Physics 211 Exam 3, Form A

Problem 1	Problem 2	Problem 3	Problem 4	Total
/25	/25	/25	/25	/100

Name: ______________________________

Recitation section number: __________

(see next page)

- There are four questions worth a total of 100 points.
- **You must show your reasoning to receive credit**. A numerical answer with no logic shown will be treated as no answer.
- You are encouraged to use both pictures and words to show your reasoning, not just algebra. Show your reasoning as thoroughly as possible for partial credit.
- If you run out of room, leave a note saying "see back page", and continue your work on the blank page at the end.
- Do not attempt to communicate with anyone other than teaching staff during the exam.
- You may use an ordinary scientific or graphing calculator, but not one that will do algebra for you. If you do not have a calculator, leave your answers in symbolic form.
- Other electronic devices (laptops, smartphones, smartwatches) are not allowed during the exam.
- You may use $g = 10\,\mathrm{m/s^2}$ throughout, except where indicated, to minimize arithmetic.
- Reference material and an extra sheet of paper is on the last page.

Recitation Schedule

M003	8:25-9:20	106	Chad
M016	8:25-9:20	208	Nada
M004	9:30-10:25	B129E	Chad
M013	9:30-10:25	106	JT
M017	9:30-10:25	208	Nada
M005	10:35-11:30	B129E	Patrick
M014	10:35-11:30	106	JT
M018	10:35-11:30	208	Adil
M006	11:40-12:35	B129E	Sierra
M015	11:40-12:35	106	Gentian
M019	11:40-12:35	208	Adil
M007	12:45-1:40	B129E	Sierra
M020	12:45-1:40	208	Manabputra
M021	12:45-1:40	Whitman 306	Gentian
M008	2:15-3:10	B129E	Gabriel
M022	2:15-3:10	Maxwell 110	Manabputra
M009	3:45-4:40	B129E	Gabriel
M010	5:15-6:10	B129E	Gentian
M011	5:15-6:10	104N	Patrick

Reference

The work-energy theorem:

$$\frac{1}{2}mv_0^2 + W_{\text{all}} = \frac{1}{2}mv_f^2 \tag{1}$$

The work-energy theorem incorporating potential energy:

$$\frac{1}{2}mv_0^2 + PE_0 + W_{\text{other}} = \frac{1}{2}mv_f^2 + PE_f \tag{2}$$

The definition of work:

$$W = \vec{F} \cdot \Delta\vec{s} \equiv F(\Delta s)_{\parallel} = F_{\parallel}(\Delta s) = F\Delta s \cos\theta \tag{3}$$

Expressions for potential energy:

$$PE_{\text{grav}} = mgy \tag{4}$$

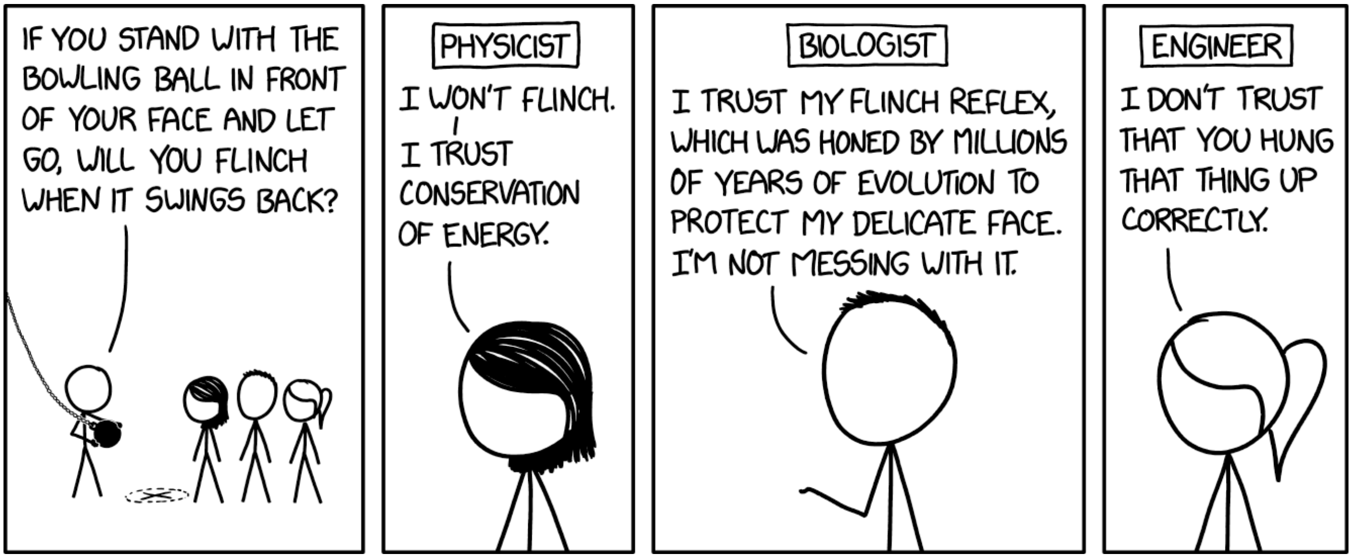
$$PE_{\text{spring}} = \frac{1}{2}k(\Delta x)^2 \tag{5}$$

Power applied by a force:

$$P = \vec{F} \cdot \vec{v} \tag{6}$$

Conservation of momentum:

$$\sum m\vec{v}_i = \sum m\vec{v}_f \tag{7}$$


IF YOU STAND WITH THE BOWLING BALL IN FRONT OF YOUR FACE AND LET GO, WILL YOU FLINCH WHEN IT SWINGS BACK?
PHYSICIST
I WON'T FLINCH.
I TRUST CONSERVATION OF ENERGY.
BIOLOGIST
I TRUST MY FLINCH REFLEX, WHICH WAS HONED BY MILLIONS OF YEARS OF EVOLUTION TO PROTECT MY DELICATE FACE. I'M NOT MESSING WITH IT.
ENGINEER
I DON'T TRUST THAT YOU HUNG THAT THING UP CORRECTLY.

Question 1

Suppose that a student removes the little spring from a clicky-pen and uses it to shoot little pebbles vertically into the air. (Perhaps they are bored in class, or perhaps they are experimentally verifying Hooke's law!)

Suppose that their spring is capable of propelling a small pebble 2 meters into the air if it is compressed by 2 cm.

a) What would the new maximum height be if they compressed their spring only 1 cm? *(5 points)*

b) What would the new maximum height be if they instead replaced the spring with one that had a spring constant twice as big (from their neighbor's larger clicky-pen)? *(5 points)*

c) What would the new maximum height be if they instead replaced their small pebble with a larger pebble that had twice the mass? *(5 points)*

d) What would the new maximum height be if they instead launched their pebble at a $45°$ angle above the horizontal, instead of vertically? *(5 points)*

e) Suppose the student launches their small pebble (using their original spring, compressed by 2 cm) from the surface of their desk at some angle θ above the horizontal. It flies across the room and hits the floor.

The speed v_f with which it hits the floor doesn't depend on the angle θ. Explain why v_f doesn't depend on the angle it was launched at. *(5 points)*

Question 2

A spacecraft of total mass $m = 1000$ kg (fuel, cargo, astronauts, propellant, etc.) wants to dock with a large space station. The docking hatch faces in the $x-$direction, so the spacecraft's velocity needs to be only in the $x-$direction at $+0.2$ m/s. In symbols, the spacecraft needs to be moving at $\vec{v} = (0.2, 0)$ m/s.)

However, the spacecraft is currently moving at $\vec{v} = (0.4, 0.3) m/s$. Thankfully, it has a maneuvering thruster: a rocket that exhausts gas at $v_e = 2000$ m/s that can be pointed in any direction. The pilot waits until the spacecraft is lined up with the docking hatch, then fires the rocket to correct the spacecraft's velocity.

a) Draw at least one cartoon that will help you solve this problem, showing the spacecraft, the station, and the exhausted gas. (5 points)

b) Determine the direction that the pilot needs to point the thruster, and how much gas (in kg) they should use, to make this maneuver. *(Note: There is a certain approximation that you might choose to make in this problem. If you make this approximation, call attention to the fact that you have made it, and explain why this approximation doesn't change your result by enough to matter.) (20 points)*

Question 3

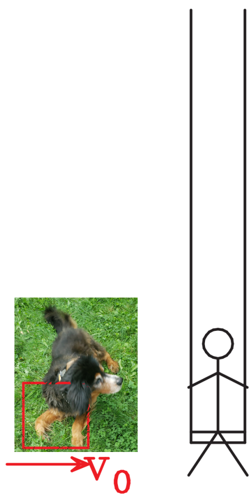
A person is sitting on a swing: a piece of wood suspended from a tree by ropes of length L. She has mass M.

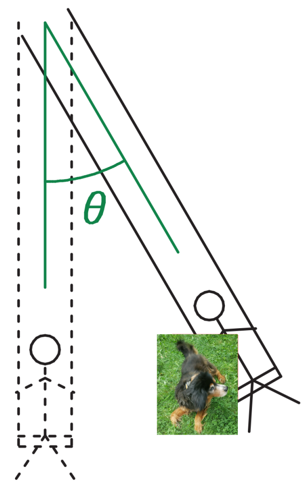
Their dog of mass m wants to play, and runs and jumps into her lap. The dog is moving horizontally when he jumps on her.

This causes the swing to swing back as shown in the diagram; it reaches a maximum angle θ.

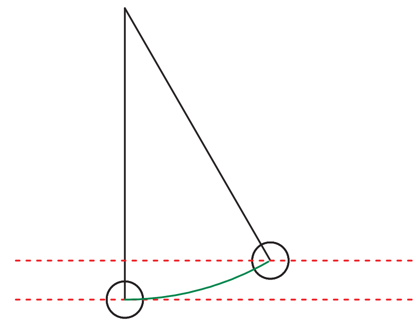
In this problem, you will determine the initial velocity of the dog v_0 as a function of θ, m, M, and L.

This page is here for you to draw more diagrams on if you choose.





a) The diagram to the right shows the path of the swing. Determine the distance between the two dotted lines in terms of L and θ. (This is a hint for the rest of the problem; this is just an exercise in geometry.) *(5 points)*



b) You will need to use both conservation of momentum and the work-energy theorem to determine the relationship between v_0 (which you want to find) and θ, M, m, L, and g.

Which part of the motion will you use conservation of momentum for, and which part will you use energy methods for? (**Hint:** There is space on the previous page to draw another diagram between the two that I have drawn for you. You may give your answer on that page if you want.) *(5 points)*

c) Determine v_0 in terms of M, m, L, g, and θ. *(15 points)*

Question 4

Most submarines throughout history have propelled themselves using electric batteries underwater. This limits their endurance when operating underwater since the same mass of batteries does not store as much energy as diesel. When surfaced, they use diesel generators (which require air) to recharge their batteries.

In this problem, you will consider the limitations on a submarine traveling underwater because of its battery capacity. The numbers here are roughly accurate for a 1940-era submarine.

Submarines traveling underwater encounter a drag force from the water they pass through. At low speeds, this force is proportional to their speed; the relationship is given by the simple formula

$$\vec{F}_{\text{drag}} = \gamma \vec{v},$$

where the number γ (gamma) is a "drag coefficient" that tells you streamlined the submarine is.

Consider a submarine with $\gamma = 80 \frac{\text{kN}}{\text{m/s}}$. This means that if the submarine is traveling at 1 m/s, it encounters a drag force of 80 kN; if it travels at 2 m/s, it encounters a drag force of 160 kN, etc..

This submarine has batteries that store $E = 15$ GJ (1.5×10^{10} J) of energy, and electric motors that can convert it into mechanical work at a maximum of $P = 2$ MW. Assume that any other uses of energy are small, so that the batteries are depleted after the motors do 15 GJ of work.

Note: You may calculate the following as numerical values, or may determine them in terms of γ, E, and P. All of the calculations here should be one or two lines. If you find yourself doing messy math, you are overthinking things. The mass of the submarine does not matter.

a) For how much time t can the submarine operate at full power before its batteries are depleted? *(5 points)*

b) What is the top speed v_{top} of the submarine traveling underwater? *(5 points)*

c) How far can the submarine travel submerged at top speed before its batteries are depleted? *(5 points)*

d) Suppose that the submarine's crew wants to travel $d = 100$ km underwater; perhaps they are passing under sea ice, or perhaps they need to hide.

A sailor suggests that they don't have to run the engines at full power, so that they will travel slower but their batteries will last longer. They claim that this will let them travel further before their batteries are depleted. Will this work? If so, calculate the speed v they must travel at so that they can go $d = 100$ km without recharging their batteries. If not, explain why not. *(10 points)*

Scratch Paper

More Scratch Paper