PHY141 Fall 2012 Final Exam

Name:

You have 2.5 hours to complete this exam. There are 8 questions with a total of 200 points. You may consult up to three handwritten sheet of notes during the exam. You may use any kind of calculator which does not have communication or network capabilities. All working and answers should be completed on the exam sheets. You may use the front and back sides of the paper and there is a spare sheet at the end of the exam where you can continue problems if you need to. Partial credit will be given for answers which, while finally incorrect, contain sensible, legible, and physically correct working.

Some potentially useful information for this exam:

Ideal gas constant $R = 8.314 \text{ J mol}^{-1}\text{K}^{-1}$

Boltzmann’s constant $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

Standard atmospheric pressure 1 atm = 101.3 kPa

Mass of Earth, $M_E = 5.98 \times 10^{24} \text{ kg}$

Radius of Earth, $R_E = 6380 \text{ km}$

Gravitational Constant $G = 6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2}$

Constant volume molar specific heat capacity for a monatomic gas $c_{V,m} = \frac{3}{2}R$

Constant pressure molar specific heat capacity for a monatomic gas $c_{P,m} = \frac{5}{2}R$

Constant volume molar specific heat capacity for a diatomic gas $c_{V,m} = \frac{5}{2}R$

Constant pressure molar specific heat capacity for a diatomic gas $c_{P,m} = \frac{7}{2}R$
Question 1. (25 points)

A satellite in a circular geostationary orbit above the Earth’s surface (meaning it has the same angular velocity as the Earth) explodes into three pieces of equal mass. One piece remains in a circular orbit at the same height as the satellite’s orbit after the collision, but the velocity of this piece is in the opposite direction to the velocity of the satellite before the explosion. After the explosion the second piece falls from rest in a straight line directly to the Earth. The third piece has an initial velocity in the same direction as the original direction of the satellite, but now has a different magnitude of velocity. The diagram is obviously not remotely to scale!

(a) (10 points) At what height above the Earth does the satellite orbit?

(b) (5 points) What is the magnitude of the velocity of the satellite along its original circular path?

(c) (5 points) For the piece that falls to the ground, what is the magnitude of the velocity when it strikes the ground? You may neglect any effects due to air resistance.

(d) (5 points) What happens to the third piece? Does it fall to the ground, continue in an orbit around the Earth (not necessarily a circular one), or escape the gravitational pull of the Earth? Justify your answer.
**Question 2.** (25 points)

An inclined plane has a coefficient of static friction $\mu_s = 0.4$ and kinetic friction $\mu_k = 0.3$.

(a) (5 points) What is the maximum inclination angle $\theta$ for which a stationary block on the plane will remain at rest?

(b) (10 points) If a ball ($I = \frac{2}{5}Mr^2$) is placed on the incline when it has the inclination angle you found in part (a) and rolls through a distance of 1.5m, what is the translational velocity of the ball when it reaches the bottom of the incline?

(c) (10 points) What percentage of the kinetic energy of the ball is rotational while it is rolling down the incline?
Question 3. (30 points)

A plane is flying horizontally with a constant speed of 100 m/s at a height \( h \) above the ground, and drops a 50 kg bomb with the intention of hitting a car that has just begun driving up a 10° incline which starts a distance \( l \) in front of the plane. The speed of the car is a constant 30 m/s. For the following questions use the coordinate axes defined in the figure, where the origin is taken to be the initial position of the car.

(a) (5 points) What is the initial velocity of the bomb relative to the car? Write your answer in unit vector notation.

(b) (5 points) Write equations for both components \((x, y)\) of the car’s displacement as a function of time, taking \( t=0 \) s to be the time the bomb is released.

(c) (5 points) Write equations for both components \((x, y)\) of the bomb’s displacement as a function of time, taking \( t=0 \) s to be the time the bomb is released.

(d) (5 points) If the bomb hits the car at time \( t=10 \) s what was the height of the plane above the ground \( h \) when it dropped the bomb?

(e) (5 points) What is the horizontal displacement of the plane relative to the car when the bomb hits the car at \( t=10 \) s.

(f) (5 points) How much kinetic energy does the bomb have when it hits the car?
Question 4. (20 points)

A 90cm tall cylindrical steel oil drum weighs 15kg and has a external volume of 0.2m$^3$. When full the drum contains 190L of crude oil. The density of crude oil is 900kg/m$^3$ and of water is 1000kg/m$^3$.

(a) (5 points) What is the external diameter of the oil drum?

(b) (10 points) If the oil drum has fallen overboard and is floating upright in the sea, what length of the oil drum $x$ sticks up above the water? As a simplifying approximation you may assume that the all the steel is on the sides of the drum, and the top and bottom do not contribute to the mass of the drum.

(c) (5 points) What is the pressure at the bottom of the drum? You may assume standard atmospheric pressure for the air above the drum.
Question 5. (25 points)

The system shown in the figure is initially in static equilibrium. The inclined plane with an inclination angle of $\theta$ is frictionless. The mass $m_2$ which is hanging from the rope is heavier than the mass $m_1$ which lies on the inclined plane. The pulley in this problem has mass $m_3$ and radius $r$. The mass $m_1$ is attached to a spring with spring constant $k$, the other end of this spring is fixed. For all of the following questions try to simplify your answer as much as possible.

(a) (5 points) Find an expression for $x_0$, the distance that the spring is extended from it’s natural length in terms of some or all of the variables, $m_1$, $m_2$, $m_3$, $r$, $\theta$ and $k$.

(b) (5 points) The mass $m_2$ is now pulled down by a distance $A$. Write an expression for the work done on the system during this process in terms of some or all of the variables, $m_1$, $m_2$, $m_3$, $\theta$, $r$, $k$ and $A$.

(c) (5 points) The system is now released. Write an expression for the frequency of the subsequent simple harmonic motion in terms of some or all of the variables, $m_1$, $m_2$, $m_3$, $\theta$, $k$, $r$ and $A$.

(d) (5 points) Find an expression for the magnitude of the maximum velocity of the system in terms of some or all of the variables, $m_1$, $m_2$, $m_3$, $\theta$, $k$, $r$ and $A$. At which value or values of the displacement of $m_2$ from it’s original equilibrium position does this occur?

(e) (5 points) Find an expression for the magnitude of the maximum acceleration of the system in terms of some or all of the variables, $m_1$, $m_2$, $m_3$, $\theta$, $k$, $r$ and $A$. At which value or values of the displacement of $m_2$ from it’s original equilibrium position does this occur?
Question 6. (25 points)

The speed of sound in air is \( v = 331 + 0.6T \text{ms}^{-1} \) where \( T \) is the temperature in °C. Two organ pipes of length 0.6m which are open at both ends are used to produce sounds of slightly different frequencies by heating one of the tubes above the room temperature of 20°C.

(a) (5 points) What is the lowest frequency sound that can be produced in the room temperature pipe?

(b) (5 points) Draw on the figure the form of the standing wave amplitude for both displacement and pressure that produces this sound.

(c) (5 points) To produce beats with a beat frequency of 1Hz with the sound produced in (a) using the first harmonic of the heated pipe what should the temperature of the heated pipe be?

(d) (5 points) What is the frequency of the second harmonic that the room temperature pipe produces?
Question 7. (25 points)

3 moles of a ideal monatomic gas are heated from atmospheric pressure 20°C to 120°C at constant volume. The gas is then further from 120°C to 220°C at constant pressure.

(a) (5 points) How much does the internal energy of the gas change in each process?

(b) (5 points) How much heat is added to the gas in each process?

(c) (5 points) How much work is done by the gas in each process?

(d) (5 points) What is the entropy change of the gas in each process?

(e) (5 points) What is the final pressure and volume of the gas?
Question 8. (25 points)

The diagram shows the P-V diagram for a 40% efficient ideal Carnot engine. Assume the gas used in this Carnot engine is an ideal diatomic gas.

(a) (5 points) For every Joule of work obtained from the engine, how much heat needs to be added to engine?

(b) (5 points) For every Joule of work obtained from the engine how much heat is lost to the environment?

(c) (5 points) At points B and D the gas in the system has the same volume, but different temperatures. If the gas at point D is at twice atmospheric pressure, what is the pressure of the gas at point B?

(d) (5 points) If the volume of the gas at point B is 1L what is the volume of the gas at point C?

(e) (5 points) How much does the net entropy of the engine and the environment change for every Joule of work done by this Carnot engine?
Blank Sheet to be used if you need more space. Please clearly label any responses you put here, and make a note in the original question space that I should look here!