Question 1. (25 points) The length of the Martian day is very close to that of the Earth (for this problem you can consider it to be the same). However the radius of Mars is half that of the Earth and its mass is $\frac{1}{10}$ that of our planet. The Martian’s have decided that they like our GPS satellite system. They therefore want to launch their own GPS satellites. Our GPS satellites go around the Earth twice every day, and the Martians want their’s to do the same. At what height above the surface of Mars should their GPS satellites fly so that they do this?

Some useful constants:

Mass of Earth, $M_E = 5.98 \times 10^{24}$ kg
Radius of Earth, $R_E = 6380$ km
Gravitational Constant $G = 6.67 \times 10^{-11}$ Nm$^2$kg$^{-2}$
Question 2. (25 points)

I want to raise a 1 kg object from the ground by pulling on a rope that passes over a pulley which has mass 200 g and radius 10 cm and can be treated as frictionless. For a solid disk the moment of inertia is \( \frac{1}{2} MR^2 \). The 1 kg object is initially at rest and I would like to lift it at a constant speed of 1 ms\(^{-1}\).

(a) (5 points) In order to have the weight be moving with this velocity 0.5 s after I start pulling on the rope, what should the force I apply be. (Assume uniform acceleration of the object)?

(b) (5 points) What is the angular acceleration of the pulley while I am doing this?

(c) (5 points) Once the object has reached a constant speed of 1 ms\(^{-1}\) what force should I apply to maintain that speed.

(d) (5 points) What is the angular velocity (in rpm) of the pulley while I am raising the object with a constant speed of 1 ms\(^{-1}\)?

(e) (5 points) What is the angular momentum of the pulley while I am raising the object with a constant speed of 1 ms\(^{-1}\)? Give both the magnitude and the direction (ie. left, right, up, down, in to the page, out of the page).
Question 3 (25 points) In a pinball machine you pull back on a spring with spring constant $k=15 \text{ N/m}$. When you release the spring it pushes a solid stainless steel ball of mass 80 g so that it rolls up the slope (you can assume that the spring is massless and that all the energy is transferred from the spring to the ball). The horizontal distance from the spring to the back wall of the machine is 1 m. Recall that the moment of inertia of a solid sphere is $I = \frac{2}{5}MR^2$

(a) (15 points) If the pinball machine is on a slope of $10^\circ$ how far do you need to pull back the spring for the ball to hit the back wall of the machine.

(b) (10 points) What percentage of the kinetic energy of the ball is rotational while it is rolling up the slope?
Question 4 (20 points) A standard spherical latex balloon has mass 3 g. Helium has a density of 0.18 kg m$^{-3}$ and air has a density of 1.2 kg m$^{-3}$. What is the minimum diameter to which you should inflate the balloon with helium so that it will rise? You may neglect the volume of air which the latex displaces (but not the mass of the latex).
Question 5 (25 points) A bullet of mass 100 g is shot into a ballistic pendulum with velocity 100 m/s. The ballistic pendulum consists of a wooden block of mass 9.9 kg suspended from a 1.5 m long string. After the collision the pendulum will oscillate back and forth in simple harmonic motion. For the questions below you may treat the wooden block as a point object.

(a) (5 points) What is the velocity of the combined block and bullet immediately after impact?

(b) (5 points) What is the period of oscillation of the pendulum?

(c) (5 points) What is the magnitude of the acceleration of the pendulum when the block is at the highest point of its motion?

(d) (10 points) What angle $\theta$ does the string make with the vertical at this point?
**Question 6** (25 points) To perform a Ruben’s tube demonstration in a classroom which is at a temperature of 20°C you take a 2 m long tube with numerous holes on top and flow propane into it so that the pressure is always 10% higher than atmospheric pressure. The tube is sealed at one end and has a speaker at the other end. The locations where the flames are highest correspond to nodes in the pressure standing wave (i.e., to points where there is no variation of the pressure around the mean pressure). Atmospheric pressure is $1.01 \times 10^5$ Pa, the molar mass of propane is 44.1 g/mol, and the gas constant $R = 8.314 \ \text{J mol}^{-1} \text{K}^{-1}$

(a) (10 points) By taking the bulk modulus of the propane in the tube to be $1.1 \times 10^5$ Pa, and by approximating the propane as an ideal gas, find the speed of sound in the propane.

(b) (5 points) When a standing sound wave is generated in the tube do the ends of the tube experience maximum or minimum pressure variation from the mean pressure in the tube? Explain how this relates to the boundary condition for displacement at the ends of the tube.

(c) (5 points) What frequency of sound should you use to produce the top pattern?

(d) (5 points) What frequency of sound should you use to produce the bottom pattern?

(Note: when considering questions (b) and (c) pay attention that the holes stop about 10cm before the end of the tube on the left hand side.)
Question 7 (25 points) An ideal diatomic gas at pressure $P_0$ and temperature $T_0$ expands from its original volume $V_0$ to $2V_0$.

(a) (5 points) Sketch a Pressure-Volume diagram for this expansion which shows on the same graph an isothermal process and an adiabatic process for this expansion. In which process does the gas do the most work?

(b) (5 points) Express the final pressure in terms of the original pressure $P_0$ for the case where the expansion is isothermal.

(c) (5 points) Express the final pressure in terms of the original pressure $P_0$ for the case where the expansion is adiabatic.

(d) (5 points) After the adiabatic expansion you considered in (c) what is the temperature of the gas in terms of the original temperature of the gas $T_0$?

(e) (5 points) What is the change in entropy for the adiabatic expansion?
**Question 8.** (30 points)

An ideal refrigerator which operates on the Carnot cycle is used to convert 1 L of liquid water at 0°C in to ice cubes at 0°C. The waste heat from this process is dumped in to a room with a temperature of 20°C. Some physical data you may (or may not) find useful are:

- Density of liquid water $\rho = 1000 \text{ kg/m}^3$
- Latent heat of fusion of water $L_f = 3.34 \times 10^5 \text{ J/kg}$
- Latent heat of vaporization of water $L_v = 2.226 \times 10^6 \text{ J/kg}$
- Specific heat of water $c_w = 4181 \text{ J/(kg.K)}$
- Specific heat of ice $c_i = 2050 \text{ J/(kg.K)}$

(a) (10 points) How much heat is rejected in to the room?

(b) (10 points) How much electrical energy must be provided to the refrigerator during this process?

(c) (10 points) What is the total entropy change of the system due to this process?