Physics 105
Extended Problems

These problems are assigned as part of your homework on an occasional basis. They are to be worked out with the solution sheets that follow. You are to use the methods taught in “The Competent Problem Solver” and part of your grade will be determined by how well you follow the plan.
Go for It!

Just for the fun of it, you and a friend decide to enter the famous Tour de Utah bicycle race from Kanab to Blanding and on to Moab. You are riding along at a comfortable 20 mph when you see in your mirror that your friend is going to pass you at what you estimate to be a constant 30 mph. You will, of course take up the challenge and start to accelerate just as she passes you until you pass her. If you can accelerate at a constant 0.25 miles/hour each second until you pass her, how long will she be ahead of you?

Possibly useful information:

\[ x = x_0 + v_0 t + \frac{1}{2} at^2 \]
\[ v = v_0 + at \]
\[ v^2 = v_0^2 + 2ax \]
\[ 1 \text{ mph} = 0.447 \text{ m/s} \]

quadratic formula: \[ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]
Extended Problem # 2

Could He Have Done It?

You are an intern in the county prosecutor’s office and a case comes up that needs your help, because of your knowledge of physics. It seems that a few years ago a student broke into the Standards office (then located in the SWKT) and stole a few files filled with incriminating material. He was seen and was chased up to the observation deck of the SWKT, which happened to be open that night. The University police claim that he threw the briefcase off of the roof of the SWKT and onto the roof of the second floor of the ESC, where it was retrieved by an accomplice. They did not actually see this occur, but it is what they figure must have happened, because the briefcase was never found. The person’s defense attorney claims that this is impossible, that the student would have to have thrown the briefcase with a speed of at least 35 mph (16 m/s) off of the roof to reach the roof of the ESC and in tests that they have tried with similar students, they were never able to throw a briefcase faster than 25 mph (11 m/s). They also claim that the briefcase would probably not survive the impact on the roof of the ESC. It is your job to determine whether the defense attorney’s argument is correct. You get the following information from the police report:

Height of Kimball Tower: 49.1 m

Height of roof of second floor of ESC: 7.6 m

Distance between Kimball Tower and ESC: 27.5 m

Estimated mass of Briefcase: 5.6 kg (weight about 12 lbs)

Time of Occurrence: 3:24 AM

Wind Speed: Calm

Possibly Useful Information: For constant acceleration in the direction of \( x \),

\[
 x = x_0 + v_0 t + \frac{1}{2} a t^2
\]

\[
 v = v_0 + at
\]

\[
 v^2 = v_0^2 + 2ax
\]

1 mph = 0.447 m / s

quadratic formula: \( x = \frac{-b \pm \sqrt{b^2-4ac}}{2a} \)

You may only use formulas on this sheet or those that you derive from them in your solution.
Extended Problem # 3

How Small Can It Be?

You have been hired to design the interior of a special executive express elevator for a new office building. This elevator has all the latest safety features and will stop with an acceleration of \( g/3 \) in the case of any emergency. The management would like a decorative lamp hanging from the unusually high ceiling of the elevator. You design a lamp which has three sections which hang one directly below the other. Each section is attached to the previous one by a pair of thin wires which also carry the electric current. The lamp is also attached to the ceiling by a thin pair of wires. Each section of the lamp weighs 7.0 N (about 1.5 lbs). Because the idea is to make each section appear that it is floating on air without support, you want to use the thinnest wire possible. Unfortunately the thinner the wire, the weaker it is. In order to determine the thinnest wire that can be used for each stage of the lamp, determine the force on each wire in case of an emergency stop.

You have been given the following information about the elevator by the company that builds it:

- Mass: 780 kg
- Stopping acceleration: \( g/3 \)
- Maximum upward speed: 4.2 m/s
- Maximum downward speed: 4.0 m/s
- Height of ceiling: 3.2 m
- Dimensions of floor: 2.5 m x 2.0 m
Extended Problem # 4

An Olympian Task.

You have landed a summer job with a company that has been given the contract to design the ski jump for the next Winter Olympics. The track is coated with snow and has an angle of $25^\circ$ from the horizontal. A skier zips down the ski jump ramp so that he leaves it at high speed. The winner is the person who jumps the farthest after leaving the end of the ramp. Your task is to determine the height of the starting gate above the end of the ramp, which will determine the mechanical structure of the ski jump facility. You have been told that the typical ski-jumper pushes off from the starting gate at a speed of 2.0 m/s. For safety reasons, your design should be such that for a perfect run down the ramp, the skier’s speed before leaving the end of the ramp and sailing through the air should be no more than 80 km/hr. You run some experiments on various skis used by the jumpers and determine that the coefficient of static friction between the skis and the snow is 0.10 and the coefficient of kinetic friction is 0.02. Since the ski-jumpers bend over and wear very aerodynamic suits, you decide to neglect the air resistance to make your design.

Possibly Useful Information:

\[ F = ma \]
\[ W = Fd \cos \theta \]
\[ W_{net} = \Delta KE \]

If no dissipative forces, $\Delta KE + \Delta PE = 0$

\[ W_{nc} = \Delta KE + \Delta PE \]
\[ PE_g = mg \]
\[ PE_x = \frac{1}{2} k x^2 \]

Conversion factors:

1 m = 3.281 ft 1 lb = 4.448 N 1 m/s = 2.237 mi/hr
1 mi = 5280 ft = 1.609 km

You may only use the equations on this page in your solution of this problem.
Extended Problem # 5

Superman saves Lois

Because movie producers have come under pressure for teaching children incorrect science, you have been appointed to help a committee of concerned parents review a script for a new Superman movie. In the scene under consideration, Superman rushes to save Lois Lane who has been pushed from a window 300 feet above a crowded street. Superman is 0.50 miles away when he hears Lois scream and rushes to save her. He swoops down in the nick of time, arriving when Lois is 3.0 feet above the street, and stopping her just at ground level. Lois changes her expression from one of horror at her impending doom to a smile of gratitude as she gently floats to the ground in Superman’s arms. The committee wants to know if there is really enough time to express this range of emotions, even if there is a possible academy award on the line. The chairman asks you to calculate the time it takes for Superman to stop Lois’ fall. To do this calculation you assume that Superman applies a constant force to Lois in breaking her fall and that she weighs 120 lbs. While thinking about this scene, you also wonder if Lois could survive the force that Superman applies to her.

Possibly Useful Information:

\[ F = m a \]

\[ W = Fd \cos \theta \]

\[ W_{net} = \Delta KE \]

\[ W_{nc} = \Delta KE + \Delta PE \]

\[ PE_g = mg y \]

\[ PE_s = \frac{1}{2} kx^2 \]

\[ \mathbf{p} = mv \]

\[ \text{Impulse} = F \Delta t \]

\[ F \Delta t = \Delta \mathbf{p} \]

\[ \Sigma \mathbf{p}_i = \Sigma \mathbf{p}_f \]

Conversion factors:

\[ 1 \text{ m} = 3.281 \text{ ft} \quad 1 \text{ lb} = 4.448 \text{ N} \quad 1 \text{ m/s} = 2.237 \text{ mi/hr} \]

\[ 1 \text{ mi} = 5280 \text{ ft} = 1.609 \text{ km} \]

You may only use the equations on this page in your solution of this problem.
A New Tarzan?

You need a break from school, so you sign up with Budget Jungle Safaris for a between semester visit to an African jungle. In the course of your “interesting” experience with this semi-competent group of guides, you get separated from your group. Somehow you find yourself on the opposite side of a river in a gorge. The only way you can see to get to the other side is to swing across the river on one of the nearby vines. Being a careful person, you are concerned about the safety of this procedure. You want to start as high as possible in order to ensure reaching the other side, but you also do not want the vine to break when you are over the middle of the river. You find two virtually identical vines on a tree and decide to do a test before you swing across. You estimate that the vines are 25 feet long. You find a piece of wood that you estimate weighs two-thirds as much as you do. You tie the piece of wood to one of the vines and find by trial and error that the vine breaks when you climb to a height of 25 feet into the trees and release the wood from rest from that height. How high can you climb into the trees and safely swing across? Could you hold onto the vine as it swings through the bottom of its arc?
Deploying the antenna

You have a job working with a company selling communication equipment to the military. A new type of antenna to communicate with submarines has been developed by your company. It involves raising 500 m of antenna wire by use of a large weather balloon. The balloon is attached to the wire, which is wound on a large spool. The balloon pulls on the wire, which then unwind from the spool. Your boss needs to have an estimate of the shortest time that can elapse while this antenna is being deployed to its full height for a meeting with the military brass. He wants to be able to make a comment something like “You can’t get this up any faster than ...” You have been given the job of making that estimate. You decide to ignore the weight of the wire itself, because that makes the job too difficult and the deployment time is longer if you include the wire anyway. You also decide that you need to allow the balloon to accelerate upward to the halfway point and then slow down to zero velocity with the same magnitude acceleration, so that it comes to rest just as the antenna is fully deployed. You have the following measurements from the system:

Diameter of balloon: 2.5 m
Balloons filled with He, (density 0.179 kg/m³)
Mass of balloon before it is filled: 4.0 kg
Density of air 1.29 kg/m³
Diameter of spool: 52 cm
Construction of spool: Thin cylindrical shell with the wire wrapped on the outside
Mass of spool: 50.3 kg

Moments of Inertia:
Hoop or shell: \( I = MR^2 \)
Cylinder or disk: \( I = \frac{1}{2} MR^2 \)
Sphere: \( I = \frac{2}{5} MR^2 \)

Geometric Relationships:
Circumference of circle: \( C = 2\pi r \)
Area of circle: \( A = \pi r^2 \)
Volume of sphere: \( V = \frac{4}{3} \pi r^3 \)
Surface area of sphere: \( A = 4\pi r^2 \)

Kinematics Equations:
\( x = v_0 t + \frac{1}{2} at^2 \)
\( v = v_0 + at \)
\( v^2 = v_0^2 + 2ax \)
\( \theta = \omega_0 t + \frac{1}{2} \alpha t^2 \)
\( \omega = \omega_0 + \alpha t \)
\( \omega^2 = \omega_0^2 + 2\alpha\theta \)

Dynamics Equations:
\( F = ma \)
\( \tau = I\alpha \)
Hold on to your roof.

After you graduate from BYU you take a job in southern Florida. You enjoy your work, but the possibility of hurricanes bothers you. You have seen many pictures of houses with their roofs ripped off by hurricane winds and you are concerned about the magnitude of the forces that are involved. You decide to estimate the magnitude of the lifting forces on your roof. Your roof has dimensions of 20 ft by 40 ft. You look up the definition of a hurricane and find that there must be sustained winds of at least 70 miles/hour to call a storm a hurricane. You decide to calculate the forces for winds higher than that, at 100 mph. You climb up into your attic and find that there are 21 roof trusses holding the plywood and shingles on the roof and that each truss is held to the main part of the house by two metal straps called hurricane ties. You wonder how much force each tie has to withstand in order to keep your roof on.

Kinematics Equations:  
\[ x = v_0 t + \frac{1}{2} a t^2 \]  
\[ v = v_0 + at \]  
\[ v^2 = v_0^2 + 2ax \]  
\[ \theta = \omega_0 t + \frac{1}{2} \alpha t^2 \]  
\[ \omega = \omega_0 + \alpha t \]  
\[ \omega^2 = \omega_0^2 + 2\alpha \theta \]

Fluid Equations:  
\[ F = PA \]  
\[ B = \rho g V \]  
\[ A_v = \text{constant} \]  
\[ P + \frac{1}{2} \rho v^2 + \rho gh = \text{constant} \]

Conversion Factors:  
1 m = 3.281 ft  
1 mile = 1.609 km  
1 hour = 3600 sec

Density of Air = 1.29 kg / m³

You may only use the equations on this sheet to work this problem.
Building a Bridge

You have a friend who has a cabin in the mountains. In order to get there it is necessary to drive through a stream on a dirt road. This can be difficult in the spring when the runoff level is high. Your friend wants to build a bridge across the stream that would make it easier to get in to the cabin. A contractor poured concrete piers on each side of the stream to provide a support for the bridge and your friend intended to place two steel supports across the stream and build a road on it with wooden crosspieces. The concrete was poured in the fall of the year and then the winter came, so construction stopped. Your friend wanted to get the bridge in before the spring runoff, so early in the morning on an crisp early spring day he had the steel supports cut to length and inserted snugly into the concrete supports on both ends. The bridge worked nicely through the spring, but on a particularly hot summer day the concrete on the ends of the bridge cracked and shifted. Your friend was very upset and was considering whether to sue the concrete contractor when he realized that it might have been his fault for the way he cut the steel supports. Since he knows that you have taken physics, he asks you to estimate the forces that the steel supports would have exerted on the concrete piers. You go out to his cabin and make the following measurements:

Length of the bridge: 17.6 feet
Width of bridge: 12 feet
The steel supports are square steel tubing, the outside dimensions are 4.0 inches on each side and the walls are 5/8 inches thick.

You talk to your friend and find that there isn’t a thermometer up at the cabin, so nobody knows exactly what the temperature was on either day.

You look in your physics text and find the following information about steel:

<table>
<thead>
<tr>
<th>Young’s Modulus (Pa)</th>
<th>Shear Modulus (Pa)</th>
<th>Bulk Modulus (Pa)</th>
<th>Coefficient of Expansion (C°)¹</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 x 10¹⁰</td>
<td>8.4 x 10¹⁰</td>
<td>16 x 10¹⁰</td>
<td>11 x 10⁻⁶</td>
<td>7.86 x 10³</td>
</tr>
</tbody>
</table>

Possibly useful equations:

\[ Y = \frac{F / A}{\Delta L / L_0} \]
\[ T_f = \frac{9}{5} T_c + 32 \]
\[ T_c = \frac{5}{9} (T_f - 32) \]
\[ T = T_c + 273.15 \]
\[ \Delta L = \alpha L_0 \Delta T \]

1 in = 2.54 cm
1 m = 3.281 ft
Keep the Heat in!

You are remodeling your house and you want to make it as energy efficient as possible, without spending more than you need to. You look at replacing your old 1⁄4 inch thick single pane windows with double pane windows. The double pane windows use two sheets of 1⁄4 inch thick glass separated by a ½ inch thick layer of air. You wonder if you could do just as well by putting in a much cheaper single pane window made of ½ inch thick glass without the air gap. You also wonder how much money you could save on your heating bill during the winter by using the better of the two new windows instead of the other one. You measure the windows in your house and find that you have a total window area of 11.5 m². You usually keep your thermostat at 72 °F. You find some reference books in the library and find the following information:

Average temperature (day and night) in Provo during the winter months (December, January and February) is 31.6 °F

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity J/(s·m·°C)</th>
<th>Specific heat J/(kg·°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>0.84</td>
<td>837</td>
</tr>
<tr>
<td>Air</td>
<td>0.0234</td>
<td>445</td>
</tr>
</tbody>
</table>

Average cost of heat is about 1 cent per million joules (natural gas heating).

\[
T_f = \frac{9}{8} T_c + 32 \\
T_c = \frac{5}{8} (T_f - 32) \\
T = T_c + 273.15 \\
H = \frac{Q}{\Delta t} = kA \left( \frac{T_2 - T_1}{L} \right) \\
Q = mc\Delta T \\
P = \sigma A e (T^4 - T_0^4) \\
1 \text{ inch} = 2.54 \text{ cm} \\
1 \text{ day} = 86,400 \text{ seconds} \\
\sigma = 5.669 \times 10^{-8} \text{ W / m}^2 \cdot \text{K}^4 \\
\text{Power} = \frac{\Delta W}{\Delta t}
\]

You may only use the equations on this sheet to solve this problem.

Hint: The rate of heat flow through each layer of a compound window has to be the same. You need to define variables for the intermediate temperatures in order to solve this. Your grade will be based mainly on the set-up of the problem and not so much on whether you reach the final numerical value.
What does it weigh?

As you drive down a raised section of freeway one day you notice that your car starts to bounce up and down with a fairly large amplitude, indicating that you are going over the bumps on the road at the same frequency as your car’s natural bounce frequency. You time how long it takes for you to go through 10 bounces and you find that it takes 18 seconds. You look at your speedometer and note that you are traveling at 67 miles per hour. As you consider what is happening, you realize that with a little more information this will allow you to estimate how heavy your car is. When you get to your destination, your father gets out of the car you notice that the car rises about 2 inches when he gets out. He tells you that he weighs about 200 lbs. What is an estimate for the mass of your car?

Possibly Useful Equations:

\[ F = -kx \]
\[ a = -\frac{k}{m}x \]
\[ PE_s = \frac{1}{2}kx^2 \]
\[ T = 2\pi \sqrt{\frac{m}{k}} \]
\[ f = \frac{1}{T} \]
\[ T = 2\pi \sqrt{\frac{L}{g}} \]
\[ v = \pm \sqrt{\frac{k}{m}} \left( A^2 - x^2 \right) \]
\[ x = A \cos \left( 2\pi ft \right) \]

Conversion factors:

1 m = 3.281 ft
1 in = 2.54 cm
1 mi/hr = 1.61 km/hr = 0.447 m/s
1 N = 0.2248 lb
How Loud Should It Be?

You are working for your home town in a summer job in the recreation department. They are designing a new athletic complex for the city. One of the fields in the complex is a combined football/soccer field with grandstands and loudspeaker system. The speakers are located on one side of the field, near the middle. Your boss is looking at what kind of speaker and amplifier system to put in. He wants the sound at the stands to be loud enough to be heard over a noisy crowd and game, but he also does not want to violate the city’s noise ordinance, which states that the sound level at the edge of the property can be no more than 70 dB. He wants you to find the sound level at the grandstand and also 10 cm in front of the speakers. He also wants to know how powerful an amplifier he needs to install in order to drive the speakers and produce this sound level. He tells you that the speakers are 200 m from the nearest edge of the property and that the speakers are to be mounted on poles 5.00 m from the grandstand. You call a friend who is an audiophile and he tells you that most speakers are about 1% efficient in converting electrical power to acoustical power.

Possibly Useful Information:

**Geometric Relationships:**

- **Circumference of circle:** \( C = 2\pi r \)
- **Area of circle:** \( A = \pi r^2 \)
- **Volume of sphere:** \( V = \frac{4}{3}\pi r^3 \)
- **Surface area of sphere:** \( A = 4\pi r^2 \)

\[
\beta = 10 \log \left( \frac{I}{I_0} \right)
\]

\[
I_0 = 1.0 \times 10^{-12} \text{ W/m}^2
\]

\[
I = \frac{P_{av}}{4\pi r^2}
\]

**Efficiency** = \( \frac{\text{Power out}}{\text{Power in}} \)
Extended Problem # 13

The Deer Whistle

While browsing through a catalog you come upon a device that is purported to prevent collisions of cars with deer. When the car is moving at 35 mph or higher it is supposed to create an ultrasonic sound that the deer can hear and the occupants of the car cannot. That is supposed to scare the deer away from the road and prevent collisions that are inconvenient and expensive for the car driver and not too much fun for the deer either. You order one and find that it is essentially a tube which is open at both ends and is arranged so that the wind from the motion of the car blows over the top of the tube. There is also a reflector that directs most of the sound forward. You measure the tube and find that it is 1.0 cm long. You wonder what range of frequencies this device can send forward to the deer as the car’s speed changes and as the temperature of the air in the mountains changes. You make some reasonable assumptions about those and get your estimate.

Possibly Useful Information:

\[ v = (331 \text{ m/s}) \sqrt{1 + \frac{T_c}{273}} = (331 \text{ m/s}) \sqrt{\frac{T_k}{273}} \]

\[ f' = f \left( \frac{v \pm v_a}{v \mp v_s} \right) \]

\[ \lambda f = v \]

\[ f_n = nf \quad n = 1, 2, 3, \ldots \]

\[ f_b = |f_1 - f_2| \]

\[ T_k = T_c + 273 = \frac{5}{9}(T_f - 32) + 273 \]

Conversion Factors:

\[ 1 \text{ mi/hr} = 1.61 \text{ km/hr} = 0.447 \text{ m/s} \]

\[ 1 \text{ in} = 2.54 \text{ cm} \]

\[ 1 \text{ lb} = 4.448 \text{ N} \]

You may only use the formulas on this sheet to work this problem.