Physics 231 **Exam 2** **2014**

Name_______________________________________

• ***Use correct notation for vectors and scalars.***

• Read all problems carefully before attempting to solve them.

• Your work must be legible, and the organization must be clear.

• Correct answers without adequate explanation will be counted wrong.

• Incorrect explanations mixed in with correct explanations will be counted wrong.

• Make explanations complete but brief. Do not write a lot of prose.

• Include diagrams where appropriate.

• Show what goes into a calculation, not just the final number: $\dfrac{\left(8\times10^{-3}\right)\left(5\times10^{6}\right)}{\left(2\times10^{-5}\right)\left(4\times10^{4}\right)} = 5\times10^{4}$

• Give physical units with your results.

If you cannot do some portion of a problem, invent a symbol for the quantity you can't calculate (explain that you're doing this), and do the rest of the problem.

Things you must know:

(1) Definition of and approximation for average velocity (and the position update formula)

(2) Definition of momentum $\gamma = \dfrac{1}{\sqrt{1-\left(|\vec{v}|/c\right)^2}}$

(3) The Momentum Principle (also, the momentum update formula and derivative form)

(4) Definitions of total energy, rest energy, and kinetic energy of a particle

(5) The Energy Principle – *be able to apply to "point particle" systems and real systems*

EVALUATING SPECIFIC PHYSICAL QUANTITIES

Projectile Motion: $x_f = x_i + v_{xi}\Delta t$ $y_f = y_i + v_{yi}\Delta t - \frac{1}{2}g(\Delta t)^2$ $v_{xf} = v_{xi}$ $v_{yf} = v_{yi} - g\Delta t$

$F_x = -\dfrac{dU}{dx}$ $\vec{F}_{\text{grav on 2 by 1}} = -G\dfrac{m_1 m_2}{|\vec{r}|^2}\hat{r}$ $U_{\text{elec}} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{|\vec{r}|}$

Near the Earth's surface $\left|\vec{F}_{grav}\right| \approx mg$, and $\Delta U_{grav} = \Delta(mgy)$

$\vec{F}_{\text{elec on 2 by 1}} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{|\vec{r}|^2}\hat{r}$ $U_{grav} = \dfrac{-Gm_1 m_2}{|\vec{r}|}$ $\left|\vec{F}_{spring}\right| = k_s|s|$, opposite the stretch

$U_{spring} = \frac{1}{2}k_s s^2 + U_o$ $\omega = \sqrt{\dfrac{k_s}{m}}$ $Y = \dfrac{F/A}{\Delta L/L} = \dfrac{k_{s,atomic}}{d_{atomic}}$ $v_{sound} = d_{atomic}\sqrt{\dfrac{k_{s,atomic}}{m}}$

$\Delta E_{\text{thermal}} = c_v m\Delta T$ Power = energy/time (watts = joules/second)

$\vec{F}_{air} \approx -\frac{1}{2}C\rho A v^2\hat{v}$ $\left|\vec{F}_{buoyancy}\right| = $ weight of displaced fluid $E_{light} = -\Delta E_{source} = \Delta E_{recipient}$

$K \approx \frac{1}{2}mv^2 = \dfrac{p^2}{2m}$ for $v << c$ $E^2 - (pc)^2 = \left(mc^2\right)^2$ $W = \vec{F}\cdot\Delta\vec{r}_{Force}$ (for constant force)

Circular motion at constant speed: $\dfrac{d\vec{p}}{dt} = -\dfrac{m\omega^2}{\sqrt{1-|\vec{v}|^2/c^2}}\vec{r}$, or $\dfrac{d\vec{p}}{dt} \approx -m\omega^2\vec{r}$ for $|\vec{v}| << c$ Where $\omega = \dfrac{d\theta}{dt} = \dfrac{2\pi}{T}$

$|\vec{v}| = \dfrac{2\pi|\vec{r}|}{T} = \omega|\vec{r}|$ $\vec{F}_{\parallel} = \dfrac{d|\vec{p}|}{dt}\hat{p}$ $\vec{F}_{\perp} = |\vec{p}|\dfrac{d\hat{p}}{dt} = |\vec{p}|\dfrac{|\vec{v}|}{R}\hat{n}$

Multiparticle Systems: $\vec{r}_{cm} = \dfrac{m_1\vec{r}_1 + m_1\vec{r}_1 + \ldots}{m_1 + m_2 + \ldots}$ $\vec{P}_{cm} \approx M\vec{v}_{cm}$ (v<<c)

$K_{tot} = K_{trans} + K_{rel}$ $K_{trans} \approx \frac{1}{2}Mv_{cm}^2$ (v<<c) $K_{rel} = K_{rot} + K_{vib}$

CONSTANTS

$G = 6.7\times10^{-11}$ N·m²/kg² $g = 9.8$ N/kg $c = 3\times10^8\, m/s$ $\dfrac{1}{4\pi\varepsilon_o} = 9\times10^9\, N\cdot m^2/C^2$

Avogadro's number = 6×10^{23} molecules/mole $m_{\text{electron}} = 9\times10^{-31}kg$ $m_{\text{proton}} \approx m_{\text{neutron}} \approx m_{\text{hydrogen atom}} = 1.7\times10^{-27}kg$

Typical atomic radius $r \approx 10^{-10}m$ Proton radius $r \approx 10^{-15}m$ Specific Heat of water $c_v = 4.2\times10^3$ J/(kg K)

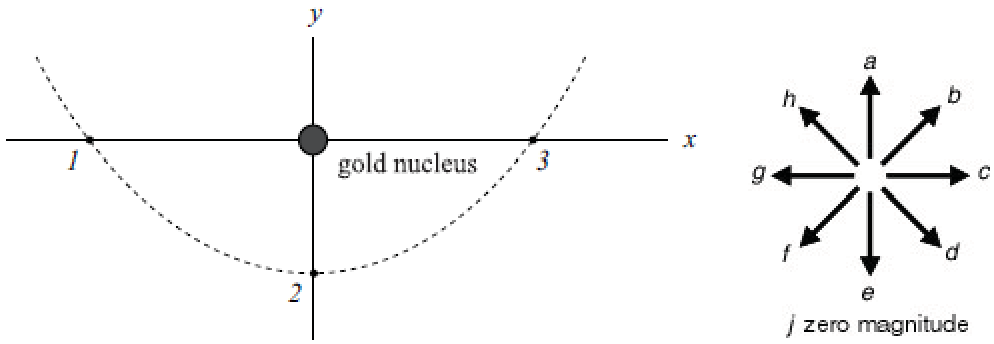
$M_{moon} = 7\times10^{22}kg$ Radius of the Moon = 1.75×10^6 m $M_{sun} = 2\times10^{30}$kg 1eV = 1.6×10^{-19}J

1. A load of 190 kg is supported motionless above the ground by two ropes. Rope 1 exerts a force of <−300, 500, 0> N on the load.

(a) (3pts) Draw a diagram showing all the forces acting on the load. All vectors should be drawn to the same scale, so that longer arrows correspond to larger magnitudes. Clearly label each force to identify it. Note: Once you've don't part *b* (calculated the force that the rope exerts), you may wish to correct / refine this diagram.

(b) (4pts) What is the force exerted by rope 2? Explain carefully and completely, starting from a fundamental principle (I recommend *starting* on the diagram for part b, getting a quantitative answer here in part *a*, and then refining your diagram in part *b*. so the scales and direc)you drawing the diagram in part b may help.)

2.



The diagram above shows the path that an electron (negatively charged) follows while moving from point 1 to 2 to 3 near a gold nucleus (positively charged).

(a) (3pts.) What is the direction of the momentum of the electron at each point? **Write the letter corresponding to the correct direction arrow.**

Momentum direction at point 1:_________

Momentum direction at point 2: _________

Momentum direction at point 3: _________

(b) (3pts.) What is the direction of the net force on the electron at each point? **Write the letter corresponding to the correct direction arrow.**

Net force direction at point 1: _________

Net force direction at point 2: _________

Net force direction at point 3: _________

Considering the alignment of the momentum and force at each point, circle the best response for the next two questions.

(c) (1pt) At point 1, the speed of the electron is:

A. increasing B. decreasing C. not changing

(d) (1pt) At point 3, the speed of the electron is:

A. increasing B. decreasing C. not changing

3. An alpha particle with mass 6.8×10^{-27} kg is moving with a speed of 2.9×10^{8} m/s.

(a) (4pts) What is the rest energy of this alpha particle?

(b) (4pts) What is the total energy of this alpha particle?

(c) (4pts) What is the kinetic energy of this alpha particle?

4. (9pts) In outer space, a piece of space junk whose mass is 60 kg is subject to a constant net force $\langle 13, -9, 12 \rangle$ N. When the space junk is at location $\langle 10, 6, -4 \rangle$ m, its speed is 0.8 m/s. When the space junk has moved to location $\langle 13, 8, -2 \rangle$ m, what is its speed?

5. (7pts) A proton (1.6726×10^{-27} kg) and a neutron (1.6749×10^{-27} kg) at rest combine to form a deuteron, the nucleus of deuterium or "heavy hydrogen." In this process, a gamma ray (high-energy photon) is emitted, and its energy is measured to be 22,000 keV (2.2×10^{6} eV).

Keeping all five significant figures, what is the mass of the deuteron? Assume that you can neglect the small kinetic energy of the recoiling deuteron.

6. (10pts) A spring whose stiffness is 3500 N/m is used to launch a 4 kg block straight up in the classroom. The spring is initially compressed by 0.2 m, and the block is initially at rest when it is released. When the block is 1.3 m above its starting position, what is its speed?

7. A rock is moving with a speed of v_i extremely far from the Sun, at a distance of r_i from the Sun (quite far from the Sun). Later, it is much nearer, r_f from the center of the Sun. In terms of these parameters and the mass of the sun, M_s, what is the speed of the rock at this new location?

(a) (5pts) First, draw a graph of kinetic energy K, of potential energy U, and of kinetic plus potential energy $K + U$ vs. separation r for this process. **Label each of the three curves.**

(b) (10pts) Now, explicitly starting from the energy principle, with the Sun and rock as your system, develop the relation for the rock's speed when r_f from the sun.

$\Delta E = \ldots$

8. (5pts) You put a thin aluminum pot containing 2 liters (2000 grams) of room-temperature (20°C) water on a hot electric stove. You observe that after 4 minutes (240 s) the water starts to boil (temperature 100°C). What was the change $\Delta E_{\text{thermal}}$ in the water?

9. Once every 200 million years, the sun orbits about the center of the Milky Way Galaxy at a distance of 30,000 light-years from the center (1 light-year = 9.46×10^{15}m).

(a) (7pts) Estimate the mass of the galaxy. State clearly the assumptions, if any, you made.

(b) (3pts) With a mass of 2×10^{30}kg, our Sun is a pretty average star. Given your estimate in part (a), approximately how many stars are there in the Milky Way Galaxy? (If you didn't get an answer to part (a), just call it M_G for the sake of this part, and get an answer in terms of that)

10. (10pts) A baseball has mass 155 grams (0.155 kg) and radius 3.5 cm (0.035 m). The baseball is moving through the air at high speed, so air resistance is important. The density of the air is 1.3 kg/m^3 . and the bluntness coefficient is *C* = 0.35. Initially, the baseball's position is <25.00, 12.00, 3.00> m and its velocity is <40.00, 30.00, 0> m/s. Fill in the missing lines of code that would model the ball's motion through the air.

```
from visual import *

Baseball = sphere(pos = (_________,___________,__________), r = ______________, color=color.blue)

Baseball.m = ____________

Baseball.p = ______________________________
C = 0.35
d = 1.3
g = 9.8

t = 0
tmax = 2
deltat = 0.001

while t < tmax:                    (fill in the missing code in the while loop)







    Baseball.pos = Baseball.pos + (Baseball.p/Baseball.m)*deltat
    t = t + deltat
```

11. (7pts) Light containing photons of a wide range of energies from 0.1 eV to 10 eV passes through a collection of cold gas, and downstream the light is found to be depleted ("dark lines") in photons of energies 9 eV, 7.2 eV, 6.3 eV, 3.9 eV, and 2.2 eV. Next this light source is turned off, and a beam of electrons with kinetic energy 8 eV passes through the gas. What are the energies of photons emitted from the excited gas? Explain carefully, *using a diagram to make your reasoning clear.*

Bonus (5pts) what is the central principle of this course that I keep returning to? I'll get you started:

"*Motion…*