs

Multiple Choice

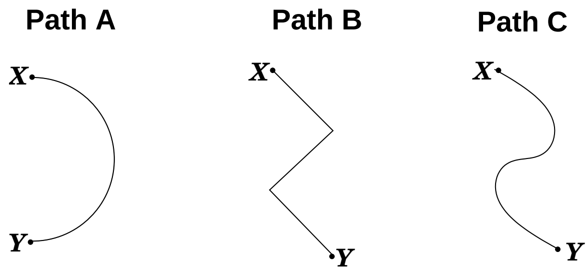
Circle the single *best* answer for each question. Be sure only one final answer is given.

1 . **[5 points]** In the Greek geocentric cosmology, the celestial sphere is truly a physical sphere on which the stars are located. In this geocentric picture, what is the spin period of the celestial sphere?

(a) **1 day**
(b) 1 week
(c) 1 month
(d) 1 year

The stars rise and set daily, so in a geocentric framework, the requires that the entire celestial sphere spins once daily around us.

2 . **[5 points]** A particle moves from point X to point Y. Possible paths from X to Y are shown at right. Which of these paths *must* have nonzero acceleration somewhere along the path?



(a) A only
(b) B only
(c) C only
(d) A and C only
(e) **A, B, and C**

Acceleration is a change in velocity *which is to say a change in* either *speed or* direction *of motion. Note that none of the paths are straight lines, so all of them must involve a change in direction of motion, so all of them must involve acceleration at some point, even if speed is held constant.*

3 . **[5 points]** A star is observed one night with the mighty U of Illinois telescope at the campus Observatory. Which of these properties of the star can be inferred *without* knowledge of its distance?
I. chemical composition II. luminosity III. speed along the line of sight

(a) I only
(b) II only
(c) III only
(d) **I and III only**
(e) I, II, and III

Compoisiton comes from looking at the wavelength and depth of lines in the spectrum, and no distance information is needed. Speed along the line of sight come from the Doppler effect, which come from shifts in wavelengths, also requiring no distance information. But luminosity does *require knowledge of distance, since one can only measure apparent brightness or flux F and then $L = 4\pi R^2 F$.*

4 . **[5 points]** Which has more total kinetic energy?

(a) **one baseball moving at 100 mph**
(b) two baseballs each moving at 50 mph
(c) (a) and (b) have the same total kinetic energy

Since $KE = \frac{1}{2}mv^2$, two objects of mass m and speed v have total kinetic energy $KE_2 = 2 \times \frac{1}{2}mv^2 = mv^2$. On the other hand, one object of mass m and speed $2v$ has kinetic energy $KE_1 = \frac{1}{2}m(2v)^2 = \frac{1}{2}4mv^2 = 2mv^2$, so the answer is (a).

5 . **[5 points]** Which has more (i.e., a more negative) total gravitational potential energy? (Only consider the gravity due to the Earth, not any other celestial object.)

(a) one baseball on the earth's surface (radius $R_{\rm Earth}$)

(b) two baseballs at radius $2R_{\rm Earth}$

(c) **(a) and (b) have the same total gravitational potential energy**

The gravitational potential energy of an object of mass m at a distance R from a gravitating body of mass M is $PE = -GMm/R$. Thus one mass m object at $R = R_{\rm Earth}$ has $PE_1 = -GmM_{\rm Earth}/R_{\rm Earth}$. On the other hand, two objects of mass m but distance $R = 2R_{\rm Earth}$ have total potential energy

$$PE_2 = 2 \times \left(-\frac{GmM_{\rm Earth}}{2R_{\rm Earth}}\right) = -\frac{GmM_{\rm Earth}}{R_{\rm Earth}} = PE_1 \tag{1}$$

and thus the answer is (c).

6 . **[5 points]** A carbon-12 (^{12}C) nucleus consists of 6 protons and 6 neutrons. Focus only on the nucleus, ignoring gravity and/or any influence from orbiting electrons. How many forces are exerted on a proton inside a ^{12}C nucleus?

(a) zero

(b) exactly one

(c) **more than one**

The protons repel each other due to their like electric charges. This means that there is at least one force on each proton. But they would accelerate and fly apart if this were the only force, so there must be at least one more force, since a proton at rest must have zero net force on it. In fact, the other force is the nuclear force, which must be attractive, and must also be strong enough to overcome the mutual repulsion of the protons.

7 . **[5 points]** Which of these *definitely* has an orbit period $>$ 1 year?

I. a planet with semimajor axis $a = 1.001$ AU and high eccentricity

II. a planet whose orbit is always outside the Earth's

III. an asteroid with orbit currently at 1 AU

(a) I only

(b) **I and II only**

(c) II and II only

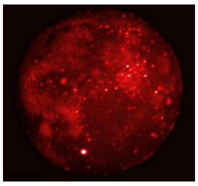
(d) I, II, and III

We know that $P_{\rm yr}^2 = a_{\rm AU}^3$, which means orbit period is entirely determined by semi-major axis. Thus if $a > 1$ AU, then $P > 1$ year. Cases I and II both have $a > 1$ AU, but case III may or may not have $a > 1$ AU, so the answer is (b).

Short Answer

Answer briefly but completely. Your responses should not require more than 1-2 sentences.

1. *The Eclipsed Moon in Infrared.*
   At right is a picture of the Moon as seen in infrared light. The image was taken during a lunar eclipse, when the Moon is completely inside the Earth's shadow and thus the Moon receives no sunlight.



(a) **[10 points]** Why does the unlit, eclipsed Moon still emit radiation?
All objects with nonzero temperature emit thermal radiation.

(b) **[5 points]** What do we learn about the Moon from the fact that its radiation is infrared?
Wein's law tells us that the color (peak wavelength) of thermal radiation is determined by the object's temperature. *In fact, as several of you remembered, human beings emit infared thermal radiation, so the Moon must be about the same temperature, and indeed it is.*

2. *Star clusters.* Star cluster Gaga is discovered, and is made of stars that were all born at the same time. Cluster Gaga is found to only contain stars with masses $< 1M_{\odot}$.

   (a) **[10 points]** What is the most likely reason that cluster Gaga has only stars less massive than $1M_{\odot}$? Explain in 1–2 sentences.
   Sites of star formation create stars in a wide range of masses. However, high-mass stars have much sorter lifetimes than low-mass stars, and so a lack of high-mass stars means that enough time has passed that they have all died off.

   (b) **[10 points]** Is cluster Gaga likely to be the site of future supernova explosions? Briefly explain why or why not.

Supernova explosions mark the death of high-mass stars, and since there are no remaining high-mass stars, we do not expect any supernovae in the future.

3. *Alternate Universes: High Gravity.* Imagine that the strength of the gravitational force is increased, by somehow increasing the value of the constant G in the gravitational force law; the contents and properties of the universe (masses, compositions) are otherwise unchanged. We will focus on the Sun's response to this stronger gravity.

   (a) **[10 points]** Compared to the ordinary temperature at the center of the "normal-gravity" Sun, would the central temperature of the "high-gravity" Sun be higher, lower, or the same? Briefly explain in 1–2 sentences.
   A star in hydrostatic equilibrium balances the inward force of gravity with outward pressure. The higher gravity star will require correspondingly higher pressure, and higher pressure in turn requires higher temperature.

   (b) **[10 points]** Compared to the color of the ordinary "normal-gravity" Sun as observed from Earth, would the "high-gravity" Sun's color change? If so, how and why? If not, why not? Briefly explain in 1–2 sentences.
   We have seen that temperature will be higher, and Wein's law says that color follows temperature: $\lambda \propto 1/T$*, so that hotter means shorter wavelength and thus bluer color.*

4. *Supernova Explosions Across the Universe.* Astronomers observe 100 supernova explosions in 100 different galaxies. These supernovae are known to be standard candles. It is observed that the set of supernovae have a range of apparent peak brightnesses–some bright, some dim, some in between.

   (a) **[10 points]** Why do the supernovae appear to have different apparent brightness?
   Because the supernovae are standard candles, they have a fixed peak luminosity L. Thus differences in flux $F = L/4\pi d^2$ can only be due to differences in distance. Supernovae which appear fainter are farther away.

   (b) **[5 points]** Cosmologists use supernovae to learn about the past history of the universe. How can two supernovae of different apparent brightnesses tell us about two different times in the past? Briefly explain in 1–2 sentences.
   Since fainter supernovae are farther away, their light has taken longer to reach us. Thus the more distant supernovae probe earlier cosmic times.

   (c) **[5 bonus points]** The dimmest supernovae are found to inhabit galaxies with the lowest amount of heavy elements, while the brightest supernovae are found in galaxies with the highest amount of heavy elements. How would you explain this trend?
   We know that heavy elements are made by stars generally, and largely by supernovae in particular. The more supernovae that have exploded in a galaxy, the more heavy elements it should have–heavy elements should build up over time. The dimmest supernovae are in the galaxies in the distant past and they have the smallest amount of heavy elements, which is reasonable because they have had the least time to accumulate heavy elements through the deaths of previous generations of stars.